Master Thesis

Applying Agility in the Make and Plan Processes of the Semiconductor Supply Chain

Rafik Ramzi Helmy Foad

Institute of Production Science and Management

Univ.-Prof. Dipl.-Ing. Dr.techn. Christian Ramsauer

Graz, 2016

Statutory Declaration

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

....

Date   Signature

Abstract

Agility as a manufacturing paradigm has gained increasing importance within the previous years. It is highly believed that companies that are not agile will not be able to survive in the future, given the challenging and changing conditions the business world is currently experiencing. An agile manufacturing system can be defined as a system that is capable exploiting the ever-changing volatile market demand in a cost-efficient manner, by rapidly providing customer oriented products, through a set of capabilities (such as speed, flexibility, responsiveness, and market visibility) in a knowledge-rich environment.

Having continuous innovation as its main driver, the semiconductor industry is characterized by being a very challenging industry to manage, due to the immense speed of change it experiences and the volatile environment it operates in. As a result of those conditions, semiconductor manufacturers face tremendous challenges in managing their supply chains. According to the mentioned definition, agility could be considered instrumental for semiconductor companies that are required to survive and flourish in such a business environment.

Existing agility literature mostly deliberate theoretical definitions and concepts, with seldom attempts to embody the concept into practically applicable tools. In this thesis, a broad literature research about agility and supply chain agility is done, in order to explore the concepts of agility elaborated in the literature and their respective benefits. Afterwards, a case study is carried out in the supply chain department of a typical semiconductor manufacturer. The case study results in developing a tool that aims at practically applying a prominent concept of agility in the examined company's supply chain that would potentially help in managing some of the challenges it faces. A methodology is developed to implement the tool within the manufacturing and planning system of the company's supply chain, in order to realize its benefits mentioned in the literature. Finally, an example to demonstrate the application of the tool and suggested methodology is given based on an actual case in the examined company.

Acknowledgements

I feel deeply indebted to many people for their support throughout my master's journey in TU Graz and my stint within the company to do my internship and thesis. I would like to start by thanking the PSM institute headed by Univ.-Prof. Dipl.-Ing. Dr.techn. Christian Ramsauer, as their connections with the industry gave me this chance to carry out the thesis with one of the leading companies in the semiconductors field. I am also grateful for the guidance I received from Mr. Alexander Pointner throughout my internship and thesis.

I would like to express my deep gratitude to Hans Ehm, my thesis supervisor from the company's side for his extensive support and continuous encouragement. If it wasn't for him, my career definitely wouldn't have gone this far within the company. Thank you, Hans for believing in me. I am very grateful as well to Josef Brugger, my work supervisor in Villach during my thesis time. His invaluable support was substantial for my thesis and my career.

My family of friends in Graz have been an enormous support for my journey in Austria from day one, and even before that. I definitely couldn't have made it without their help throughout the different endeavors I've undertaken. A huge thank you to Amir Kozman, Fady Abdel Malek, John Hanna, Joseph Salib, Karim Moataz, Mohamed Essam, and Omar Gamali. Special thanks to John Hanna for helping me with the scientific writing for the thesis.

A big thank you also goes out to Rafik H. Halim, my cousin and friend, for taking from his free time to diligently proofread this thesis. Thank you, Kiko.

Last, but by no means least, no words could do justice to the support of my loving family, for they believed in me from day one, and continuously stood by me throughout the ups and downs of a journey that was as tough for me as for them. Thank you so much, my dear parents.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

APICS SCC	American Production and Inventory Control Society, Supply Chain Council
APS	Advanced Planning System
BE	Back-end
BEST	Backend Steering
BNR	Baunumber
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
CT	Cycle Time
CVD	Chemical Vapor Deposition
DB	Die Bank
DC	Distribution Center
DCA	Distribution Center Asia
DCE	Distribution Center Europe
DCU	Distribution Center USA
FE	Front-end
FEST	Frontend Steering
IC	Integrated Circuit
IT	Information Technology
JIT	Just in Time
OEM	Original Equipment Manufacturer
PDP	Product Delivery Process
PVD	Physical Vapor Deposition
SCOR	Supply Chain Operations Reference
SCP	Supply Chain Planner
SKU	Stock Keeping Unit
SMED	Single Minute Exchange of Die
TQM	Total Quality Management
VBA	Visual Basic for Applications
WIP	Work in Process/Work in Progress

1 Introduction

In this chapter, the motivation for the research undergone in this thesis will be discussed, leading the objectives of the research and research questions that the work done in this thesis will attempt to answer. Finally, the methodology of the research and the structure of the thesis will be exhibited in the last subchapter.

1.1 Research Motivation

The semiconductor industry is considered one of the most challenging industries to manage. It is characterized by having a dynamic and fast changing business environment, as continuous innovation is the main driver that drives the industry (Ballhaus, et al., 2009). These conditions inevitably affect the industry's supply chain, making its management a very challenging task. A typical semiconductor manufacturer is plagued with numerous challenges in the process of managing his supply chain. To mention a few, he has to manage a highly complex and capital intensive manufacturing process with a very lengthy manufacturing cycle time, while having a highly volatile and unpredictable customer demand (Aelker, et al., 2013).

In recent years, agility has been introduced as a new manufacturing paradigm, and coined as the 21st century's manufacturing strategy (Nagel & Dove, 1991). Uncertainty and volatility in the business world have been identified as the main reasons for the failure of companies in the modern world (Sharifi & Zhang, 2001). Agility as a business concept aims at efficiently utilizing a company's resources, in order to adapt to the inevitable volatility in the market place, and the unavoidable changes that an organization experiences in the modern business environment (Gunasekaran, 1998; Yusuf, et al., 1999). The main focus of agility as a paradigm is fulfilling the customer demand as a priority. The essence of agile manufacturing is to adapt to constantly changing customer requirements, as agility views changes and fluctuations as opportunities rather than threats, aiming at exploiting them for the benefit of the company (Sharifi, et al., 2001; Guisinger & Ghorashi, 2004).

In the modern business world, the emphasis on the importance of supply chain management has increased dramatically within the previous years. It is greatly reckoned that in today's business environment, competition is no longer between companies, but rather between supply chains (Christopher, 2000). Agility in the context of a company's supply chain has also been vastly discussed in the literature. Lots of papers have discussed different concepts and ideas on how to make a company's supply chain more agile towards the customer. The literature about supply chain agility mostly focuses on implementing the concept with a wider scope which includes the company's extended stakeholders of suppliers and customers. They also introduce and discuss specific concepts and tools that a company should consider applying in order to improve their end to end supply chain agility under uncertain and volatile business conditions (Dove, 1996; Naylor, et al., 1999).

Based on the above, agility could be considered a potential strategy that could help in managing the challenges in the semiconductor industry's supply chain. The motivation of this research is to explore a practical way through which agility as a paradigm could be applied within the industry. The target is to attempt to realize the benefits of such a paradigm in managing those challenges in a practical way.

1.2 Research Objectives and Questions

The existing literature about agility is considered to be on a high theoretical level, as the majority of the works mostly discuss the definition of the term and its different conceptualizations and models. However, agility literature has limited input that discusses how to practically roll out and apply these definitions and concepts in a company or a firm (Sanchez & Nagi, 2001). Although some works have discussed agility in the context of different industries, few of them explored the concept and its application within the semiconductor industry and its supply chain. This is why a research gap has been identified between the high level of literature, defining basics and general concepts of agility, and the practical elements and tools that enable the application of this paradigm on a practical level, specifically in the context of semiconductor industry's supply chain.

Accordingly, a research gap has been identified between the high level of literature, defining basics and general concepts of agility, and the practical tools and levers that could enable the application of this paradigm on a practical level, especially within the context of the semiconductor industry's supply chain, as it is considered a highly complex and volatile environment, which –according to the literature- agility should be effective within.

The objective of this thesis is to come up with a methodology that allows practical applications of the concepts of agility stated in the literature in the specific context of the semiconductor industry. This will be done by carrying out a case study in a typical semiconductor manufacturer, which will be referred to as "the examined company" in this thesis. The aim of the case study is to attempt to practically apply on of the concepts of agility identified in the literature in the examined company's supply chain, in order to manage the challenges it faces.

Based on the above discussion, three research questions have been posed that could potentially help in closing the research gap. The objective is to try to answer those questions by means of a case study carried out within the examined company, as an example of a typical semiconductor manufacturer. The three questions are:

- Which challenges in the semiconductor supply chain could agility fit best for as a mitigation strategy?
- How could the theoretical concepts in the existing literature about agility be transformed to “tangible” tools and levers on the practical level in the context of the semiconductor industry’s supply chain?
- How could agility be applied as a potential strategy for managing the challenges associated with a typical semiconductor’s supply chain?

The literature review and case study undergone in the thesis will focus on solving those research questions by means of a practical case study within the examined company.

1.3 Methodology and Thesis Structure

In order to apply the concepts of agility within the semiconductor industry’s supply chain and answer the research questions, the thesis has been structured into two main sections. The first section is the literature review, which will be divided into two parts; the first part will be focused on describing and discussing the semiconductor industry, starting by an overview of the industry, and moving on to discussing its supply chain according to the SCOR model, which is the model the examined company uses to describe and model its supply chain activities. The supply chain challenges faced by a typical semiconductor manufacturer according to the literature and the examined company will be explored afterwards. The second part of the literature review will be focused on discussing agility and its diverse definitions within the literature. Next, the literature focusing on agility in the supply chain context will be reviewed. The final part of the literature review will be focused on highlighting the semiconductor industry’s need for agility in its supply chain, and correlating the definitions and concepts of agility discussed to the semiconductor supply chain challenges identified earlier.

The second section will exhibit the empirical part of the thesis, which describes the attempt done in this thesis to materialize a concept of agility and practically apply it within the examined company’s supply chain. The empirical part starts by explaining the status quo of the company’s planning and manufacturing system, and accordingly identifying the potential opportunity for applying the chosen concept. The next step would focus on establishing a methodology that could help implement the concept within the examined company, given the status quo. An example to demonstrate the application of the computed methodology on a real case within the examined company will be afterwards given.

Finally, the results of the case study carried out will be summarized in the last chapter to highlight the benefits of the suggested methodology within the examined company, and show how the case study helped in answering the research questions. Recommendations for the future research will be accordingly given, in order to realize the full benefit of the concept to be applied for the company.

2 Literature Review

In order to discuss the application of agility in the semiconductor industry's supply chain, a literature review on the relevant topics has to be carried out first. The literature review will be conducted in this chapter, which will be structured as follows: First, a literature review about the semiconductor industry will be done, starting with an overview of the industry, and then reviewing the supply chain processes in the industry according to SCOR model. The challenges facing the semiconductor industry's supply chain will then be highlighted in a separate section. Later, a review about agility and agile manufacturing will be carried out, beginning with a brief overview of the history of the term in the manufacturing context. A broad discussion about the term's definition in the literature will be afterwards conducted, and a review of the literature with focus on agility in supply chain will be done in a separate section. The last subchapter will discuss the relevant definitions and tools of agility and supply chain agility to the semiconductor industry's supply chain and its specific challenges, in order to come up with a hypothesis about the application of agility in the industry's supply chain, and how it could be beneficial in managing the challenges in such environment.

The literature review will be commenced in the next subchapter by giving an overview of the semiconductor industry, then discussing the industry's supply chain according to SCOR model. The challenges facing the semiconductor industry's supply chain will afterwards be identified in the last section of the subchapter.

2.1 The Semiconductor Industry

In this subchapter, a literature review about the semiconductor industry will be undergone. The review will be commenced by giving an overview of the industry, then the industry's supply chain will be focused on, and finally, the challenges facing the semiconductor supply chain will be discussed.

2.1.1 Overview of the Semiconductor Industry

In today's world, semiconductors are an indispensable component of most consumer products. Smartphones, tablets, and flat screens are just few examples of consumer products that semiconductors form a fundamental part of (Neshati, 2013). The broadness of applications of semiconductors is reflected in the worldwide sales data of the industry shown in Figure 1. The graph reveals the dominant trend of growth over the years. In 2014, the semiconductor worldwide sales reached an all-time high with a total of 336 Million USD, achieving an increase of 9% compared to 2013 (Semiconductor Industry Association, 2014).

As mentioned, the applications of semiconductors in recent times have become countless. Ballhaus, et al. (2009) segmented the sales of semiconductors by application, mentioning that around 38% of semiconductor sales are generated by data processing applications, whereas communications form 26% of the sales volume, consumer electronics comprise 18%, industrial applications contribute with 10%, and the automotive applications' share is around 8% of the sales volume (Ballhaus, et al., 2009).

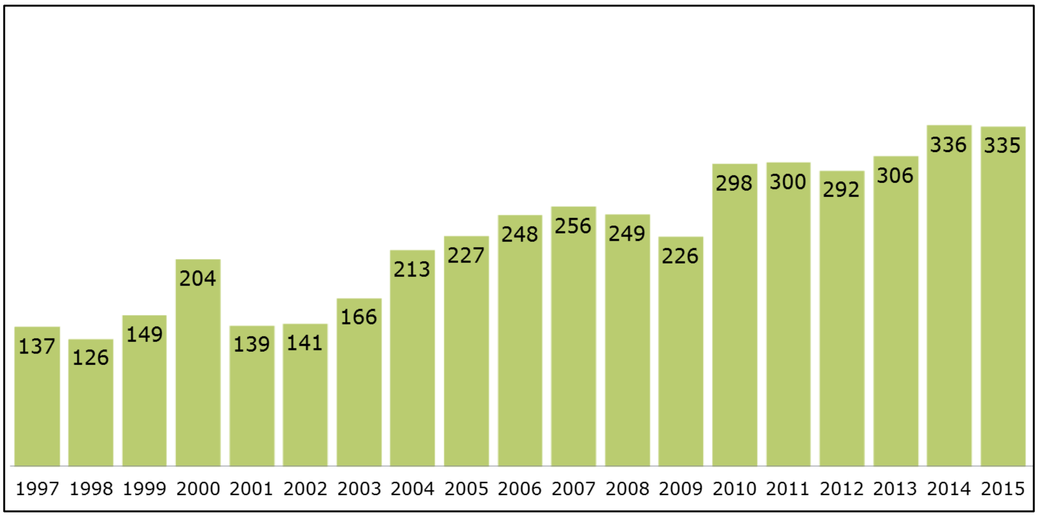

Figure 1: Global Growth of the Semiconductor Industry's Sales in Million USD (Source: Internal Document)

In Figure 2, Ballhaus, et al. depict the interaction between the different parties comprising the semiconductor industry. The chain starts with the suppliers of the semiconductor industry, including the raw materials suppliers and the semiconductor manufacturing equipment suppliers. Then the different business models of semiconductor manufacturers themselves are show. Finally the diverse applications of semiconductors for customers mentioned in the above classification are depicted at the end of the chain (Ballhaus, et al., 2009).

The growth of worldwide sales is also coupled with a vast pace of product development in the semiconductor industry. It is widely believed that the pace of development of the industry is governed by the famous "Moore's Law", proposed in 1965 by Gordon Moore, one of the founders of the Intel Corporation (Neshati, 2013). In his 1965 article, Moore predicted that the numbers of transistors on a certain area of integrated chip will double roughly every year. He also argued that prices of semiconductors will inevitably decrease by time (Moore, 1965). In 1975, he revised the rate he had originally proposed, hypothesizing that the doubling will happen nearly every 18-24 months (Moore, 1975). Figure 3 depicts the fulfillment of Moore's law in numbers over the years.

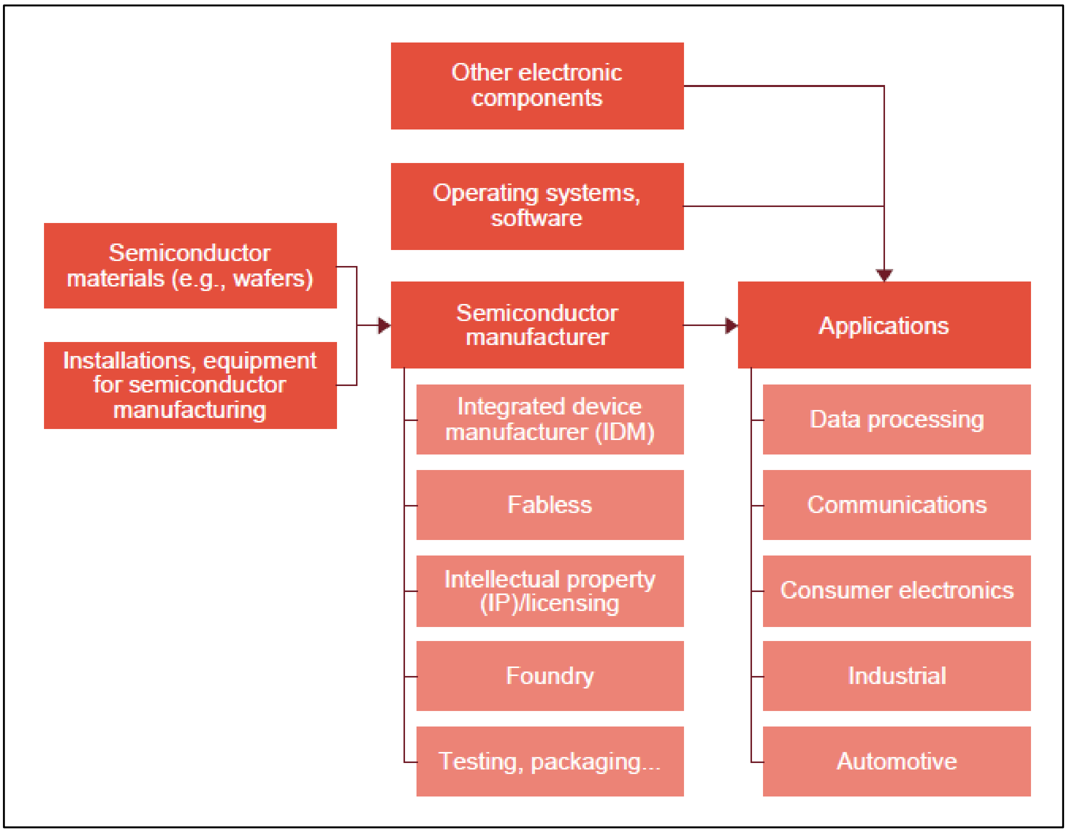

Figure 2: Interaction between Various Sectors in the Semiconductor Industry (Source: Ballhaus, et al. (2009))

It goes without saying that Moore's law shows the importance of research and development in the semiconductor industry. A study done by McKinsey & Company (2011) revealed that R&D costs comprise more than 20 percent of the revenue for the top 20 players in the industry. According to them, the importance of R&D is mainly due to the fact that time to market is a crucial metric to compete in the semiconductor world. They also highlighted that semiconductor product lifecycles are pretty short, and companies are accordingly always asked to rapidly deflate their prices. The previous reasons show why semiconductor companies have to invest a lot in their R&D (McKinsey & Company , 2011).

The diverse applications of semiconductors, the rapid growth of the industry's sales, alongside the intensity of the R&D process and its implications on the product portfolio of companies are all factors that unequivocally burden the supply chain of the semiconductor companies that need to deliver the right products at the right time in such an environment. This is why managing the supply chain of a semiconductor manufacturer is considered to be a challenging task. In the following sections, the semiconductor industry's supply chain according to the supply chain operations reference (SCOR) model will be exhibited, and the challenges faced by a typical semiconductor supply chain will be discussed.

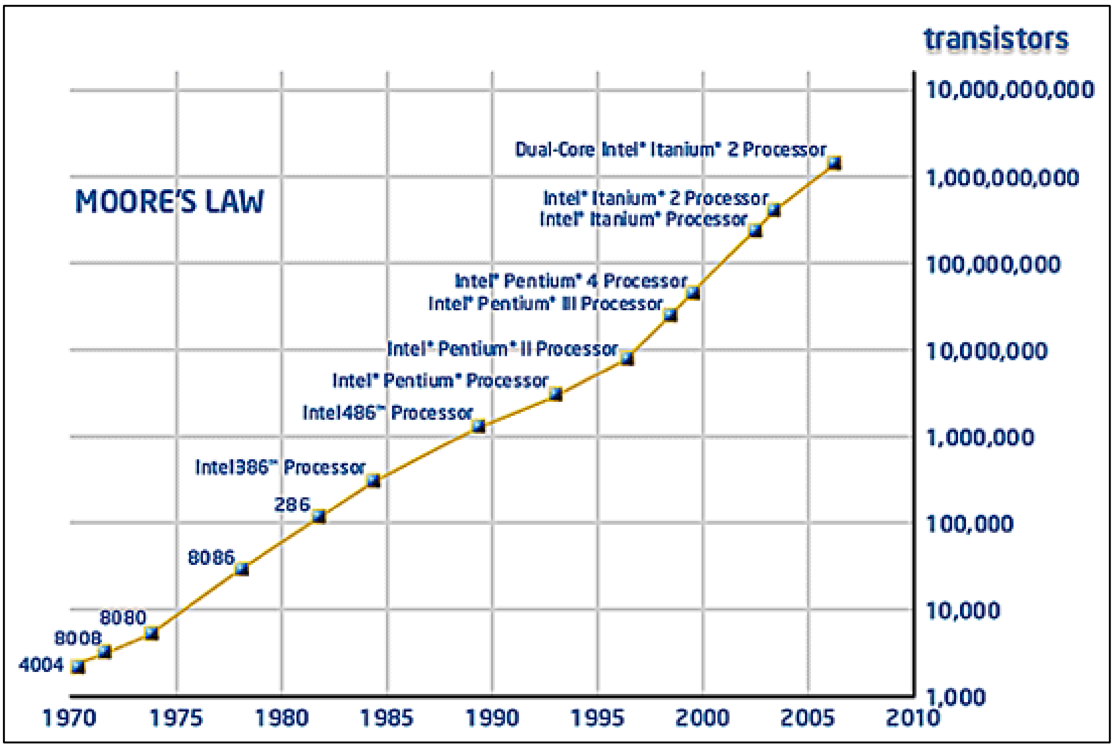

Figure 3: The Development of the Number of Transistors per Chip according to Moore's Law (Source: Neshati (2013))

2.1.2 The Semiconductor Industry's Supply Chain According to SCOR Model

The awareness of companies about the importance of supply chain management has grown more and more over the past years. It is widely believed that in today's business environment, competition is no longer between companies, but rather between supply chains (Christopher, 2000). Lambert, et al. (1998) define supply chain management as "... *the integration of key business processes from end user through original suppliers that provide products, services, and information that add value for customers and other stakeholders*." (Lambert, et al., 1998). Due to the various reasons mentioned in the previous section, supply chain management of semiconductor companies is considered to be a challenging task. An overview of the SCOR model and its application in the examined semiconductor company will be exhibited in the following subsections.

2.1.2.1 Overview of the SCOR Model

The semiconductor company examined in this thesis bases its supply chain processes on the Supply Chain Operations Reference (SCOR) model. The SCOR model is a framework which was developed and endorsed by the APICS supply chain council (APICS SCC), a global non-profit consortium that has about 1,000 corporate members worldwide and has established international chapters in Australia/New Zealand, Europe, Greater China, Japan, Latin America, North America, South East Asia, and Southern Africa (APICS, 2014; Internal Document, 2015a).

The aim of the SCOR model is to describe the different phases of the end to end business activities needed to fulfill customer demand. The model defines six management processes for a supply chain, which are Plan, Source, Make, Deliver, Return, and Enable. Figure 4 depicts the SCOR model, showing that it spans from the supplier's supplier to the customer's customer. All the transactions required from the customer order entry till payment of invoice are covered by the model. Services and indirect materials suppliers, such as equipment and spare parts suppliers are also part of the model's scope (APICS, 2014).

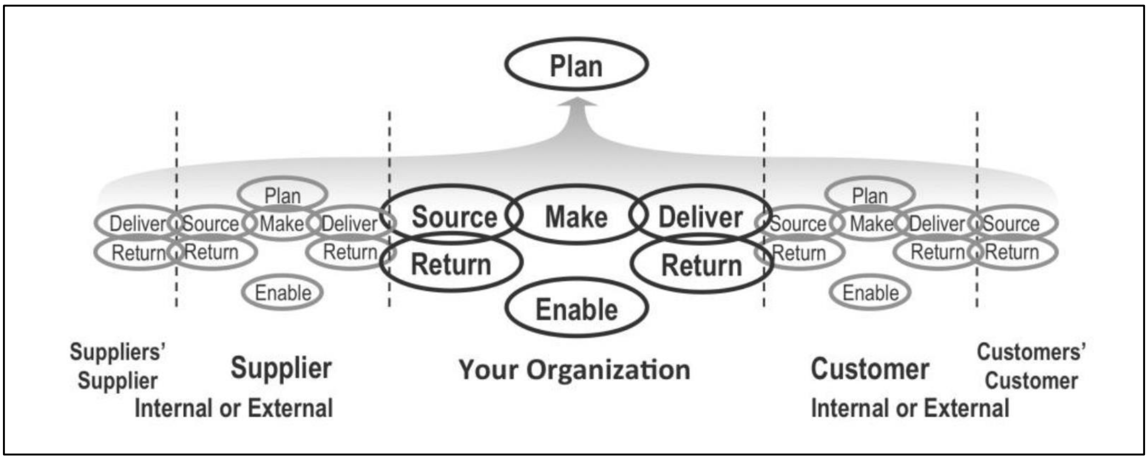

Figure 4: The SCOR Model (Source: APICS (2014))

The examined company adopts five of those six management processes, which are, Source, Make, Deliver, Return, and Plan (shown in Figure 5). It lists three benefits of using the SCOR model which are: visibility and harmonization of the interrelations of Supply Chain relevant sub-processes, enabling standardization by using an inter-industrial reference model that is also used by leading software companies for supply chain tooling, and allowing reliable and fast benchmarking, as the SCOR model provides a common base for benchmarking between companies using it (Internal Document, 2015a).

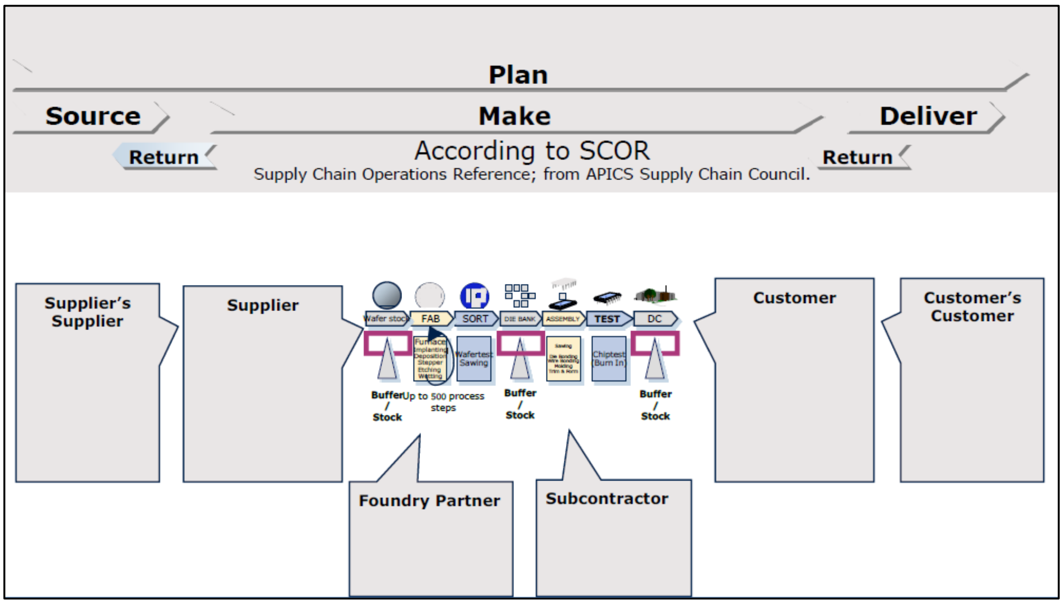

Figure 5: Supply chain of the Examined Company according to SCOR (Source: Internal Document (2015a))

In the upcoming subsections, the examined company's application of the five management processes it incorporates from the SCOR model will be reviewed, with a special focus on the make and plan processes, as they are the topic of the study of this thesis.

2.1.2.2 Source

According to APICS SCC, the scope of the source process covers all the company's purchasing activities ranging from purchasing of raw material and sub-assemblies, to even services (APICS, 2014). The purchasing activities encompassed in the examined company's source process are supply market research, negotiation with potential suppliers, contract conclusions and sourcing logistics activities. The goals of the source process defined by the company are to secure supply of high quality products, and to ensure low material, transport and warehousing costs (Internal Document, 2015b).

The framework that enables the source process in the examined company starts by selecting the suitable supplier and establishing contracts and business rules with him. Afterwards, business processes, like forecasts are established and aligned with the supplier. Security, performance and quality audits are then undergone. Import and export requirements are then managed, and data connections between the company and the supplier have to be established in order to eventually enable a smooth source process (Internal Document, 2015b).

Figure 6 depicts the execution of the source process in the examined company, consisting of five main steps. It starts with scheduling the product deliveries with the suppliers, in alignment with the planning and production departments to determine which material should be delivered to which location in which quantities at what time.

The next step is the product receipt at the company's site, where the received products are checked against the placed orders, and the goods received (GR) is booked in the company's IT-System. Next, the products received are verified with means of quality checks. Depending on the type of product, the check ranges from counting and visual inspection to technical measures like stress-tests, chemical analysis or x-rays. The next step in the source process is to manage the internal transportation and warehousing of the received materials, making sure that the material is correctly transported and stored in the point consumption. Finally, the supplier payment takes place after all incoming criteria are fulfilled (Internal Document, 2015b).

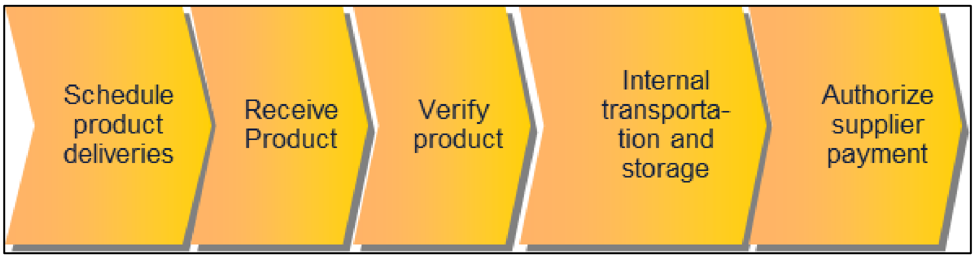

Figure 6: The Source Process Execution at the Examined Company (Source: Internal Document (2015b))

2.1.2.3 Make

APICS SCC relate the make process in a company's supply chain to the concept of adding value to a product. They list a set of diverse processes, such as separating, forming, machining, and chemical processes that the make process in a company could incorporate (APICS, 2014). The make process in the semiconductor Industry is composed of two main processes; produce and test. It is grouped into Front End (FE), where wafer production takes place, and Back End (BE) where assembly and test processes occur. FE and BE are separated by a Die Bank (DB) (Internal Document, 2008).

After receiving raw silicon wafers from suppliers, the semiconductor manufacturers carry out the FE and BE process. The main steps in FE are fab and sort. In the fab process, integrated circuits are printed on to the wafer surface. On the other hand, the sort process is the process where testing and sorting of defective chips on the waters takes place. The finished wafers are afterwards delivered to the DB. In BE, the main steps are called assembly and test, followed by the delivering the finished parts to the Distribution Centers (DC's). A typical wafer manufacturing cycle time of FE is usually between forty and one hundred days, while a typical cycle time for the BE processes would range from five and twenty days. The FE and BE processes will be reviewed in detail in the following points (Internal Document, 2008). Figure 7 depicts the manufacturing process flow from FE to BE.

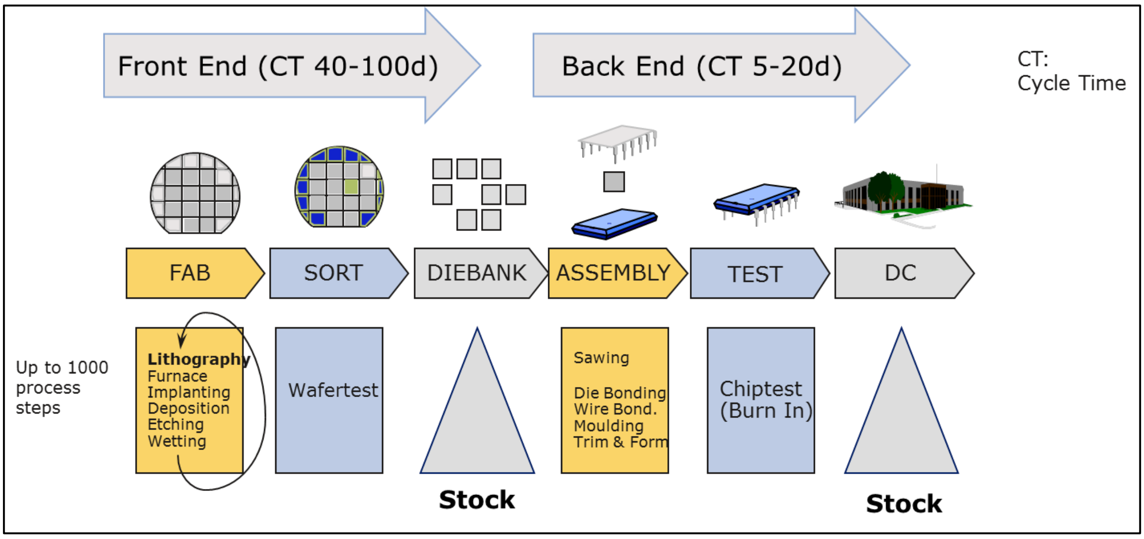

Figure 7: The Semiconductor Manufacturing Process (Source: Internal Document (2008))

Frontend Process

The FE process is the most complicated process in semiconductor manufacturing. It is carried out in cleanrooms, where several control steps are implemented to ensure low defect densities and high quality. The FE process constitutes two mains processes, fab and sort. The fab process is the process of forming the chips on the wafer, whereas the sort process is concerned with testing out the chips against the required specifications. The fab process comprises more than 500 steps. Many of those steps are repeated or revolving steps. Figure 8 depicts a schematic of the FE fab processes. The red line represents the path of the wafer between the different operations, clarifying the loops that take place between them (Internal Document, 2008).

FE production consists of a series of chemical and physical processes basic process steps are:

- Lithography
- Layering with oxidation, PVD or CVD
- Furnace oxidation
- Dry and wet etching

- Cleaning and control
- doping, ion implantation and diffusion
- and finally chemo-mechanical polishing

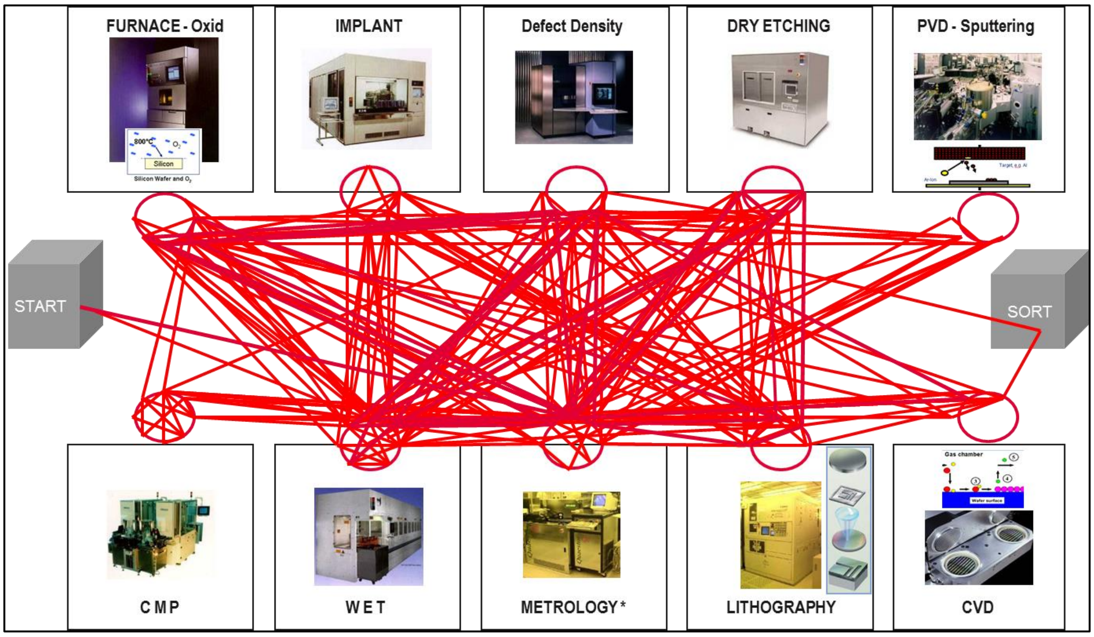

Figure 8: The FE Manufacturing Process (Source: Internal Document (2008))

Since the FE manufacturing process is a highly complex process that includes lots of technical details, an overview will be given on two of the main processes for FE production steps, which are lithography and layering.

Lithography is considered to be the key process in FE production. In this process, the design of the chip is transferred via masks (reticles) to the wafers. The process starts by spreading a photo resisting layer on the wafer, then exposing light through the mask, which then shows the effect on the open places in the mask. Finally, the photo resisting material is removed from the wafer's surface, leaving only the remaining structure on the wafer. After some time for deposition, these steps are repeated up to 35 times. Figure 9 illustrates the process cycle of lithography, depicting its different steps (Internal Document, 2008).

Another important process in FE production is the layering process, where specific materials are added to the wafer. The layering process could either be a physical or chemical process. One way of adding material to the wafer is by oxidation, where silicon reacts with the oxygen of the air, thereby creating silicon-dioxide. Another method for layering is the Chemical Vapor Disposition (CVD) process, where chemicals in the gas phase react with the wafer surface in a chamber generating a thin layer on the wafer surface. The third process for layering is the

Physical vapor Disposition (PVD) or sputtering process. Recently, it has become the most used process in the semiconductor industry. During this process, gas atoms (mostly argon), strike out atoms from the cathode in an electric field which then form a thin film on the wafer surface (Internal Document, 2008).

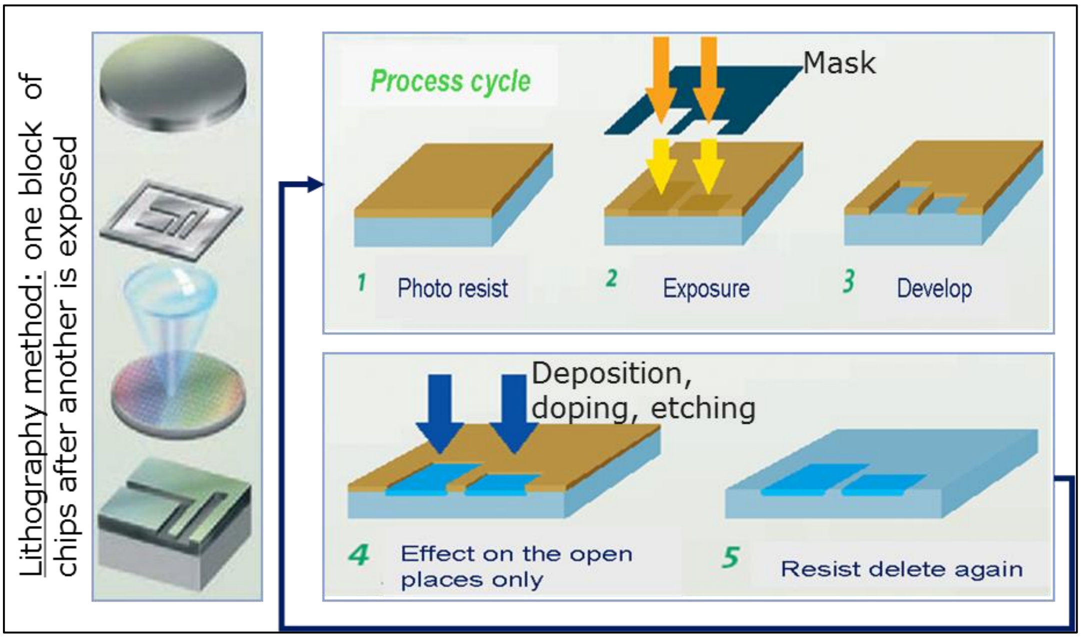

Figure 9: Lithography Process in FE Production (Source: Internal Document (2008))

After the formation of the chips on the wafer in the fab process, the sort process is carried out. A circuit test is conducted to verify whether all electrical circuit parameters lie within the specified limits for the chips produced on the wafers. The chips have to be carefully tested before BE processing in order to ensure that only the chips which fulfill the required technical specs will undergo the BE process. Good chips and bad chips are identified through a process called inking. Wafers could be physically inked, marking the bad chips with real ink, or they could also be inkless, and in this case an electronic wafer map is used to indicate the condition of each chip by means of computer software. Afterwards, the wafers are stored in boxes and delivered to the DB, which signifies the end of FE manufacturing (Internal Document, 2013a).

After briefly reviewing the FE Process, an overview will be given on the BE process where the assembly and test take place.

Backend Process

The BE process constitutes two main processes: assembly and test. After delivering the tested wafers to DB, the wafers are then sent to the assembly facilities where the BE process begins. At the assembly facilities, the good chips are picked out individually from the wafers and packaged into their commercial forms (final product). The packaged products then undergo a round of tests at the testing facilities, where they are tested for their functionalities and screened for defects. Products which undergo the test process are then packed and delivered to DCs (Internal Document, 2013a).

The BE process starts with the assembly process. The assembly process depends on the package that the chip goes into. In this subsection, the assembly processes for the packages using the leadframe will be reviewed, as an example for the general assembly process. The packaging process consists of two main steps: front of line and end of line (shown in Figure 10). The first process in the front of line step is wafer mounting, where the fabricated wafers are first sent to the wafer mounting process. In the wafer mounting process, a specialized adhesive tape is pasted across the backside of the wafer to ensure that the individual dies (or chips) remain firmly in place during the next process, which is wafer sawing. The purpose of the wafer sawing process is to divide each wafer into its individual die units. The number of chips per wafer ranges from sixty chips to tens of thousands of chip, depending on the chip size and wafer diameter. Once a wafer has been sawn, the chips remain on the mounting tape until they are extracted by the die handling equipment (such as the die bonder) in the die attach process. The mounting and sawing processes are commonly referred to as the pre-assembly processes (Internal Document, 2013a; Internal Document, 2013b).

In the die attach process, each individual die is picked up and either glued or soldered to a leadframe, which is the chip carrier of a leaded package. It is the main component which holds the die in the package. Soft solder, diffusible metal alloy, or epoxy glue could be used to attach the die onto the die pad using a die bonder machine. Once the dies are attached onto the leadframes, the leadframe strips are sent to the next process; the wire bonding process. In the wire bonding process, the dies are electrically connected to their individual leadframes via thin wires made of aluminum, copper, or gold, in order to create an electrical connection between the die and the leadframe (Internal Document, 2013b).

For some special products, the leadframe strips are sent to a process called A2 plating, which is an electroplating process, during which the conducting material is electrically coated with another metallic material for quality enhancement purposes. Other products skip the A2 Plating process and are sent directly to the final process of the front of line which is the auto vision. The auto vision process is where visual checks on the semi-packaged products are performed, whereby defective chips from the entire front of line process are screened, making sure that minimal defective parts undergo the end of line process (Internal Document, 2013b).

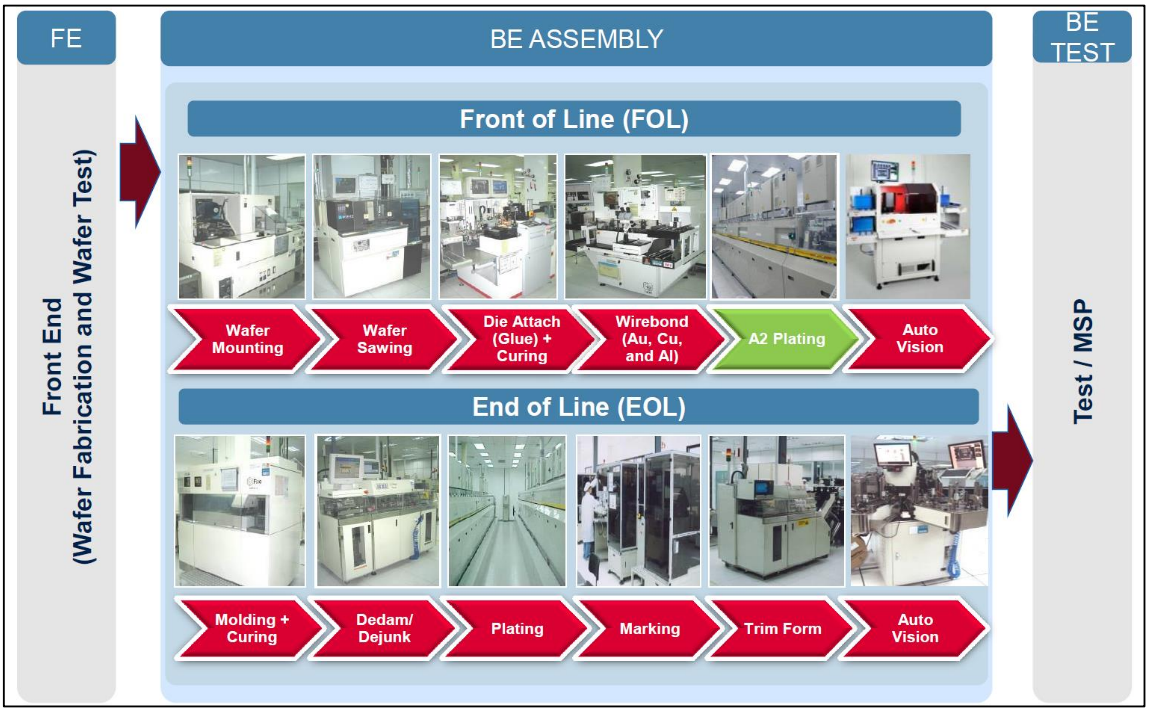

Figure 10: BE Assembly Processes (Source: Internal Document, (2013))

The next step of the BE assembly process is the end of line step. The first end of line process is molding and curing. At molding, the semiconductor die is encapsulated together with the wire bond and the center portion of the leadframe with a black material called the mold compound. The purpose of that is to protect the sensitive components mechanically and environmentally from direct light, heat, humidity and dust, thus preventing damages and contamination. The process of molding is done by a molding machine, and is illustrated in Figure 11. After the molding process, the parts move to the curing process, where they are placed in an oven for some hours to ensure that the mold compound is completely cured. By exposing the parts to high temperatures for a long time, higher strength and robustness can be achieved (Internal Document, 2013c).

After that, the chips undergo a process called dedam/dejunk. Leadframes are designed with a dam-bar which holds the leads together and also helps blocking the mold compound from flowing to external lead areas during the molding process. After molding and curing has been completed, the dam-bar must to be removed to separate the conjoined leads into single pieces. In addition, the excess mold compound also has to be removed. This is done in the dedam/dejunk process (Internal Document, 2013c).

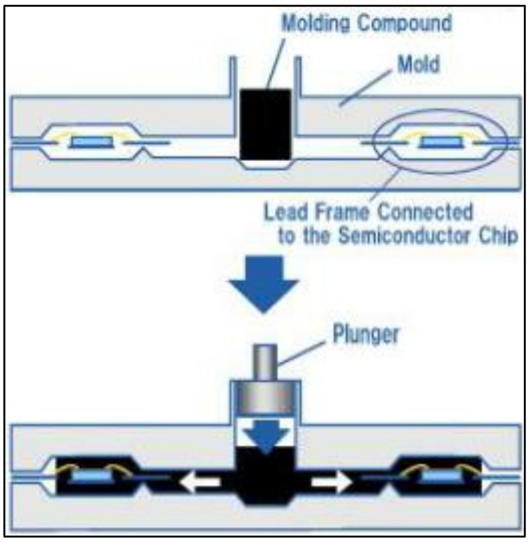

Figure 11: The Molding Process in BE (Source: Internal Document (2013c))

After that, the chips undergo a process called dedam/dejunk. Leadframes are designed with a dam-bar which holds the leads together and also helps blocking the mold compound from flowing to external lead areas during the molding process. After molding and curing has been completed, the dam-bar must to be removed to separate the conjoined leads into single pieces. In addition, the excess mold compound also has to be removed. This is done in the dedam/dejunk process (Internal Document, 2013c).

In the subsequent plating process, a layer of material is deposited on the package to enhance its quality by increasing its abrasion and wear resistance. It also improves the soldering property of the leads, as the products are usually connected to external circuit boards via soldering. The metallic layer plated onto the leadframes has better solderability, and therefore improves in the connection between the leads and the external circuit boards. The plating process is similar to the A2 Plating process which was previously described in the front of line, but the difference is that it is done for all products. Thereafter, the chips undergo the marking process, where various traceability and distinguishing marks are printed on the package of an IC for easier identification and traceability of the devices (Internal Document, 2013c).

The marked packages then are finally separated and shaped into individual pieces at the trim and form process. Right before trim and form, the individual leadframes are still connected together on a leadframe strip. The purpose of the trim & form process is to bend the leads according to its product package specification, and to cut the leadframe strip into individual pieces of leadframes. After trim and form, the final packaged products are formed. The last stage of end of line is the auto vision process, where the packages stored in tubes enter the auto vision machine. The Auto Vision machine captures visual images of the device using cameras, to perform quality checks on every single package in the batch. This process marks the end of the assembly process in BE. Figure 12 illustrates the packaged product in its final form, showing the different components mentioned above on the right side of the photo (Internal Document, 2013c).

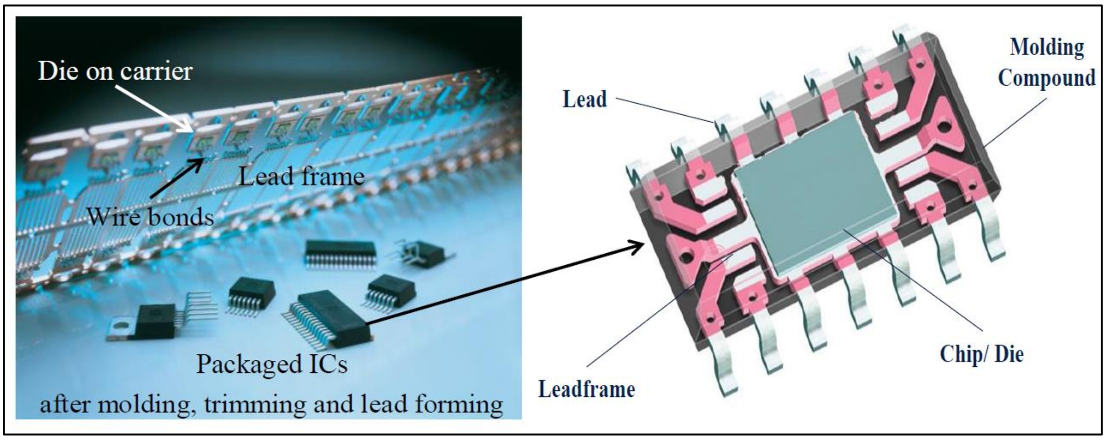

Figure 12: Illustration of a Packaged Chip (Source: Internal Document)

After finishing the assembly operations, the parts move to the testing process, which is the last process in BE. Testing is done in two stages; electrical testing and bake in. In electrical testing, the packaged dies are functionally tested once more, to ensure that the assembly processes have been correctly performed and that the dies have not been damaged in the process. Moreover, electrical testing guarantees that the parts meet their application specifications. Bake In, which is the second phase of the test process, is a form of drying process to help remove moisture from the mold compound. The mold compound may crack at high temperature during usage if the moisture level of the compound is too high due to the high pressure formed. Therefore, the bake in process helps to eliminate the so-called popcorn effect during board soldering. This is only done for some specific products depending on product specifications, such as the moisture level required. Afterwards, the parts undergo checks on the marking to ensure that they are properly marked and in good condition. After successfully passing the different tests, the parts are then clear to be packed and shipped to DC's (Internal Document, 2013d).

2.1.2.4 Deliver

The definition of the deliver process in the SCOR model according to APICS SCC is associated with the processes of customer order management and fulfillment (APICS, 2014). The aim of the deliver process at the examined company is to ensure quick processing of customer requests and orders until delivery of goods to the customer and realization of receivables, and to efficiently manage product returns. This is done via distribution logistics, which is the process of storage and transport of finished goods to the customers requesting them. Distribution logistics also takes care of choosing the hubs locations, storekeeping, dispatching, order completion, packing as well as for the goods dispatch and the transport safety (Internal Document, 2015c).

The examined company uses the distribution center concept to deliver the finished goods to customers. Figure 13 depicts the concept, showing how products manufactured in different BE locations could be distributed to customers all over the world. It is also worth mentioning that the chips used in those different BE locations are also originated from different FE Fabs all over the world. DC's are replenished from all the BE sites finished products, in order to stock the finished goods only in DC's. Customer deliveries are only performed by the regional DCs. The examined company has three main DC's: the DCU in the USA, which is responsible for North America, the DCE in Germany to deliver products within Europe, the Middle East and the rest of the world, and the DCA located in Singapore, taking care of the customers in Asia Pacific. The DC concept allows a 24 hour door-to-door delivery from the DC to customers. It increases the delivery reliability compared to multiple stoking points at the BE's because the DC's are closer to customers. Furthermore, by reducing the number of stocking points, the general stock levels can be reduced (Internal Document, 2015c).

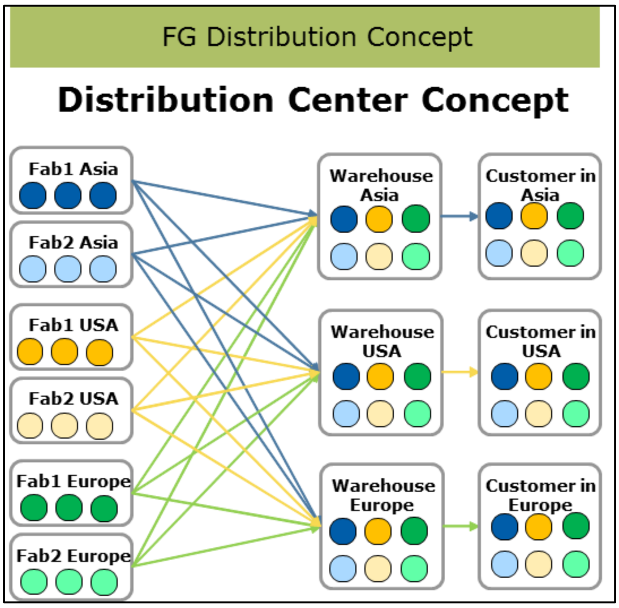

Figure 13: Distribution Center Concept at the Examined Company (Source: Internal Document (2015c))

The benefits of the DC concept according to the examined company is that it enables short delivery times to customer sites and accordingly supports shorter order fulfillment lead-time. Using DCs for distribution also reduces the need for customer consignment warehouses and transit hubs, as the DC is nearer to customer. Moreover, reduction of stocks by means of consolidating the finished goods' stocks worldwide could be achieved. Additionally, the DC concept enables the reduction of warehouses and warehousing operations and the optimization of transport routes and costs through improved consolidation of shipments to customer (Internal Document, 2015c).

2.1.2.5 Return

The return process according to APICS SCC is concerned with the reverse movement of goods and materials from customers back in the supply chain. The reasons for this could be product, ordering, or manufacturing defects, or to perform maintenance activities (APICS, 2014). Figure 14 shows the process flow of the return process in the examined company. The company defines three different return types within the return process: logistical, technical and commercial returns (Internal Document, 2015c).

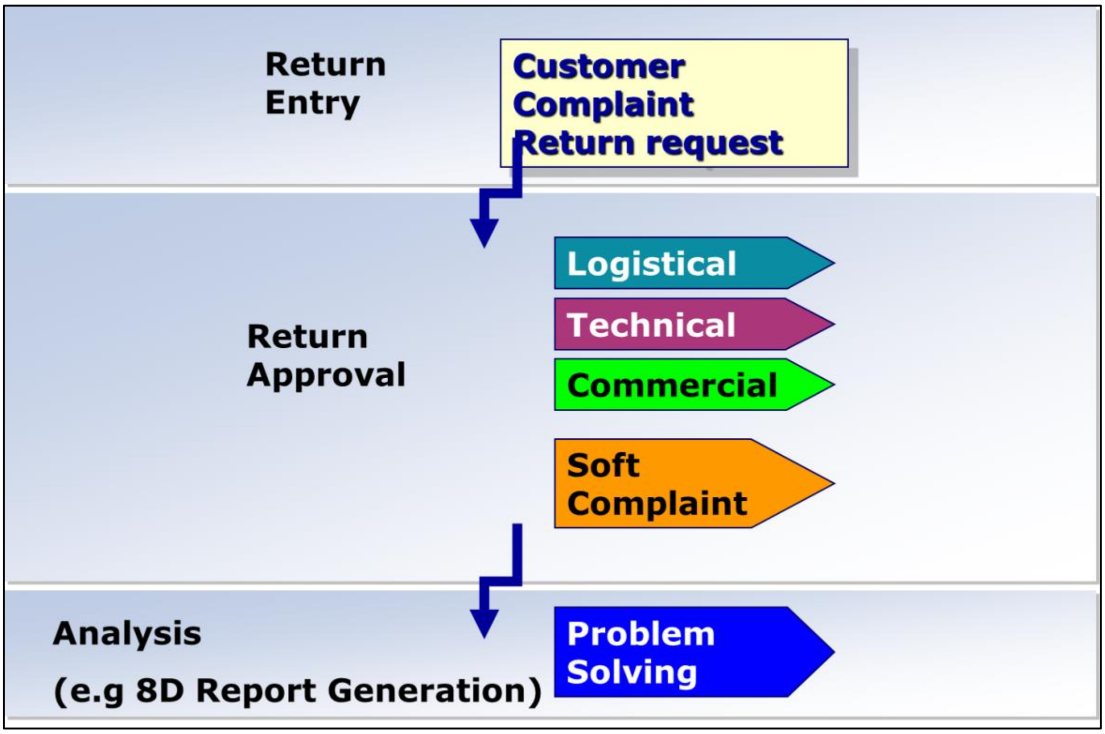

Figure 14: The Return Process in the Examined Company (Source: Internal Document (2015c))

Logistical returns occur due to a failure from the supplier (in this case the examined company); which is not due to technical reasons. For example, a logistical return could occur when the quantity shipped is larger than the quantity ordered by and invoiced to the customer. It could also happen when material shipped and invoiced is different from the material ordered, when the material is damaged during transportation and the supplier was responsible for the shipment, or the shipment is lost and the supplier was responsible for the shipment (Internal Document, 2015c).

Technical returns occur due the failure in product technicalities from the supplier (which is in this case the examined company). For example, a technical return takes place when the quality of the product is not according to standards, when wrong labels are put on the reels in production, or when there are too few devices in a product box. Finally, commercial returns occur due to customer failure or contractual obligation. For example, if customer has ordered too much or ordered the wrong product or the customer has selected the buyback option (Internal Document, 2015c).

The process flow of the return process is opposite to the regular process flow defined by the SCOR model, which is source, then make, and afterwards deliver. The parts that execute the return process, move the opposite way, till they reach the point of the problem. The problem solving is then triggered at the point of the process where the problem occurred (Internal Document, 2015c).

2.1.2.6 Plan

APICS SCC define the plan process in the supply chain as *"... the development and establishment of courses of action over specified time periods that represent a projected appropriation of supply chain resources to meet supply chain requirements for the longest time fence constraints of supply resources."* (APICS, 2014) The supply chain complexity is handled mainly in the plan process.

The examined company defines planning as an outlook that attempts to anticipate future events and is a crucial instrument for important decisions. Its planning landscape is based on four planning levels, which are the execution level, operational level, tactical level, and strategic level. Figure 15 illustrates the four planning levels incorporated in the company (Internal Document, 2014a).

The execution level is called FEST/BEST: these are last minute production plan changes in Front End and Back End. The operational level is called production program, where detailed plans are set for the next 26 weeks. The production program processes are supported by an advanced planning system that calculates the supply chain plans on a daily basis, by establishing a demand-supply match according to changed inputs such as newly received orders, new capacity availability, or any changes in the demand/supply inputs (Internal Document, 2014a).

The tactical level is called business scenario (biz scenario), which covers the time horizon from 26 weeks to 18 months. In business scenario, demand/supply match is done semi-automatically, providing several scenarios for that time horizon to help tactical planning decisions. The strategic planning level is called min max planning, which is the process with the longest planning horizon, aiming outlining the implementation of long term vision of the company on all levels. As shown in Figure 15, the four planning levels discussed are linked to one another. The planning logic is to reuse the lower-level plan in the higher level plan (Internal Document, 2014a).

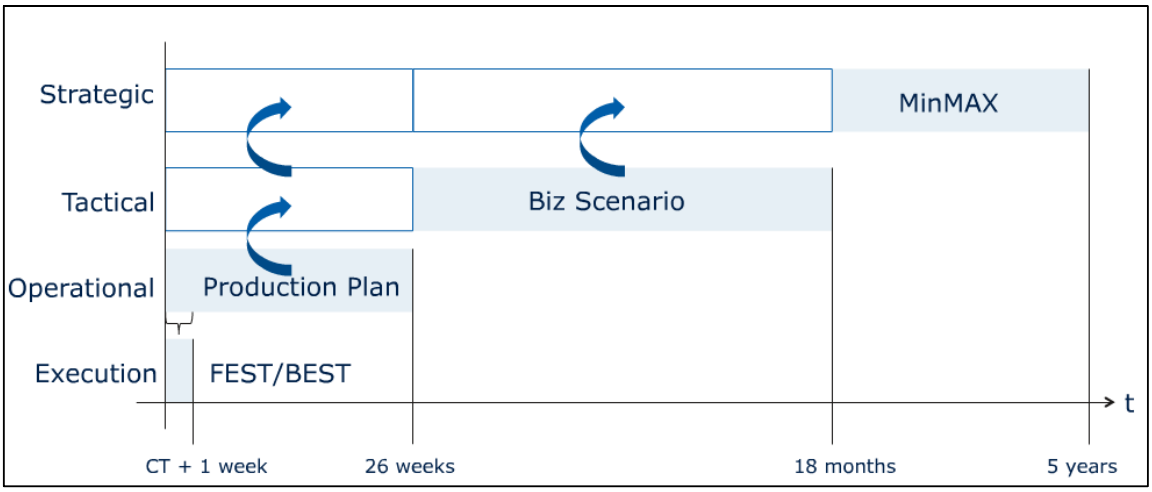

Figure 15: Planning Landscape at the Examined Company (Source: Internal Document (2014))

The examined company incorporates five main planning sub-processes endorsed in the SCOR model, which are demand planning, capacity planning, supply planning, production planning, and order management. Figure 16 illustrates the five processes, their roles, and their relationships within the planning system of the examined company. The five processes will be briefly reviewed, starting with the demand planning process (Internal Document, 2015d).

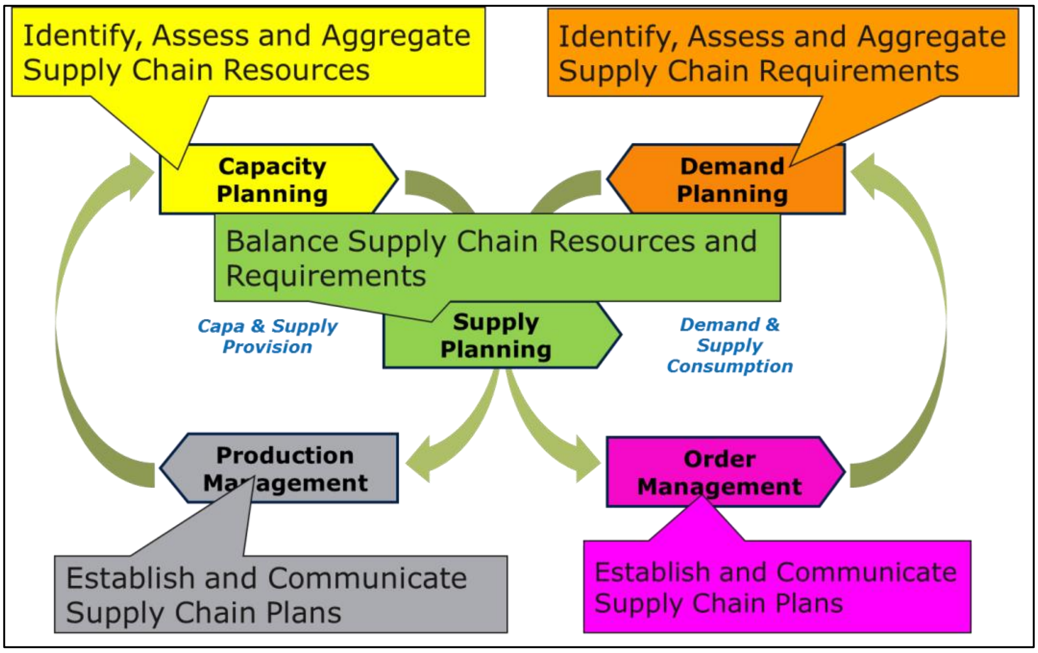

Figure 16: The Planning Process in the Examined Company (Source: Internal Document (2015d))

Demand Planning

The demand planning process is carried out on two levels; the operational level and the tactical level. On the tactical level, the demand planning process starts with sales demand planning. This is where the sales function discusses with the customer to define an unconstrained forecast which is what the company could sell to the customer without taking into account its capacity limitations. Accordingly, the products required by the customer are specified, as well as the dates and quantities they are required in. The second step on the tactical level would be the marketing demand planning process. The marketing function consolidates the different customers' demands defined by sales in their demand plan, and adjusts the total resulting demand in light of some strategic product and market updates. The total resulting demand is then used as input for the business scenario supply planning process called scenario planning. On the other hand, demand planning on the operational level is done by the SCP. The most important processes in demand planning on the operational level are operational demand maintenance and the stock target adjustments. In the operational demand maintenance, the SCP sets the demand plan for the next six months (26 weeks) for his/her dedicated products, taking into consideration ramp ups /downs or seasonal effects. The supply plan for the 26 weeks is afterwards set based on this demand plan. On the other hand, stock target adjustment process is where the SCP sets the stock targets for the different stocking points in the supply chain (DB, DC, and other stocking points), based on the demand picture seen (Internal Document, 2014b).

Capacity Planning

Capacity planning is the process identifies, assesses, and aggregates the resources in the company's supply chain. Similar to demand planning, capacity planning processes are done both on the operational and tactical levels. On the operational level, capacity planning defines the capacity bottlenecks that reflect real capacity constraints in the production lines, in both, FE and BE production lines. This is done by a capacity planner. The purpose of capacity planning on the tactical level is to provide scenarios for budget decisions regarding investment or de-investment, and to plan overall capacity adjustments (Internal Document, 2014c).

Supply Planning

Supply Planning combines the information from both, demand planning and capacity planning to generate a plan of what can be sold. It is also implemented on both, the operational and tactical levels. For the operational level, a weekly alignment takes place to discuss supply output improvements. The demand forecast (including orders), is planned into the available capacity generating the needed production requests to provide supply for the demand on hand. The output is to be provided to the orders management team, in order to commit deliveries to customers based on the generated plan. It also aims at optimizing bottlenecks loads considering stock levels. On the tactical level, supply planning is concerned with the go/no go decisions for proposed capacity adjustments from business side (Invest/De-invest proposals) (Internal Document, 2012).

Production Management

Production management defines the weekly loading of the different products to the production sites, aiming at meeting customer deliveries and minimum stock levels. This is undergone on both, the FE and BE levels in the FEST and BEST processes on the execution level. This is where the SCP is able to adjust the production targets, taking into consideration the orders on hand, material availability and the available capacities. Production targets calculated by the system based on the supply planning process explained above could be adjusted for the different stocking points in the supply chain. Adjustments could be due to lot size rounding, short term orders received, capacity utilization improvement, and many other reasons (Internal Document, 2008b).

Order Management

The task of the order management process is to confirm orders to the customers based on the supply plan established, acting as the interface between the supply chain planning and the customer. This occurs on the operational level. The objective of the order management is to increase the company's delivery reliability. Delivery Reliability compares the confirmation date with the actual date of delivery to customer (Internal Document, 2009).

2.1.3 Challenges in the Semiconductor Supply Chain

The semiconductor industry is characterized by being one of the most dynamic and fast changing in today's world, as it is highly driven by innovation. Companies are always under pressure to constantly develop their products in a prompt manner to meet the market's demand for increased functionality while maintaining or even further decreasing prices (Ballhaus, et al., 2009). The manufacturing process of a semiconductor is also considered one of the world's most complex manufacturing processes. With hundreds of advanced process steps comprising it, its complexity is inherent (Aelker, et al., 2013). Based on the above mentioned factors, a typical semiconductor manufacturer faces numerous challenges to manage his supply chain. The following points summarize the challenges faced in a typical semiconductor supply chain.

2.1.3.1 Capital Intensiveness

The semiconductor industry is considered to be one of the world's most capital intensive industries (Losleben, 1990). On one hand, the single largest item in any semiconductor company's earnings statement is always the capital expenditure for new production equipment (Cohen, et al., 2003). McKinsey & Company (2011) estimate the cost of building a state-of-the-art fab for producing 200mm wafers to be $1.6 billion, and for producing 300mm wafers to be around $3-4 billion. On the other hand, the time required for capacity expansion in the semiconductor industry is extremely long. Incrementing capacity to an existing fab takes at least nine months, while it takes almost one whole year to equip a clean room for wafer production. Taking into account that equipment depreciation accounts for about 70% of the total production cost (Cho, et al., 2007), efficient capacity planning and utilization is a vital focal point in the semiconductor industry's supply chain, as companies can neither afford low utilization of existing capacity due to the enormous capital cost incurred, nor loss of sales due to lack of capacity, and obviously both undesirable cases could have a significant financial impact on the companies (Geng & Jiang, 2009).

2.1.3.2 Short Product Lifecycles

Due to the rapid advancement of both product and process technologies, and the increasing dynamism in market demand of the end-product industries supplied by the semiconductor industry, the lifecycle of semiconductor products is known to be fairly short with a maximum of 3 years for one generation of technology (Cho, et al., 2007). This means that semiconductor companies need to continuously change their product and process technologies, and ramp up and down new products, which burdens all the supply chain processes.

2.1.3.3 Long Manufacturing Cycle Time

The manufacturing process of a semiconductor comprises several hundred steps, and is considered one of the most complicated manufacturing processes in the world (Sun, et al., 2015). As mentioned in section 2.1.2.3, the IC production consists of two main phases; FE, which has a cycle time (total time elapsed for the production process) of 40-100 days, and BE, which takes around 5-20 days to complete. Accordingly, the total production cycle time for the IC production is considered quite long, as it could reach up to four months (Internal Document, 2008). Figure 7 in the previous section depicts the process flow of the IC manufacturing process from FE to BE, indicating the whole process cycle time.

2.1.3.4 Inherently Complex Manufacturing Process

The semiconductor production usually takes place in several different specialized FE and BE production sites distributed all over the world. A real life example of a chip manufacturing process journey could start with a wafer being fabricated in Germany, then travelling to Malaysia afterwards for certain process steps to be carried out, and then to Austria for chips sawing and grinding. Next, it travels to South Korea for BE assembly operations, and then finally to Singapore for testing. The process explained above implies various complexities with regards to the management of information, material and financial flows between the different parties involved in the process, as well as the customs and organizational issues entailed with the logistical operations. Bearing in mind that each party is always seeking to optimize their own operations, complexities inevitably arise in such an environment (Aelker, et al., 2013).

2.1.3.5 Demand Volatility and Bullwhip Effect

Since the semiconductor industry is typically located at the upstream end of the value chain of the end products' OEMs, it is prone to greater demand variations. This means that a slight change in demand from the end customer is amplified as it reaches the semiconductor manufacturer, which causes high swings in inventory and capacity utilization. This phenomenon is commonly known as the Bullwhip Effect, which is illustrated in Figure 17 (Lu, et al., 2013). This phenomenon particularly gets more and more problematic considering the long manufacturing cycle time (see section 2.1.3.3 above), which hinders the quick response required to those fluctuations.

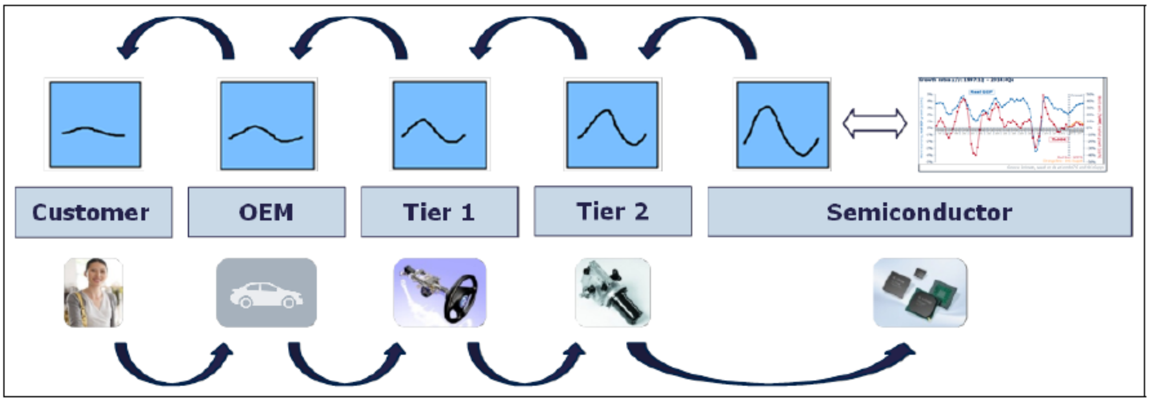

Figure 17: The Bullwhip Effect in the Semiconductor Supply Chain (Source: Internal Document)

2.1.3.6 Product Variability

Due to the expanding role technology plays in our life today, the applications of microcontrollers and chips have become countless. From automotive applications to smart phones and lightning systems, lots of products in today's world are based on semiconductors (Aelker, et al., 2013). Accordingly, a typical semiconductor manufacturer today operates different - and sometimes unrelated - business units to serve those diverse applications. This issue, alongside the short products lifecycle (see section 2.1.3.2 above), implies immense complexity in the company's product portfolio, as it has to manage a product base of over 10,000 SKUs (Sun, et al., 2015). And since those SKUs are being used for various and sometimes unrelated applications, their production processes are also different, and in many cases not interchangeable (McKinsey & Company , 2011).

2.1.3.7 High Probability and Severity of Disruption Risks

Due to its production supply chain network design being spread all over the world, the semiconductor industry is very vulnerable to disruption risks, such as fires, natural hazards and earthquakes, political turmoil, etc. A prominent example of the effect of such disruptions is Taiwan's 921 earthquake that took place in 1999, which affected 5 semiconductor facilities, and caused a 2-week interruption of their production, with losses of hundreds of millions of dollars (Sherin & Bartolett, 2000). This incident illustrates the critical effect such risks have on the semiconductor industry, as they severely affect the industry's operations, and pose a threat to its business continuity. The fact that a typical semiconductor manufacturer has production sites distributed all over the world, as previously mentioned, makes the probability of occurrence of such incidents very high, especially since many companies have manufacturing sites in Asia (as shown in the above example), which is known for being highly prone to earthquakes, volcano eruptions, and other disruption risks. Also, the fact that the product gets processed in different sites during its fabrication journey poses a bigger risk on semiconductor companies than other companies. Unlike those with a simpler and more traditional production and supply chain networks, in the case of semiconductor companies if one site is down due to disruptions, the whole production of a group of products could stop, and the worldwide supply for this product group will accordingly stop.

2.2 Agility

In this subchapter, a review about agility in the manufacturing literature will be conducted, starting by a brief review of the history of the concept, moving on to a broad review of the development of term's definition throughout the years, and finally discussing the concepts and definitions introduced in the literature about supply chain agility.

2.2.1 History of Agility and Agile Manufacturing

The definition of world-class performance in the manufacturing world has been highly variable, as each era dictated its own definition of the term. In the past, it was believed that mass production, capitalizing on economies of scale and full plant utilization, was the only way to achieve a world-class manufacturing performance. This belief overlooked the obvious disadvantages of mass production in terms of inflexibility and high WIP and inventory levels (Sanchez & Nagi, 2001).

In the 1980s, after the introduction of Lean Manufacturing by Toyota in Japan, it was highly thought that it increases companies' flexibility through waste elimination and inventory levels reduction (Sheridan, 1993). While the Lean paradigm has been optimal for an environment with high volume, low variety, and predictable demand and supply certainty, it has been proven that it falls short when rapid responsiveness to changing customer demand is required, especially on the supply chain level in volatile environments (Carvalho, et al., 2011).

With the evolution of the Lean paradigm in Japan and Asian markets, US and European manufacturing companies felt the urge to respond to the threat posed by Asia (Kidd, 1995). This is why the US industry leaders in the early 1990s thought of formulating a new concept that describes how their industrial competitiveness might or will develop (Sanchez & Nagi, 2001).

At that time, it had been realized that the world will be facing vast quick-paced changes, specifically in the manufacturing sector. Turbulence and uncertainty in the business environment had been identified as the main reasons of failures in the industry. For that reason, numerous studies had been directed towards examining and analyzing the quick trend of changes in the manufacturing field, and the need of developing and applying new progressive paradigms and visions that tackle what the conventional manufacturing philosophies had failed to handle in this new reality (Sharifi & Zhang, 2001).

In 1991, more than 150 industry executives took part in a study that resulted in a 2 volume report titled "21st Century Manufacturing Enterprise Strategy", which led to the introduction of the concept of Agile Manufacturing, and the formation of the Agile Manufacturing Enterprise Forum (AMEF), affiliated with the Iacocca Institute at Lehigh University (Sanchez & Nagi, 2001). The study emphasized that agility will be the most instrumental characteristic for an organization to thrive and flourish in the 21st century, where the business environment will inevitably be volatile and constantly changing. By 1992, the number of companies and organizations participating in the Agile Manufacturing Enterprise Forum had multiplied to reach 150. It was then when they started working on defining and developing the attributes that would be instrumental for the realization of the agile enterprise concept (Dove, 1992). In the context of manufacturing, the term agility is the same as agile manufacturing, as agility here refers to this trait within the manufacturing context.

The efforts and literature that have emerged afterwards in the 1990's and the 2000's have been focused on reaching a comprehensive definition of agility from different perspectives and in different contexts, as well as developing frameworks that would help the further research and application of the concept. In the next sections, the different definitions of agility discussed in the literature will be reviewed, and afterwards, agility in supply chain will be specifically focused on in a separate section.

2.2.2 Definition of Agility

Since the first appearance of the term *Agility* in the manufacturing literature in 1991, a multitude of various definitions have been associated with the term in the studies that have emerged afterwards (Huang & Li, 2009). The aim of this section is to review and discuss the different definitions brought up in the literature, and understand the diverse perspectives and standpoints from which each definition has arisen.

The first mention of the concept of agility in manufacturing was in the report "21st Century Manufacturing Enterprise Strategy", published by the Iacocca Institute in 1991. The purpose of the report was to establish a new strategy that enables the US to regain the supremacy it had lost to Japan and the Asian countries in the manufacturing sector. The report described agility as *"…a manufacturing system with extraordinary capabilities*," asserting the idea that the marketplace will be rapidly changing in the 21st century, and that meeting the changing customer demand should accordingly be highly focused on, which is what an agile manufacturing system, in their view, should provide (Nagel & Dove, 1991). It is worth noting that the authors used "buzzwords" such as "*extraordinary capabilities*" and "*real time response*" to emphasize the vast change of mindset needed to realize the aspired transition from the traditional manufacturing strategies to the newly defined strategy, which ultimately aims at enabling the desired shift of manufacturing dominance to the US once more.

A remarkable paper that aimed at discussing agility in the early stages of the concept was Youssef (1992). No clear definition of the term was given throughout the paper. However, the author built a clear correlation between agility, time to market, and quick response. To achieve the desired attributes of quick response and fast time to market, Youssef established a model (shown in Figure 18) that defines the relationships between the different pillars of agile manufacturing according to him (internal capabilities of the firm, suppliers and customers), indicating that a high level of organizational integration is required to achieve agility and improve manufacturing performance (Youssef, 1992).

In their later publications and papers, Roger Nagel and Rick Dove, the authors of the Iacocca Institute report, intended to further elaborate on the meaning of the term agility and how it could be more comprehensively conceptualized and defined.

In his article "The Meaning of Life and the Meaning of Agility," Dove highlighted the importance of mastering change when he defined agility. He stressed that an agile organization should continue to win even when constant innovation becomes the business driver, as the organization should be able to master change. Business process reengineering was positioned as a core strategy in his definition, as it enables quick response to the constant change required by an environment governed by innovation (Dove, 1994).

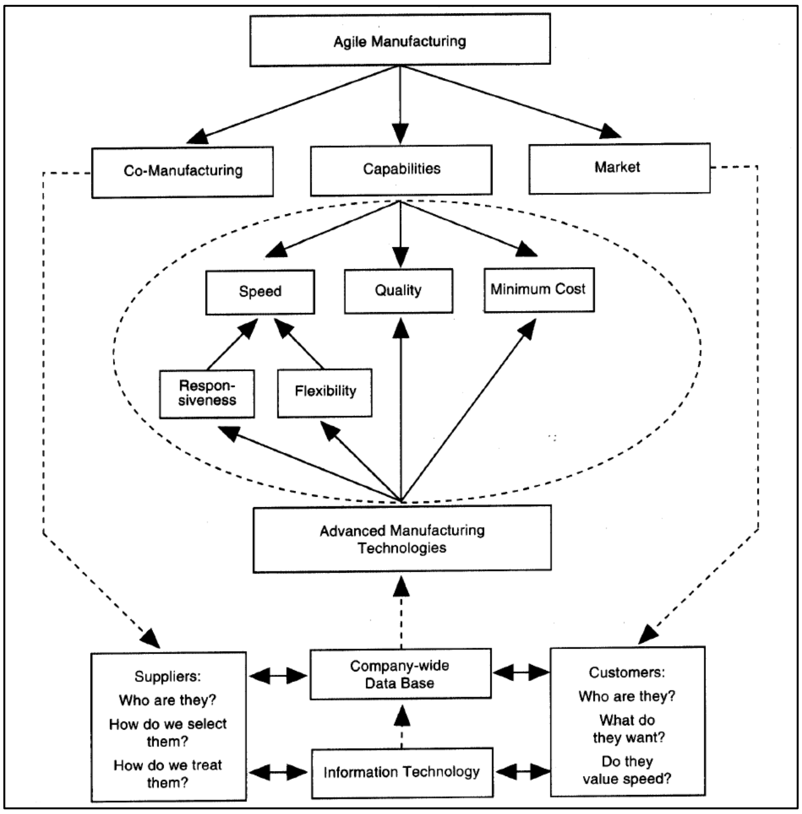

Figure 18: Agile Manufacturing Model According to Youssef (1992)

In their definition of the term, Steven Goldman and Roger Nagel (1993) tended to relate agility to the previous dominant concepts in manufacturing such as TQM, JIT and Lean. In their view, agility integrates these concepts together, while bearing in mind the lessons learned from the past applications of them, to create a managerial environment that unleashes their full potentials for the desired transformability required in agile manufacturing. The terms *speed* and *flexibility* were used to describe what an agile management should strive to achieve. The authors asserted the importance of matching the speed and flexibility of an agile management's operation with the speed and flexibility of the technology it manages (Goldman & Nagel, 1993).

Goldman and Nagel agreed with Youssef (1992) about the importance of organizational integration in agile manufacturing. They highlighted the change of relationship between the company and its suppliers and customers (as pointed out by Youssef), adding that the relationship with competitors will also change in an agile system. They argued that agility alters the classical definition of competition, as competition and cooperation could simultaneously take place between two firms in an agile manufacturing system. The competitive advantage of companies in such an environment will be determined by their speed to market in fulfilling specific customer wishes (Goldman & Nagel, 1993),

Roger Nagel and Piyush Bhargava (1994) viewed agility as a means to achieve world-class quality and manufacturing performance, which will require more than mere improvement in the manufacturing process -as the Lean paradigm suggests- in the 21st century. Agreeing with the view of Goldman and Nagel that agility incorporates speed, their definition also encompassed the concept of adaptability, pointing out that an agile system should be resourceful. They extended the scope of application of agility not only to a company's manufacturing system, but also to all its supportive functions such as marketing, finance, human resources, indicating that the whole company should constantly adapt its operations according to customer desires (Nagel & Bhargava, 1994).

Paul T. Kidd, one of the prominent writers in the area of agility, claimed that the previous definitions of agility had mostly defined it in terms of outcomes, with little focus on the operationalization of the concept. In his 1995 article "Agile Manufacturing: A Strategy for the 21st Century," he reviewed some of the previous works defining agility, alongside his own definitions of the term in the books and articles he had previously published. Creating enterprises that acquire certain core skills and competences which are brought to a joint venture operation is a cornerstone in Kidd's conceptualization of agile manufacturing in operations. He named those joint ventures *Virtual Corporations*, as they don't possess major capital of their own, which makes them more formable than traditional organizations and allows them to change more quickly (Kidd, 1994).

In a later definition, Kidd added that an agile corporation should be a robust enterprise which should be able to be rapidly reconfigured in response to market opportunities. Agreeing with Nagel and Bhargava, he viewed speed and adaptability as the key concepts to build an agile corporation. He highlighted the importance of integrating technology, organization and people in a holistic system to achieve a synergy that enables the desired leap in competitive performance. In another definition of his, Kidd emphasized the human aspect in an agile organization, asserting that knowledge is a fundamental resource in agile enterprises. (Kidd, 1995).

In an early attempt to draw a clear comparison between lean and agile manufacturing, Richards (1996) claimed that lean as a paradigm pays little attention to customers compared to its high focus on increasing shop floor efficiency. He even argued that being lean could become dangerous without equal emphasis on the interaction with the outer world. In a unique development of the definition, Richards defined agility through leanness, claiming that an agile producer is one that is lean with extended concepts and abilities, and which is also able to function in an open environment. He also attempted to compare flexibility to agility in manufacturing, pointing out that a flexible manufacturing system is one which can produce different products on one production line, while in this sense, an agile manufacturing system is one that is able to switch rapidly between the different production modes (Richards, 1996).

Introducing new concepts to the definition, Fliedner and Vokurka (1997) related agility to the cost, quality, lead time, and volumes of the products being produced by a company. They argued that agility provides enhanced value to the customer with means of customization. In their view, agility replaces the companies' classical strategic priorities of cost, quality, and dependability, with a stronger focus on responding promptly to changes in market demand, whether those changes are in the product characteristics, amounts requested in customer orders, or conditions inside the company (Fliedner & Vokurka, 1997).

Gunasekaran, who is one of the authors who extensively worked on the concept of agility, defined it as the company's ability to flourish in competitive circumstances where change is unpredictable. He agreed with Fliedner and Vokurka that an agile company should be customer driven by providing highly customized products and services in a prompt manner. His 1998 article was primarily focused on proposing enablers and establishing an implementation framework for agility. In this respect, he constructed a conceptual model (shown in Figure 19) to define agility, depicting its seven enablers he defined in the article and how they interact to form the concept. The seven enablers he defined are: (i) virtual enterprise formation tools/metrics, (ii) physically distributed manufacturing architecture and teams, (iii) rapid partnership formation tools/metrics, (iv) concurrent engineering, (v) integrated product/production/business information system, (vi) rapid prototyping tools, and (vii) electronic commerce (Gunasekaran, 1998).

It is clear that the enablers Gunasekaran proposed adopted some of the concepts that had already been defined in the previous works about agility. For example, the concepts of virtual enterprises and rapid partnerships formation are in harmony with Kidd's conceptualization of agile manufacturing in operation, where he argued that enterprises which acquire certain core skills and competences and which don't possess major capital of their own should be created and brought to a joint venture operation, naming them virtual corporations as well (Kidd, 1994).

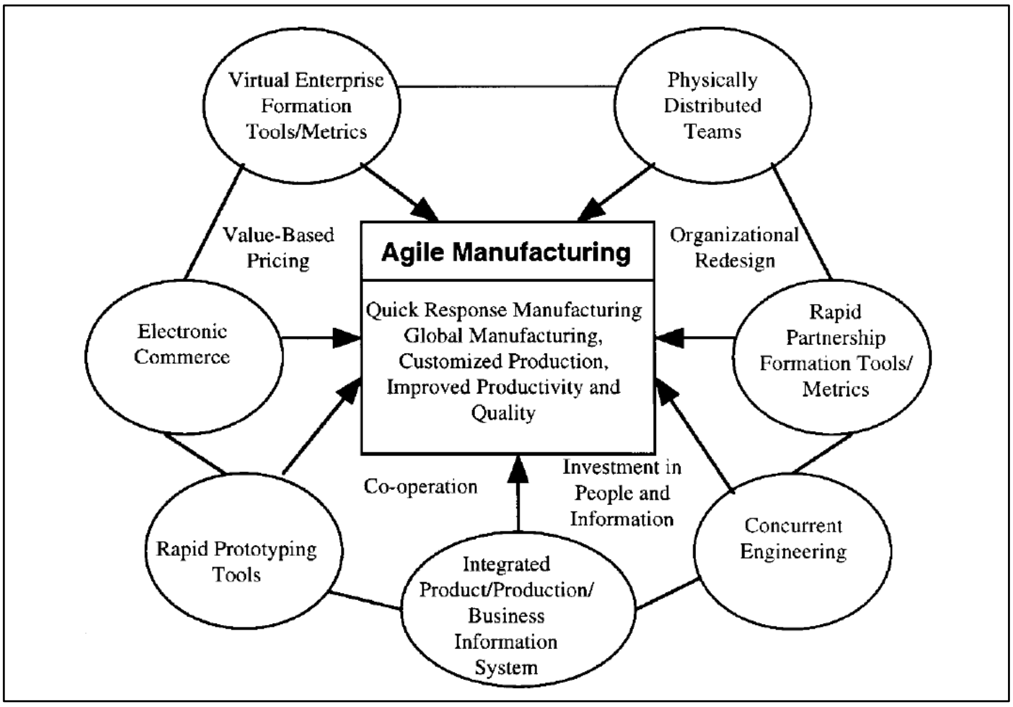

Figure 19: Gunasekaran's (1998) Conceptual Model of Agility and its Enablers

Another prominent article that aimed at conceptualizing agility was Yusuf, et al. (1999). Despite agreeing with Goldman and Nagel's approach on relating agility to the previous dominant concepts in manufacturing (JIT, TQM... etc.), they took the conceptualization to a whole new level by arguing that agility as a concept transcends mere speed and flexibility, opposed to what has been proposed in many of the previous works that mainly defined agility using those two terms. They claimed that likening agile manufacturing with speed of response or flexibility is a shallow comprehension of the concept, pointing out that agility requires immense infrastructural alterations in a company. They proposed their own definition of the term, claiming that is a comprehensive one. Their definition identified "competitive bases" that a company should explore in order to achieve agility. It agreed with Kidd's view on considering knowledge as a resource for agile manufacturing, and also with Gunasekaran on the importance of providing customer- driven products and services. The article identified four core concepts of agility (shown in Figure 20), which are core competence management, virtual enterprise, capability for reconfiguration, and knowledge driven enterprise (Yusuf, et al., 1999).

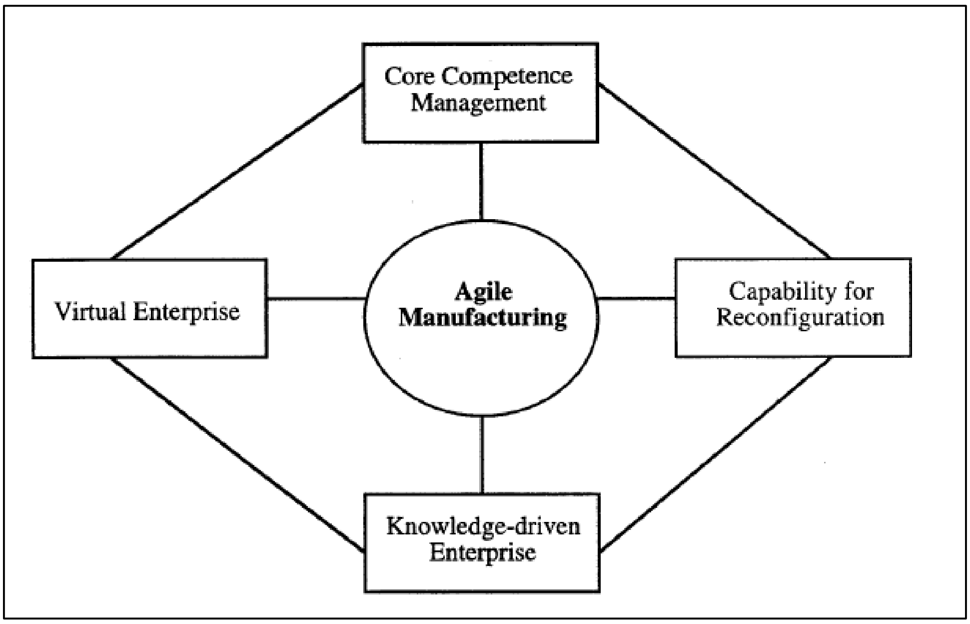

Figure 20: The Core Concepts of Agility According to Yusuf et al. (1999)

It can be noted that the four core concept indicated by Yusuf et al. are mostly aligned with what was previously proposed in the literature, especially with the works of Paul T. Kidd. The concept of core competence management was emphasized by Kidd in his definition of agility, who also asserted the concept of virtual organizations alongside Gunasekaran. Kidd has also used the term reconfiguration in his definition of the agility, and as previously mentioned, he viewed knowledge as a key resource for agile manufacturing similar to what is proposed in the article.

Entering the 21st century, more and more efforts have been directed towards developing practical methodologies to implement and achieve agility. Sharifi, et al. (2001) proposed a conceptual model, in which they differentiated between the drivers, capabilities and providers of agility. Case studies were conducted to validate the proposed model, where a questionnaire was derived out of the initial model to examine the awareness level of 30 companies about the drivers, capabilities and providers of agility explained in the model. Six companies out of the 30 were chosen for conducting more specific case studies, and more detailed interviews were carried out with senior managers of those companies. The aim of the interviews was to understand the perception of the companies about agility, comprehend the ways those companies are facing the challenges in their dynamic business environments, and to build a base for further case studies in the same direction (Sharifi, et al., 2001).

The findings of the case studies resulted in refining the initially proposed model to become the model shown in Figure 21 After assessment of the results, the authors have differentiated between two concepts, agility and responsiveness, giving each of then a unique definition. Their view of agility agrees with Dove's definition on asserting that an agile system should be able to master change, and to do it on all levels in the company, while to them, responsiveness is how well a company could collect information and predict change. According to them, an agile firm should be able to recover from the impact of changes, and even exploit them as a means for development (Sharifi, et al., 2001).

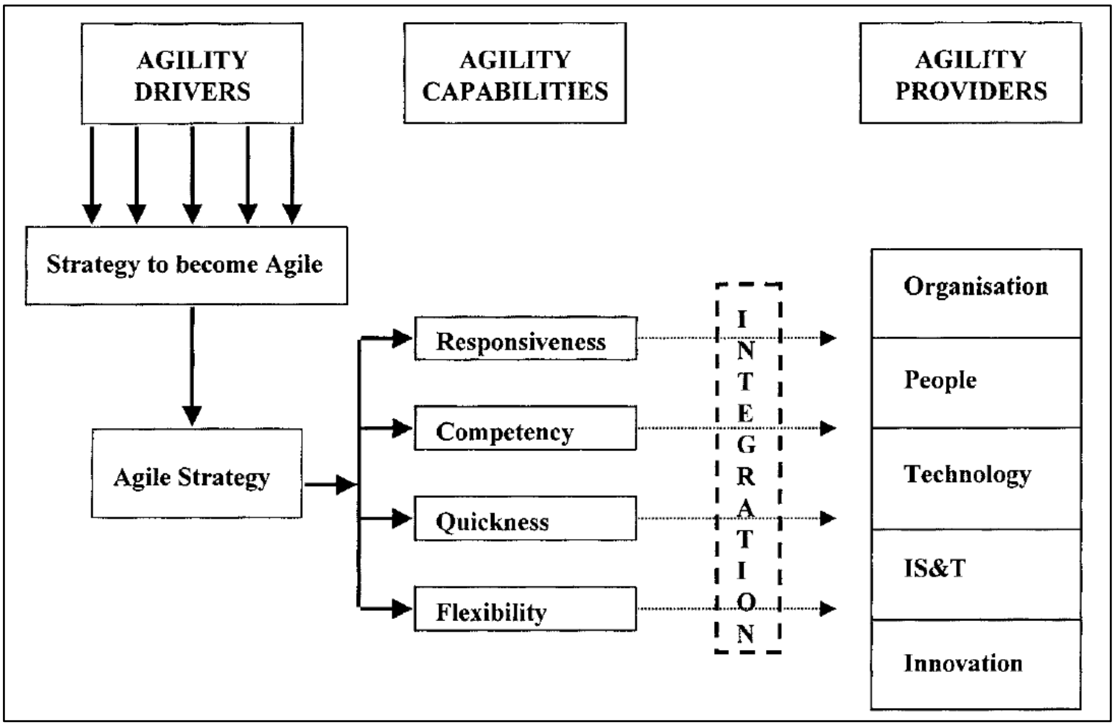

Figure 21: Conceptual Model of Agility According to Sharifi et al. (2001)

In their 2002 definition, Gunasekaran and Yusuf tended to define agility in terms of results, arguing that an agile manufacturing system should fulfill 3 targets, which are: (i) meet the changing market requirements, (ii) maximize customer service level (iii) minimize the cost of goods. They asserted that an agile organization should strive to compete in global markets with the aim of long term survival and profit potential. In line with continuous efforts to define practical techniques to apply agility, they identified four themes should be focused on in order to achieve agility. Agreeing with many of the previous literature, they viewed establishing virtual enterprises as an important strategy to apply agility. In harmony with their previous articles, they asserted the importance of quickly providing new products according to customer wishes. Gunasekaran and Yusuf explicitly emphasized the criticality of exploiting automation methods and high end technologies such as CAD, CAM, CAE... etc., and other IT tools to help the rapid ramp up of products. Finally, the need for strategic planning was strongly asserted, as it considers the strategic interests of the company and how it could survive on the long run given the market changes (Yusuf & Gunasekaran, 2002).

In an approach that greatly matches Fliedner and Vokurka's viewpoint of agility, Brown and Bessant (2003) explicitly linked agility to the concept of mass customization. In their view, agility and mass customization are not mutually exclusive, but on the contrary, they viewed mass customization as a component of agility. They stressed on the importance of having plant specific production strategies that would enable a company to be agile by means of mass customization. Brown and Bessant agreed with most of the previous definitions that agility should incorporate rapid response to changing market demands, adding that an agile firm should be proactive in understanding and developing future market opportunities (Brown & Bessant, 2003).

Some studies have also emerged with the focus of studying agility in the context of specific industries. With a special focus on the automotive industry, Elkins, et al. (2004) attempted to define agility from the industry's perspective. Their definition asserted the importance of cost effectiveness in the response of an agile manufacturing system to the changing product demand, and in the quick launching of customized products that fulfill customer wishes (Elkins, et al., 2004). Guisinger & Ghorashi (2004) conducted another study concentrated on the chemical industry, in which they emphasized that profitability is a desired outcome of agility in their definition of the term. They agreed with Elkins, et al. about the importance of responding to unpredictable changes in customer demand (Guisinger & Ghorashi, 2004). Although both of the industries reviewed are hardly related, the previously mentioned defintions reveal that the common driver of considering the application of agility in specific industry contexts is the fluctuation of customer demand.

In an empirical study that aimed at comparing lean and agile manufacturing once more, Narasimhan, et al.'s approach was different than Richards' approach in defining agility. While Richards had defined agility through leanness, Narasimhan, et al. defined both terms in explicit and vastly unrelated ways. Their definition of lean was focused on waste reduction, but on the other hand, they related agility to the efficiency of changing operating states as a reaction to demand uncertanity. (Narasimhan, et al., 2006).

After conducting an extensive literature review, Sherehiy, et al. (2007) viewed the concept of agility as the latest development of the idea of adjusting to changes. They argued that agility encompasses characteristics of the concepts of adaptability and flexibility. Their study primarily focused on the implementation of agility on an enterprise level, and that's why they claimed that the previous studies overlooked the organizational and managerial aspects of agility. The authors identified three main components of an agile organization: organization, people, and technology (Sherehiy, et al., 2007).

Looking at the topic from a rather managerial perspective, McCann, et al. (2009) contributed to the definition of agility by emphasizing the aspect of decisiveness in their definition. Another important addition to the concept's conceptualization was their argument that agility should avoid the "negative consequences of change". Transcending the traditional view of adapting to market opportunities, McCann, et al. claimed that an agile organization should also be able predict the upcoming opportunities, and even initiate them (McCann, et al., 2009).

The rather recent definitions of the agility tended to consolidate the concepts mentioned in the previous definitions of the term. In an article that aimed at conceptualizing agility on an organizational level, the definition proposed by Izadpanah & Yaghoubipoor (2012) incorporated the competitive bases identified by Yusuf et al., and also agreed with Kidd that knowledge is a cornerstone of an agile environment (Izadpanah & Yaghoubipoor, 2012). Dubey & Gunasekaran's (2015) definition used the expression "Incredible internal capabilities", which is pretty close to the terminology used in the first definition of the term by Nagel and Dove. They also agreed with Richards' view on the importance of quickly switching between the different product lines in an agile system (Dubey & Gunasekaran, 2015).

In their interpretation of the term, Rabitsch & Ramsauer (2015) focused on the aspect of proactivity in reacting to uncertainties in their definition of the term. They defined three key characteristics an agile firm should possess in order to survive in today's marketplace. The first characteristic they defined is proactive preparation, meaning that companies should always be ready for alternative decisions and scenarios. The next characteristic is fast reaction, which greatly agrees to the previous interpretations of the term, as companies should be prompt in reacting to the inevitable changes they face in today's business world. Finally they defined optimized profitability as the third characteristic, emphasizing that companies should always link their manufacturing operations to the overall financial targets of the company defined by the management.

Based on the review undergone, and for the purpose of this thesis, a comprehensive understanding of the term agility in manufacturing would be that it represents a system that is able to exploit the ever-changing volatile market demand in a cost-efficient manner, by rapidly providing customer oriented products, through a set of capabilities (such as speed, flexibility, responsiveness, and market visibility) in a knowledge-rich environment.

Table 1 lists the definitions of agility/agile manufacturing as mentioned in the works reviewed in the section.

Definition	Author(s) (Year)	Key terms
Agility means a manufacturing system with extraordinary capabilities to meet the rapidly changing needs of the marketplace and a system that shifts quickly among product models and/or between product lines, ideally in real-time response to customer demand.	Nagel & Dove (1991)	Extraordinary capabilities, meet needs quickly, shift quickly
Agile manufacturing assimilates the full range of flexible production technologies, along with the lessons learned from total quality management, 'just-in-time' production and 'lean' production. It integrates these and related resources into a distinctive managerial environment organized to liberate their full potential for dramatically transforming our conceptualization of manufacturing.	Goldman & Nagel (1993)	Flexible production technologies, 'just-in-time' production , 'lean' production, distinctive managerial environment
Being Agile means being proficient at change and allows an organization to do anything it wants to do whenever it wants to. Thus, an Agile organization can employ business process reengineering as a core competency when transformation is called for. It can hasten its conversion to Lean production while that is still useful. And importantly, it can continue to succeed when constant innovation becomes the dominant competitive strategy.	Dove (1994)	Proficient at change, business process reengineering, constant innovation
Agility is the ability to move quickly and resourcefully, and in an adaptive manner.	Nagel and Bhargava (1994)	Moving quickly and resourcefully, adaptive manner
The concept of Agile Manufacturing is built around the synthesis of a number of enterprises that each have some core skills or competencies which they bring to a joint venturing operation, which is based on using each partner's facilities and resources. For this reason, these joint venture enterprises are called virtual corporations, because they do not own significant capital resources of their own. This helps to make them Agile, as they can be formed and changed very rapidly	Kidd (1994)	Synthesis of enterprises, core skills or competencies, joint venturing operation, virtual corporations opportunities, rapid formability
The Agility that arises can be used for competitive advantage, by being able to respond rapidly to changes occurring in the market environment and through the ability to	Kidd (1994)	Fundamental resource – knowledge, dynamic teams, knowledge transformation into

use and exploit a fundamental resource - knowledge. People need to be brought together, in dynamic teams, formed around clearly defined market opportunities, so that it becomes possible to lever one another's knowledge. Through this process is sought the transformation of knowledge into new products and services.		new products and services
An Agile corporation is a fast moving, adaptable and robust business enterprise capable of rapid reconfiguration in response to market opportunities. Such a corporation is founded on appropriate processes and structures and the integration of technology, organization and people into a coordinated system in order to achieve a quantum leap forward in competitive performance by delivering capabilities that surpass those obtained from current enterprise practices.	Kidd (1995)	Fast moving, robust business enterprise, rapid reconfiguration, integration of technology, quantum leap forward in competitive performance
An agile manufacturer is a lean producer that has extended the concept to improve its ability to function as an open system (observe), change its worldview accordingly (orient), and make timely and effective decisions.	Richards (1996)	Lean producer, open system, timely and effective decision making
Agility is the ability to successfully market low-cost high-quality products with short lead times and in varying volumes that provide enhanced value to customers through customization.	Fliedner and Vokurka (1997)	Low-cost high-quality products, short lead times, varying volumes, enhanced value, customization
Agile manufacturing is the capability to survive and prosper in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by customer-designed products and services.	Gunasekaran (1998)	competitive environment, unpredictable change, changing markets, customer-designed products,
Agility is the successful exploration of competitive bases (speed, flexibility, innovation, proactivity, quality and profitability) through the integration of reconfigurable resources and best practices in a knowledge-rich environment to provide customer-driven products and services in a fast changing market environment.	Yusuf et al. (1999)	Competitive bases, proactivity, profitability, reconfigurable resources integration
Agility is the ability of an organization to effect change in its systems, structure and organization. An enterprise operating in an agile manufacturing environment has the capacity to recover from imposed changes and to use change as a means of improvement	Sharifi, et al. (2001)	Effect change, recover from imposed changes, improve using changes

Agility in manufacturing may be defined as the capability of an organization, by proactively establishing virtual manufacturing with an efficient product development system, to (i) meet the changing market requirements, (ii) maximize customer service level and (iii) minimize the cost of goods, with an objective of being competitive in a global market and for an increased chance of long-term survival and profit potential. This must be supported by flexible people, processes and technologies.	Yusuf and Gunasekaran (2002)	Proactively, efficient product development, customer service level maximization, cost of goods minimization, long-term survival, people, processes and technologies flexibility
Agile manufacturing includes the ability to respond quickly and effectively to current market demands, as well as being proactive in developing future market opportunities.	Brown and Bessant (2003)	Proactivity, developing future market opportunities
In the automotive industry, it is thought that agile manufacturing systems will permit fast cost-effective responses to unpredictable and ever-changing product demand, and support rapid product launches for previously unplanned products tailored to meet changing customer desires.	Elkins, et al. (2004)	Cost-effective responses, cost-effective responses, rapid product launches, unplanned and tailored products
An agile company can be defined as an enterprise that is capable of operating profitably in a competitive environment of continually, and unpredictably, changing customer opportunities.	Guisinger and Ghorashi (2004)	Operating profitably, unpredictable, changing customer opportunities
Production is agile if it efficiently changes operating states in response to uncertain and changing demands placed upon it.	Narasimhan, et al. (2006)	Changing operating states, uncertain and changing demands
The agile enterprise is the latest stage of evolution of the idea of the organization or enterprise able to adjust to changes, combining all important notions from the adaptive and flexible organization concepts.	Sherehiy, et al. (2007)	Adjusting to changes, adaptive and flexible organization
Agility is the capacity for moving quickly, flexibly and decisively in anticipating, initiating and taking advantage of opportunities and avoiding any negative consequences of change.	McCann, et al. (2009)	Decisiveness, anticipating, initiating and taking advantage of opportunities, avoiding negative consequences of change.
Agility is to identify successfully the principles of competition (speed, flexibility, innovation, quality and profitability), integration of resources, and appropriate actions in the environment of knowledge with rapid changes, by providing the customer-friendly products and services.	Izadpanah and Yaghoubipoor (2012)	Principles of competition, integration of resources, customer-friendly products and services

Agility means an organization with incredible internal capabilities (i.e. hard and soft technologies, human resources, educated management and information) to meet dynamic needs of the market place (i.e. speed, flexibility, suppliers, infrastructure, customers, competition and responsiveness).	Dubey and Gunasekaran (2015)	Incredible internal capabilities, hard and soft technologies, dynamic needs of the market place
Agility in manufacturing enables companies to prepare proactively for uncertainties and react quickly to changes to optimize the economic situation by leveraging the whole value chain. The principal idea is to mitigate risk in market downturns and to take advantage of opportunities in upturns.	Rabitsch and Ramsauer (2015)	Proactivity, optimize economic situation, risk mitigation in downturns

Table 1: List of Agility Definitions in the Literature

2.2.3 Supply Chain Agility

In the previous section, the definitions of agility/agile manufacturing in the literature were reviewed. The aim of this section is to discuss and review the works about agility in the context of supply chain.

One of the early works that discussed agility in the context of supply chain was Rick Dove's (1996) article titled "Agile Supply Chain Management". He argued that traditional supply chain practices based on a stable environment were not sustainable any more. He also predicted that technology will play a bigger role in supply chain management, as this will improve the information exchange efficiency and speed between suppliers and customers. In this article, he viewed agility as the ability to change proficiently, emphasizing that supply chain management, as a business practice, will inevitably have to face changes and be ready to adapt to them. Dove identified 3 areas of change that a supply chain will have to deal with: virtual enterprise partnering, production outsourcing, and component supplier network (Dove, 1996).

It is notable that many the articles discussing supply chain agility tended to discuss it alongside leanness. One of the prominent papers that discussed leanness and agility in supply chain was Naylor, et al. (1999). Opposed to the belief that the two paradigms are isolated and fundamentally different, Naylor, et al. reckoned that they are combinable, and they used the term *Leagility* to express the combined paradigm between lean and agile. Their understanding of agility encompassed exploiting profitable opportunities in a volatile marketplace, while they define leanness as the elimination of waste along the value stream to secure a level schedule (Naylor, et al., 1999).

Figure 22 depicts Naylor, et al.'s understanding of the total value a supply chain delivers to customers. They identified four metrics that define value to customer which are: service, quality, cost and lead-time. Naylor, et al. compared the importance of each of the four metrics to the leanness and agility, rating every metric as key, secondary or arbitrary with respect to each of the two paradigms (Naylor, et al., 1999).

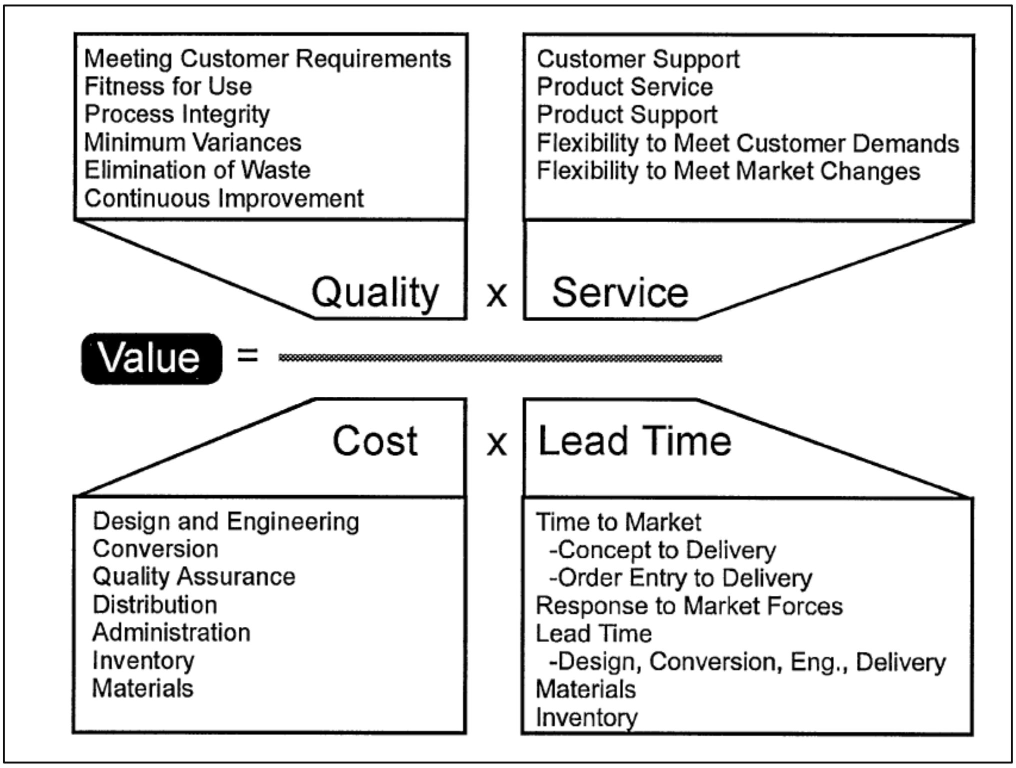

Figure 22: Total Value to Customer According to Naylor, et al. (1999)

They rated quality and lead time as a key metric to both paradigms. However, cost was considered a key metric to leanness while being a secondary metric to agility. The rationale behind the rating is that lean strongly focuses on waste reduction, which accordingly results in cost reduction. One of the ways lean seeks to achieve this is to reduce inventory levels, ideally to zero. Agility, on the other hand, deals with inventory levels more cautiously in order to ensure robustness against customer demand variations, which results in elevating inventory levels to ones higher than the levels desirable in a lean supply chain, eventually resulting in more costs incurred (Naylor, et al., 1999).

As for service, Naylor, et al. rated it as a key metric for agility and a secondary one for leanness. The reason for that is that one of lean's biggest enemies is variation, as sudden demand changes imply either idle capacities or high buffer stocks, which are both considered fundamental forms of waste in the lean paradigm. Lean manufacturing strives to smoothen and level demand via market knowledge and forward planning. Even the tools lean suggests to deal with variability (like SMED) mostly purpose to reduce the waste entailed with variability, and hardly to improve customer service levels (Naylor, et al., 1999).

On the contrary, demand instability is considered a precondition in the agile paradigm. Withstanding demand disturbances is a cornerstone in the conceptualization of agility. Agility even implies that the enterprise must take advantage of such disturbances. This is why it could offer a better customer service level by responding to demand variations with methods that might be considered wasteful in the lead paradigm, as they might lead to elevated cost, which an agile enterprise should be willing to bear in order to fulfill changing customer demands (Naylor, et al., 1999).

If a company is to follow any of the two paradigms purely, the customer requirements should be the indicator for this decision. Figure 23 depicts Naylor, et al.'s understanding of the application of both paradigms according with reference to the customer's demand in terms of the variety of products required and the variability in production rates. The darker areas indicate the tendency to follow the lean paradigm, whereas the lighter ones favor agility (Naylor, et al., 1999).

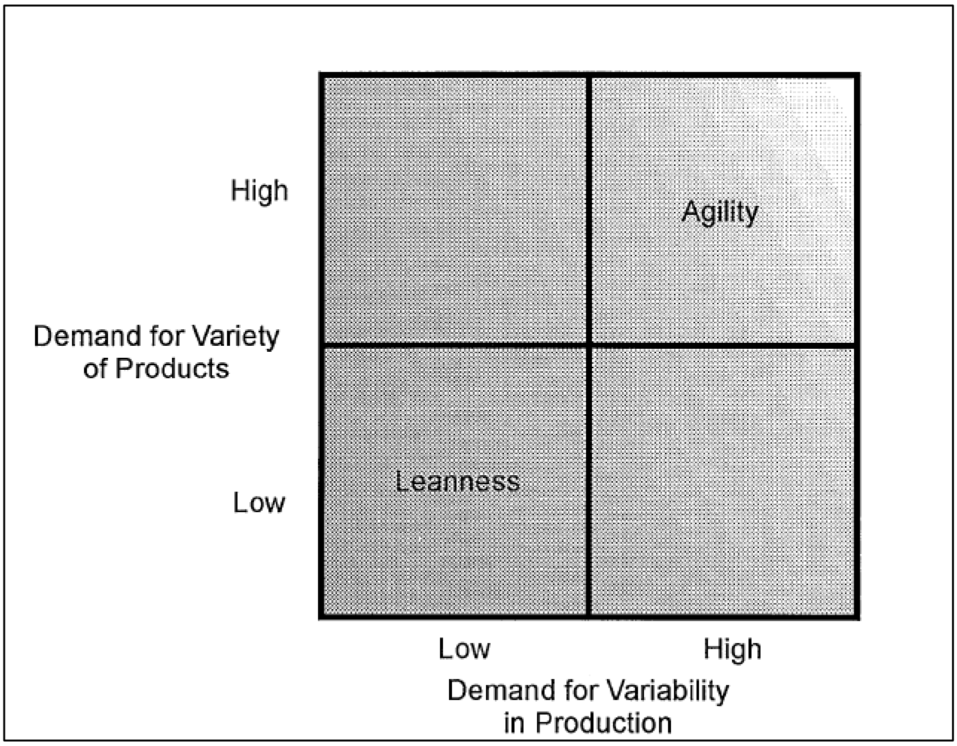

Figure 23: Application of Agility and Leanness According to Customer Requirements (Source: Naylor et al. (1999))

It could be clear from the comparisons and the ratings carried out that none of the two paradigms could be considered better or worse than the other one, as each has its clear advantages and drawbacks. Naylor et al. discussed two case studies where both paradigms were combined to form a leagile supply chain. The main methodology used to combine leanness and agility in both cases was using the *Decoupling Point*. They defined the decoupling point as *"the point that separates part of the organization (supply chain) oriented towards customer orders from the part of the organization (supply chain) based on planning."* The decoupling point concept is also connected to the concept of postponement, which aims at delaying product differentiation to the latest possible stage in the supply chain in order to increase its proximity to the customer (Naylor, et al., 1999).

Naylor et al. suggested that the decoupling point should be where the strategic stock is held, so as to act as a buffer between the part of the supply chain driven by fluctuating customer orders and/or product variability (downstream from the decoupling point), and the part which could then follow a smoothened production schedule (upstream from the decoupling point) (Naylor, et al., 1999).

This way, both paradigms could be integrated, resulting in a leagile supply chain. In the leagile supply chain, the processes upstream from the decoupling point mostly follow the lean paradigm, where the focus is more on increasing efficiency and level scheduling of production. On the other hand, the processes downstream from the decoupling are more oriented towards customer, and are focused towards fulfilling customer demand with less focus on efficiency and process leanness. Therefore the process downstream from the decoupling point could be considered agile. The two paradigms integrated together in one supply chain would result in a leagile supply chain (Naylor, et al., 1999).

Figure 24 shows the effect of the decoupling point in a supply chain as explained by Naylor, et al. As shown, production till the decoupling point follows a smooth schedule and is driven by forecast, and adopts a push approach. After the decoupling point, the customer orders are the trigger to pull the needed products from it. As the graphs in Figure 24 show, stock levels of the strategic stocks held at the decoupling point itself tend to oscillate with the variation of customer demand and the variety of the products to be customized. Naylor, et al. recommended that the decoupling point should either be positioned at the point of product differentiation itself itself or may be further upstream (Naylor, et al., 1999).

Another key article discussing leagility in supply chain is Mason-Jones, et al., (2000). In the article, they elaborated on many of the concepts presented by Naylor, et al. In their comparison between leanness and agility, they adopted the same equation shown in Figure 22 (proposed by Naylor, et al.) to calculate the total value to customer, and classified the metrics into market qualifiers and market winners as (shown in Figure 25), where service level was the main market winner for agility, while cost was the main winner for leanness (Mason-Jones, et al., 2000)..

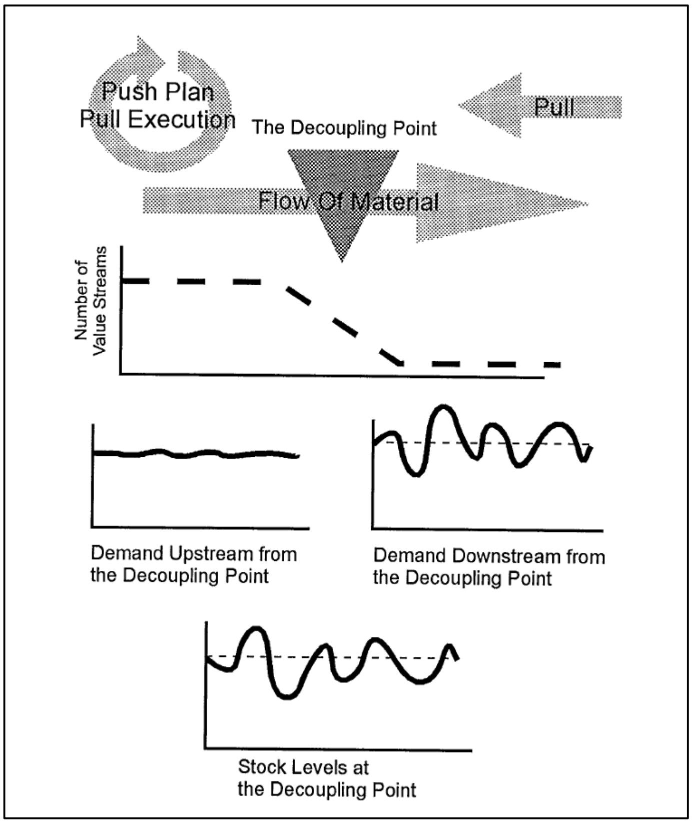

Figure 24: The Effect of the Decoupling Point in a Supply Chain (Source: Naylor et al. (1999))

They added to the discussion by proposing Equation 1 to calculate the total PDP costs, composed of two terms: Physical PDP Costs, including all costs of production, distribution and storage costs, and marketability costs, which takes into account the costs of stock obsolescence and overstock. It is clear that leanness stands out by minimizing the Physical PDP costs with its high focus on waste and cost reduction. However, agility unequivocally has the edge when it comes to marketability costs, especially in extremely competitive marketplaces where a lost opportunity could imply even bigger losses than just the direct loss of the sale itself. Mason-Jones et al. compared the different attributes of lean and agile supply in Table 2 (Mason-Jones, et al., 2000).

$$Supply\ chain\ total\ PDP\ costs = Physical\ PDP\ costs + Marketability\ costs$$

Equation 1: Total PDP Costs as proposed by Mason-Jones et al. (2000)

Distinguishing attributes	Lean supply	Agile supply
Typical products	Commodities	Fashion goods
Marketplace demand	Predictable	Volatile
Product variety	Low	High
Product life cycle	Long	Short
Customer drivers	Cost	Availability
Profit margin	Low	High
Dominant costs	Physical costs	Marketability costs
Stock-out penalties	Long term contractual	Immediate and volatile
Purchasing policy	Buy goods	Assign capacity
Information enrichment	Highly desirable	Obligatory
Forecasting mechanism	Algorithmic	Consultative

Table 2: Comparison between the Attributes of Lean and Agile Supply (Source: Mason-Jones et al. (2000))

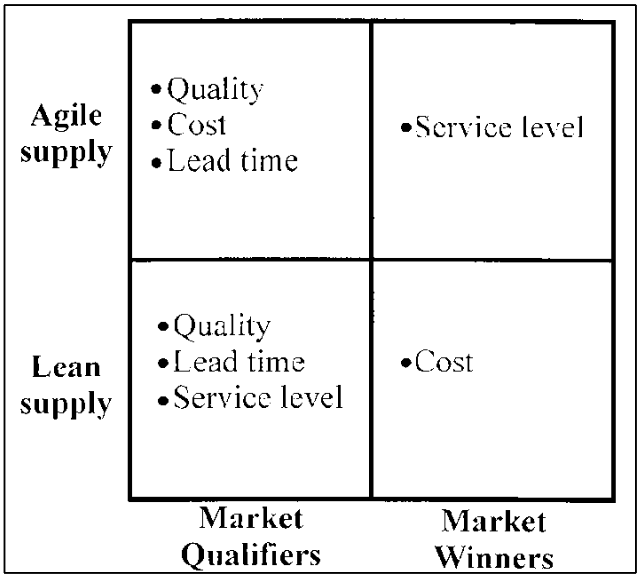

Figure 25: Market Winners and Qualifiers for Agility and Leanness According to Mason-Jones et al. (2000)

Mason- Jones et al. also viewed the decoupling point as a cornerstone for achieving leagility in the supply chain. Their understanding of decoupling points highly coincided with that of Naylor, et al. Figure 26 depicts the role of the decoupling point in forming the leagile supply chain by separating the part upstream operating according to the lean paradigm from the part downstream operating according to the agile paradigm (Mason-Jones, et al., 2000).

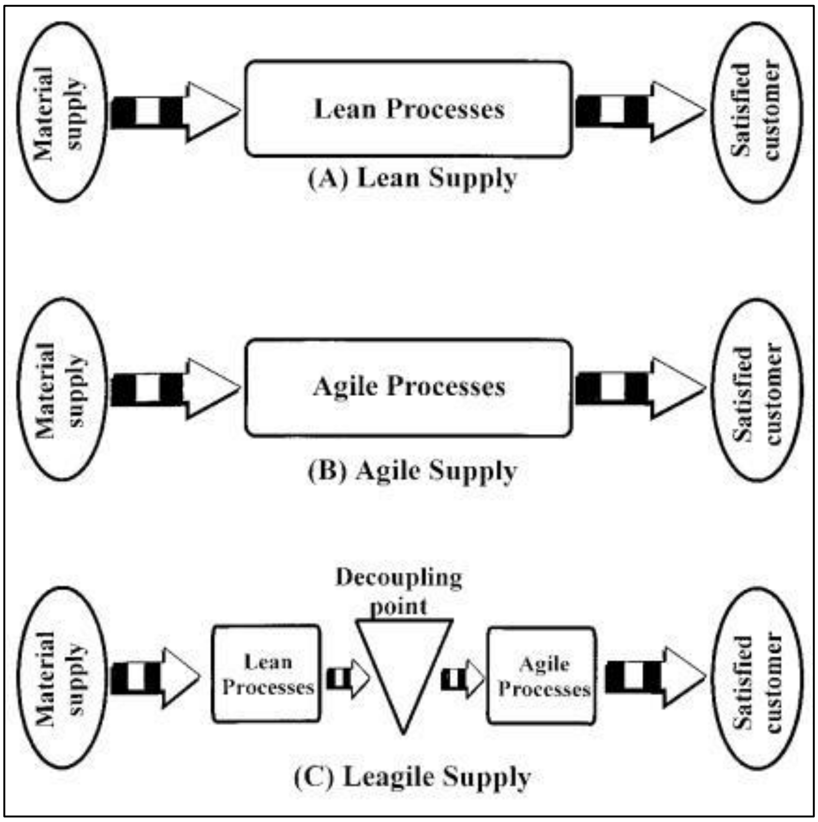

Figure 26: Lean, Agile and Leagile Supply According to Mason-Jones et al. (2000)

Another important important aspect of Mason-Jones et al.'s conceptualization of agile supply chain is having a supply chain which is enriched with information. Opposed to the typical supply chain setup where only the retailers are informed with the direct consumer demand and all other players upstream in the supply chain receive orders from their direct customers without knowledge of the consumer demand, Mason-Jones et al. asserted the importance of enriching all the players in the supply chain with the marketplace data. They claimed that distortion in the supply chain could be decreased and better decisions that are not based on guessing could be made in such an information enriched environment (Mason-Jones, et al., 2000).

Christopher (2000) emphasized the increasing importance of agility in supply chains by arguing that shorter delivery times have become an important competitive weapon in recent times. In his discussion about leanness and agility, he claimed that the impact of the lean paradigm is mostly restricted to the factory shop floor level. He elaborated on this idea by giving an example from the automotive industry, where a manufacturer had achieved a high level of shop floor efficiency and reduced the manufacturing throughput time to less than 12 hours, but in the meantime, his stock levels were overshooting while having customers waiting for months to get their ordered cars in some cases. Christopher accordingly argued that pure leanness would fail to rapidly meet customer needs, but also added that agility might incorporate leanness as an element within it (Christopher, 2000).

In order to achieve true supply chain agility, Christopher defined four characteristics a supply chain should possess (depicted in Figure 27), which are market sensitivity, process integration, being network based, and creating a virtual supply chain. His understanding of market sensitivity highly conforms to Mason-Jones, et al.'s concept of information enrichment, as he recommends that all elements of a supply chain should strive to get informed with the end customer's requirements (Christopher, 2000).

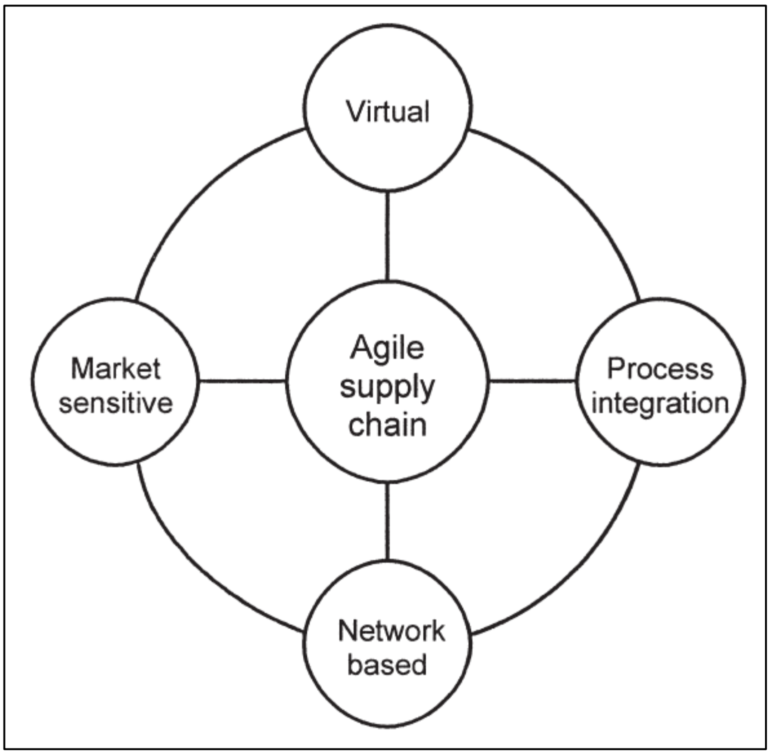

Figure 27: Characteristics of an Agile Supply Chain (Source: Christopher (2000))

In his view, information sharing between buyers and suppliers via advanced information technology systems is what creates a virtual supply chain that is based on information rather than inventory. The result of this desired sharing of information is that the supply chain partners (i.e. suppliers and customers) could work more collaboratively in areas like product development and could also use common systems. Consequently, companies can focus more on their core competencies and outsource other non-core activities to suppliers. This will result in more dependency on suppliers and stronger alliances between companies, to create what he called an "extended enterprise", where boarders between companies will dissolve via process integration. With the growth of such alliances, supply chain partners will be connected together via networks. Christopher argued that in this new era, competition will no more be between individual companies but rather between networks, and enterprises which have better structured network are the ones that win in such environment (Christopher, 2000).

Despite not using the term leagility, Christopher agreed with Mason-Jones, et al. and Naylor, et al. on the importance of combining leanness and agility in one strategy. He used the expression “hybrid strategy” to designate the combination of both paradigms. His conceptualization of supply chain agility also embraced the idea of decoupling points. In consent to Naylor et al., Christopher also believed that postponement is vastly linked to the concept of decoupling point, highlighting that companies should seek to design their products based on common platforms or modules in order to facilitate late customization during production or assembly. He claimed that the positioning a decoupling point within the information enriched supply chain could reduce the bullwhip effect (Christopher, 2000).

Another key concept to achieve agility in the supply chain in Christopher’s understanding is leveraging supplier relations. As he previously highlighted in the four characteristics of an agile supply chain, integration of operations between suppliers and customers is substantial in an agile environment. He also added that agile companies should partner with a limited number of strategic suppliers, arguing that it is nearly impossible to maintain this sort of relationship with a vast supplier base (Christopher, 2000).

Based on the belief that business competition in recent times is between supply chains and not companies, Christopher & Towill (2001) argued that combining leanness and agility will increase the competitiveness of supply chains, and that they could accordingly strive and flourish in volatile environments. In their comparison between the two paradigms, they adopted a lot of the concepts introduced by Mason-Jones et al. The same idea of market qualifiers and market winners (shown in Figure 25) was used to compare the importance of the different metrics for both paradigms, and they also adopted Table 2 to compare between the attributes of leanness and agility (Christopher & Towill, 2001).

Christopher & Towill proposed 3 methods to practically combine leanness and agility. The first method they suggested was the pareto distribution approach or the 80/20 rule, in which they claimed that 80% of a company’s revenue is generated from 20% of their products, which have a relatievly more stable and prdictable demand, while the rest of the 80% of the products comprise only 20% of the revenue, which makes their demand more unpredictable. They therfore argued that the predictable 20% percent should be managed in a lean manner, while the rest of the 80% require a rather agile way of management. The distribution of products versus demand is shown in Figure 28 (Christopher & Towill, 2001).

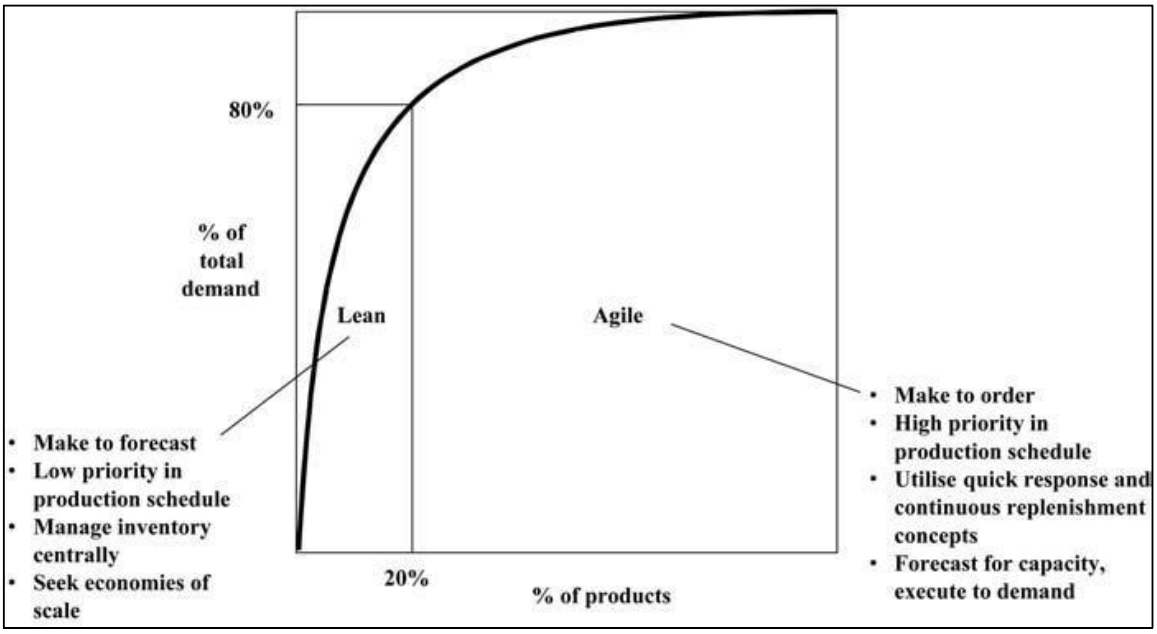

Figure 28: The Pareto Distribution of Products versus Demand (Source: Christopher & Towill (2001))

In harmony with the previous works, Christopher & Towill highlighted the importance of the decoupling point in comobining the lean and agile paradigms in the supply chain. Their conceptualization of decoupling points was vastly similar to the previous works discussing the concept. The third method they proposed was separating base and surge demand. By looking at the sales history of the company, products with predictable demand (base) could be separated from those which have rather unpredictable demand (surge). Taking advantage of economies of scale, the lean methodology could be used to fulfill base demand, while agility could be used to for the surge demand which typically incurs higher cost processes. In Figure 29, Christopher & Towill suggest a possible way to smoothen capacity utilization by smartly switching between base and surge demand (Christopher & Towill, 2001).

Another prominent work that discussed agility in the supply chain was Lee's (2004) famous article "The Triple-A Supply Chain". In this article, Lee argued that although lots of companies have reached a high level of supply chain efficiency in terms of speed and cost, they have been unable to deliver the required goods and sustain their competitive advantage. He claimed that the main reasons the supply chains of those companies failed is that they lacked three instrumental supply chain attributes: agility, adaptability, and alignment (Lee, 2004).

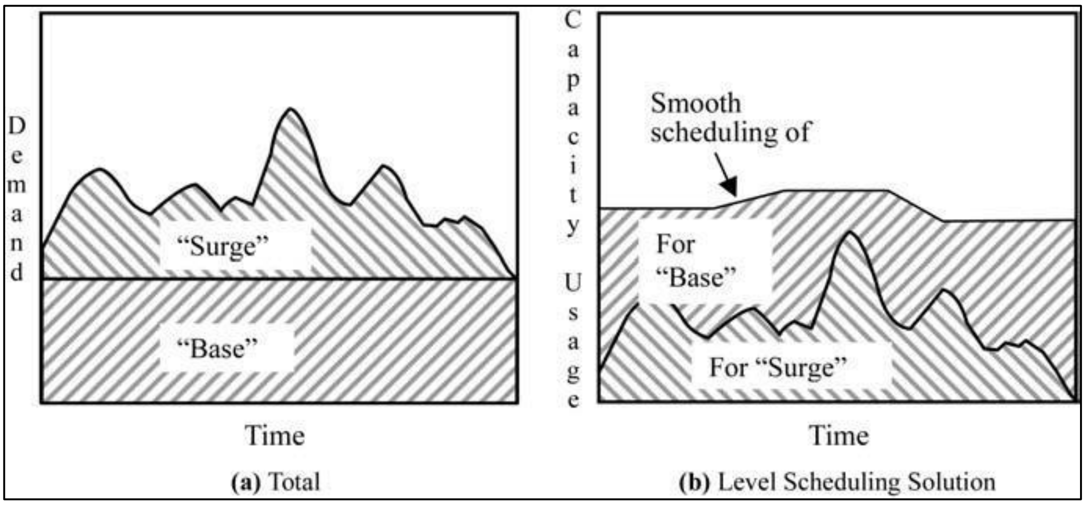

Figure 29: Combination of Base and Surge Demands (Source: Christopher & Towill (2001))

In his discussion about agility, Lee claimed that in recent times, demand and supply in most industries have been characterized as unstable. He therefore argued that agility in supply chains has become more and more critical, as companies need to respond promptly and cost efficiently in such an environment, and that the old tradeoff between speed and cost will simply not be valid any more. Agreeing with Mason-Jones et al.'s classification in Table 2, Lee gave examples of several apparel companies that successfully adopted the concepts of agility in their supply chains. He also claimed that agile supply chains recover better from sudden unexpected disruptions, such as natural disasters and political turmoil (Lee, 2004).

Lee identified six rules of thumb to build an agile supply chain. In harmony with Mason-Jones et al. and Christopher, he emphasized the importance of information exchange between supply chain partners. He also agreed with Christopher's idea of building string relationships with suppliers and customers, and that suppliers and customers should work collaboratively in areas like product development. Despite not using the term decoupling point, Lee also adopted the idea by highlighting the importance of using common platforms for different products and postponing product differentiation to the latest possible point in the production. The fourth rule he recommended was to hold inventory of low value components that often cause problems whenever companies are short of them. He also gave an example from the fashion industry where companies avoided supply chain breakdowns by holding stocks of such components. As a fifth rule, Lee asserted the importance of establishing reconfigurable logistics systems that support unplanned changes of requirements. Finally, he highlighted the importance of the human factor in agile supply chains, as he mentioned that agile supply chains can only be managed by teams and trained managers that could work out plan B's in times of crisis (Lee, 2004).

In a work specifically focused on the concept of decoupling point, Towill (2005) elaborated on the idea discussed in the earlier literature. He also adopted Christopher's idea of using modular platforms in product designs which could accordingly enable postponement and decoupling points. Towill highlighted that the correct positioning of the decoupling point enables inventory cost reduction. In harmony with the previous works, he also used the term leagile to describe the supply chain that incorporates the decoupling point. Table 3 elaborates his understanding of the different attributes of the processes before and after the decoupling point, and their specific characteristics in both cases. He mostly gave examples of companies from the computer industry which used the decoupling point concept to improve their supply chain efficiency (Towill, 2005).

Masson, et al. (2007) discussed supply chain agility in the specific context of the fashion industry in the UK. They characterized the fashion industry in Europe as a global industry with high product variety, high margins and short lifecycles. They also asserted the volatility of the marketplace and the high risk associated to the companies operating in such environment. Referring to Christopher's concept of network based supply chain, Masson, et al. claimed that the competition in such environment is a competition between supply chain networks of retailers and manufacturers. Taking the previous conditions into account, Masson, et al. related the fashion industry's specific charactersitics to the agile supply chain framework developed by Christopher (shown in Figure 27) (Masson, et al., 2007).

Business Attribute	Business Processes Before the De-Coupling Point	Business Processes After the De-Coupling Point
Delivery Philosophy	Lean ~ level the schedule	Agile ~ produce to order
Scheduling	Forecast Driven	Demand Driven
Order Volatility	Small	Large
Order Variety	Small	Large
Volume	High	Availability
Value Added	Low	Low (per option)
Product level	Generalized Modules	Customer Specific
Business Objective for this Stage	Driven by Cost	Driven by Availability
Integrated Supply Chains Objective	Wide Ranging Products Available at Reasonable Price	

Table 3: Process Characteristics Before and After the Decoupling Point (Source: (Towill, 2005))

A case study that examined the supply chains of several fashion retailers in the UK was carried out. The study was also extended to include the retailers' overseas suppliers in Asia and

Eastern Europe, as none of the retailers themselves owned any manufacturing facilities. It was found out that the retailers incorporated many agile traits such as base and surge demand separation (as suggested by Christopher & Towill), as they differentiated between the basic SKUs with long lifecycles and low demand volatility, and the high fashion content products, which were characterized with shorter lifecycles and higher demand volatility. Masson, et al. found out that the retailers applied different strategies to manage the supply chain of those groups of products. They took advantage of the economies of scale in case of the basic SKUs, whereas for the high fashion contact SKUs, a more agile approach was applied, which is what Christopher & Towill had suggested in their earlier study (Masson, et al., 2007).

Another aspect of agility the fashion companies encompassed was market sensitivity. Masson, et al. mentioned that the retailers exerted immense efforts to segment the consumers and understand their behavior, and then tried to identify the fashion trends accordingly. They gave an example by one of the retailers that had identified six female consumer groups, and understand the fashion trends they would be interested in accordingly. One important aspect of agility applied by the fashion companies is the concept of postponement. They used postponement specifically in deciding the garment color, and accordingly managed to significantly reduce the time to market and avoid stock-out situations (Masson, et al., 2007).

Most of the works discussing agility used the definition of the term itself (agility), without giving an explicit definition to supply chain agility. In an attempt to explicitly define agility in the supply chain, Braunscheidel & Suresh (2009) formulated the term a firm's supply chain agility (FSCA), giving it a clear definition of its own. They defined it as *"the capability of the firm, internally, and in conjunction with its key suppliers and customers, to adapt or respond in a speedy manner to a changing marketplace, contributing to agility of the extended supply chain."* It could be noted that the definition incorporated the main ideas of the definition of agility in manufacturing (reviewed in the previous section), but it contributed by strongly focusing on the importance of the relationship between the company and its network of suppliers and customers, which is the concept coined by Christopher (Braunscheidel & Suresh, 2009).

In an article focused on identifying practical ways to improve a company's supply chain agility, Mercier, et al. (2010) described eight methods that help companies do so. They started by exhibiting the tradeoff between the cost of lost sales against the inventory holding cost, identifying a matrix (shown in Figure 30) that dictates the recommended policy a company should follow in the different combinations between the cost of lost sales and degree of demand volatility (Mercier, et al., 2010).

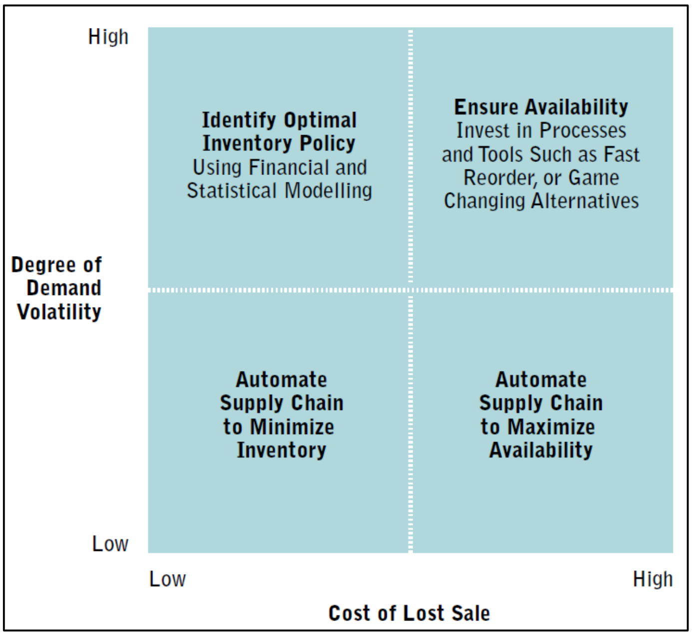

Figure 30: Policies in Different Cases of Lost Sales Costs versus Degree of Demand Volatility (Source: Mercier, et al. (2010))

Many of the concepts identified by Mercier, et al. coincided with the previous works about supply chain agility. They asserted the importance of tightening the supply chain and reducing it to the minimum needed size, arguing that the company's efforts to reduce costs by moving some activities to low cost countries are most probably outweighed by the cost incurred by the complexity entailed to such cases. They also emphasized the criticality of optimizing inventory levels with respect to customer demand and its volatility. In consent to the concept of modularization, Mercier, et al. agreed with Christopher and with Towill by asserting the importance of standardization of products and components. They added that companies should always assess their product portfolios and identify what is strategically needed and what is not in order to reduce complexity (Mercier, et al., 2010).

Mercier, et al. emphasized the importance of providing the right service level needed for each customer segment. They argued that companies should segment their customers according to profitability and identify premium customers accordingly. The service levels provided to the different customers should be prioritized according to this segmentation. Agreeing with Christopher, they also highlighted that companies should strive to outsource all non-core activities, and focus only on their core business activities in which they have a clear competitive advantage (Mercier, et al., 2010).

Data exchange efficiency was considered another important way to achieve agility according to Mercier, et al. They agreed with what Dove mentioned in his early article that advanced IT systems should play a big role in information exchange between supply chain partners in order to facilitate information exchange and decrease complexity. Identifying and measuring the right performance indicators and linking them with the employees' incentives was another method they identified that could increase a company's agility. They argued that the indicators should reflect the end to end supply chain benefit, and not just narrow scoped targets of limited relevance. Finally, Mercier, et al. adopted the same idea of Christopher that companies should maintain close partnerships with key suppliers only, highlighting the benefits of such close partnerships in terms of expedited deliveries and cost savings (Mercier, et al., 2010).

2.3 Why does the Semiconductor Industry's Supply Chain Need to be Agile?

In the previous subchapters, an overview of the semiconductor industry and its supply chain was given, and the challenges facing the industry's supply chain were discussed. On the other hand, the history of agility and its definitions in the literature were reviewed, and the concepts of agility in the context of supply chain were also exhibited. The aim of this subchapter is to build a correlation between agility and its concepts in the supply chain context on one hand, and the challenges identified in the semiconductor industry's supply chain on the other hand, in order to come up with a hypothesis about how agility could be applied in the semiconductor industry's supply chain to help manage its challenges.

From the discussion in section 2.2.2, it is clear that many of the reviewed definitions of agility strongly focused on providing customer oriented products. The industry based definitions such as Elkins, et al. (2004) and Guisinger & Ghorashi's (2004) definitions emphasized the importance of responding to volatile and fluctuating customer demand in an agile organization. The correlation built by Fliedner and Vokurka (1997) and Brown and Bessant (2003) between agility and mass customization is instrumental in this respect, as mass customization aims at providing customized products in a costly manner. One of the main challenges facing semiconductor manufacturers is the broadness of product portfolios that a semiconductor manufacturer has to offer, due to the diverse applications of semiconductors in the modern world. As mentioned in subsection 2.1.3.6, a typical semiconductor manufacturer has to manage more than 10,000 SKUs in average. The idea of modular platforms mentioned by Lee (2004) and Towill (2005) is a pivotal tool discussed in the supply chain agility literature that could help in managing a vast base of different SKUs in the supply chain, by means of using modular platforms for different groups of products. Naylor, et al. (1999) added as well that strategic stocks have to be positioned in the diversification point in the supply chain, in order to act as a buffer for unpredictable demand in case of high product variability.

It could be noted from the literature review undergone in section 2.2.3 that the concepts of supply chain agility discussed mostly revolved around the idea of the decoupling point and late diversification. Naylor, et al. (1999) claimed that positioning a decoupling point within a company's supply chain will improve production leveling for the processes prior to the decoupling point. Looking at the semiconductor supply chain, production leveling and capacity utilization are key metrics in such a capital intensive industry. As discussed in subsection 2.1.3.1, semiconductor companies try to avoid situations of idle capacities or lost sales opportunities due to inefficient capacity planning and/or utilization in such a complex environment, as both cases imply immense losses to the companies that could jeopardize their market positions.

In his discussion about the concept of the decoupling point, Christopher (2000) argued that it helps in reducing the bullwhip effect by enabling quick response to volatile demands, which is one of the key challenges faced by the semiconductor supply chain (as explained in subsection 2.1.3.5). The long manufacturing cycle time (explained in subsection 2.1.3.3) for semiconductors forms an additional risk factor in combination with the bullwhip effect and demand unpredictability and volatility, as companies require long delivery lead times in response to any change in demand. In such volatile environment, it is undoubtable that an agile response is essential to quickly and effectively adapt to such changing market conditions. The essence of an agile firm according to Sharifi, et al. (2001) and Naylor, et al. (1999), is exploiting changes in the marketplace to maximize the company's benefit.

Product variability, long manufacturing cycle time, the position of the semiconductor industry in the value chain that makes it vulnerable to the bullwhip effect and is the reason for the demand volatility it experiences, and the high capital cost incurred in such a complex manufacturing environment are all factors that contribute to the high complexity of the semiconductor industry's supply chain, making it inflexible to react to inevitable sudden changes. Taking into account that the ability to respond quickly to demand fluctuations is regarded of extreme importance in such a volatile environment, agility comes into view as a recommended strategy for managing the challenges caused by the previously mentioned factors that exist in a typical semiconductor supply chain.

As mentioned, one of main concepts suggested in the literature about supply chain agility is the decoupling point concept. Taking into account its advantages discussed above regarding improving production leveling for the processes before the decoupling point, better management of a large number of SKUs using modularization and common platforms, potentially reducing the bullwhip effect and facilitating quick response to volatile demand, it could be hypothesized that identifying and positioning a de-coupling points for a group of products in the semiconductor supply chain will increase its agility by enabling better capacity utilization of the processes before the decoupling point, and a higher speed to market for the products benefiting from the late diversification enabled by it.

3 Empirical Part

In this chapter, the empirical work done in the examined company will be described, starting by an overview of the company, and moving on to describing the case study done there, where an attempt was done to apply a prominent concept of agility in the examined company's supply chain.

3.1 Introduction to the Examined Company

The examined company is one of the leading companies in the semiconductor industry worldwide. It operates in over 50 countries and has around 35,000 employees worldwide. It has R&D centers in over 34 countries and manufacturing locations in around 19 countries. It enjoys a strong technology portfolio with more than 25,000 patents and patent applications. The company manages a vast product portfolio of more than 10,000 SKUs. Energy efficiency, mobility and security are the three focus areas of the products and solutions it offers. The company has four different business units, classified according to a market-oriented business structure, which are automotive, industrial power control, chip card security and power management and multimarket. It holds a leading market position in the four product sectors it operates in.

3.2 Appling Agility in the Company's Supply Chain

In this subchapter, the case study undergone in the examined company will be described in detail. First, the status quo of the company's planning and manufacturing system will be described, then, the case study methodology will be elaborated. Finally, the execution of the case study will be described.

3.2.1 Case Identification

Based on the hypothesis formulated in subchapter 2.3, it was needed to have a case study through which the hypothesis could be applied in the examined company's supply chain. As explained in section 2.1.2, the journey of a semiconductor manufacturer starts with FE production, which has a cycle time that could reach up to 100 days. Afterwards the finished wafers are stored in the DB. The needed wafers are then pulled to the BE process where the packaging and testing of the chips takes place. The BE process has relatively much shorter cycle time, as it ranges from 5 days to 20 days. The aim of the case study is to apply the concept of the decoupling point in order to increase the agility of the company's manufacturing and planning system. Before explaining the case study done in this thesis, the status quo of the examined company's production planning system has to be explained at first.

The planning system of the examined company is based on baunumbers. A baunumber is a data abject that acts as unique logistical identifier of the chip throughout the different steps within the supply chain. Any finished product has a so called baunumber tree. The baunumber tree is composed of a series of baunumbers that uniquely identify the product in all its different states throughout the supply chain. The uniqueness of the baunumber system implies that even if the product is based on a chip that that has two identical versions, each manufactured in a different location (but the chip itself is exactly the same), the baunumber trees for each version will be different, although the product itself is the same. Figure 31 shows an example of a baunumber tree of a product.

TREE	ML	FAC	BNO	IF_ID	UOM	DISPO
1>>>>>>>>>>>>>>>>>>>>>>>>>	VKL	DCA	99907292	4205200309	SYST	Y
. 2-----------------------	TEST	WAVEMS	97814100	4205200393	SYST	N
. . 3---------------------	TEST	TDH2MS	97814100	4205200394	SYST	N
. . . 4-------------------	ASSY	ADH2MS	97814100	4205200395	SYST	N
. . . . 5-----------------	ASSY	PAMS	65097785	4205200396	SYST	N
. 6---------------	DIEBANK	LGMS	45098690	4205198548	SYST	Y
. 7-------------	SORT	WAVEMS	45098690	4205198549	SYST	N
. . . . 8-----------	SORT	WAVEV	45375473	4205198550	SYST	N
. . . . 9---------	SORT	LAGERV	45375473	4205198551	SYST	N
. . . . 10------	SORT	SPFV	45375473	4205197758	SYST	N
. . . . 11----	FAB	1502	35375629	4205198552	SCHB	N

Figure 31: An Example of a product Baunumber Tree (Source: Internal Document)

It could be noted, that as the product moves between the different stages in the supply chain, it is assigned to a different baunumber. For example, the baunumber 45098690 designates the chip when it is on the DB, after finishing the FE process. The last column shown in Figure 31 (DISPO) is a flag that indicates whether the process for this baunumber has a disposition point (stocking point) afterwards or not. The DISPO flag for baunumber 45098690 has the flag indicated as Y, meaning that the chips are stored in the DB. The baunumber trees mostly contain baunumbers which represent the different stages of the product within the main manufacturing steps from wafer start in the fab process (fab baunumber), then the sort process (sort baunumber), moving on to DB (DB baunumber, and then pre-assembly (pre-assembly baunumber), BE baunumber (most of the time includes assembly and test), and finally DC baunumber, which is the identifier of the finished product lying in a specific DC of the company's DC's (the same product at different DC's has different DC baunumbers).

As mentioned in section 2.1.2.3, the same chip could go into different packages. This means that different end products could use the same chip, but have different packaging procedures in BE. In this case, the baunumber tree of those is then the same from wafer start till DB, where the fabricated chips are stored, and after DB, each product will have its own tree of baunumbers. In other words, in case the chip is used in different end products, it is not decided into which product it will go till DB. After DB, the chips are pulled to BE for the assembly and testing of a specific product using this chip according to this product's demand.

Figure 32 shows the changes in baunumber trees of different end products using the same chip, which are called Y-links. It could be noted that the FE and DB baunumbers are the same for all the different products, as the chip used is the same. However, the BE baunumber for the different end products are different since they have different packages, which implies having different processes in BE. This creates a Y-link after the DB baunumber for the different end products, as each product will have a different baunumber tree from this point onwards. The same logic applies to the DC baunumbers, as the same product has different DC baunumbers to designate it when it is on stock on any of the DCs, implying another Y-Link on the DC level after the BE baunumber.

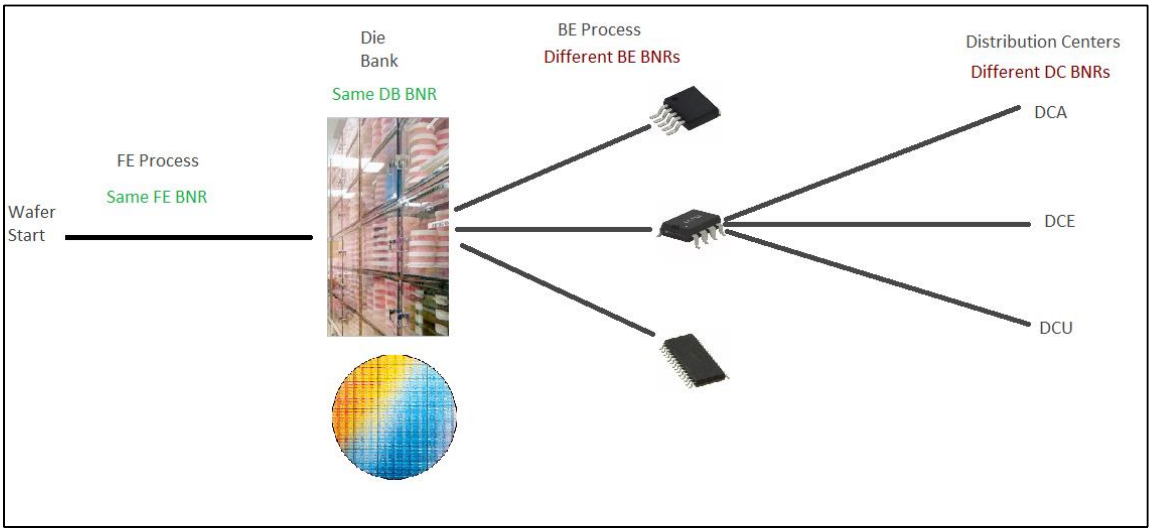

Figure 32: Possible Y-Links in the Baunumber Trees of Products Sharing the Same Chip (Source: Own Illustration)

The planning system that governs the production process in the operational level of the examined company is called the Advanced Planning System (APS). The APS balances demand and capacity in the supply planning process while considering the stocks, in order to finally commit the quantities of the product that could be produced and accordingly promised to the customer. The committed quantities are then considered Available to Promise (ATP) for the customers, as soon as they get produced and delivered to the DC's. Figure 33 depicts the advanced planning system with its different inputs from the demand and capacity sides.

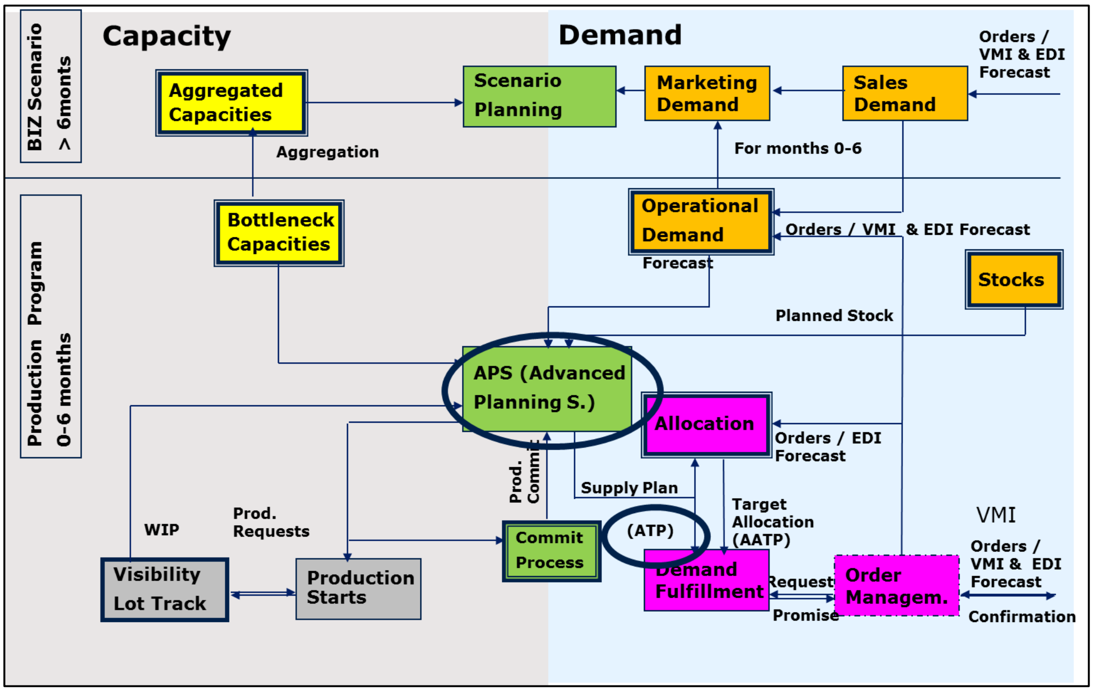

Figure 33: The Advanced Planning System of the Examined Company (Source: Internal Document)

The APS aggregates the demand for a certain product and calculates the supply via a demand backwards – supply forward calculation. Figure 34 illustrates the calculation with a simplified, unrealistic example, just to demonstrate how the system works. In this example, there is an aggregated demand of 500 pieces. In the demand backwards calculation, demand aggregation happens on the baunumber level. To demonstrate this, let us assume that the aggregated demand of 500 is originated from two customers; one in Asia requesting 300 pieces, and another one in Europe requesting 200 pieces. That means that there is a demand on two different baunumbers; 300 pieces on the DCA baunumber, and 200 pieces on the DCE baunumber. Assuming that the 30 pieces on stock are on DCA, therefore the demand on the DCA baunumber will be reduced to 270. The demand on the two different DC baunumbers is therefore aggregated to be 470 pieces on the BE baunumber, as both DC baunumbers are originated from the same BE baunumber as a Y-link. Therefore, BE needs to provide 470 pieces to meet this demand on both DC baunumbers.

In BE, there are already 20 pieces of WIP on the BE baunumber. Considering the demand of 470 pieces, 450 chips need to be pulled from DB to be accordingly started by BE. Having 50 chips on the DB baunumber, FE needs to provide 400 chips to fulfill the demand. With 20 chips already started on the FE baunumber, wafer starts to provide 380 chips are accordingly needed.

Moving on to the supply forward calculation, it could be noted from the capacity limitation in FE that the bottleneck capacity for that part limits the possible production to 240 chips. This means that wafers to provide 220 chips only could be started, as there are already 20 chips of WIP started in FE. Accordingly, the supply to DB will be 240 chips. Since BE bottleneck capacity is 400, it is enough to start the whole quantity of chips that could be supplied. Therefore, BE will start the assembly of 290 pieces, which are the 240 chips provided from FE, in addition to the 50 chips already on DB. Considering the 20 pieces of WIP already in BE, the total produced quantity will be 310 pieces. Taking into consideration the 30 pieces on stock in the DC, the system could therefore commit 340 pieces in this week to customer, as the capacity limitation didn't allow the fulfillment of the whole demand.

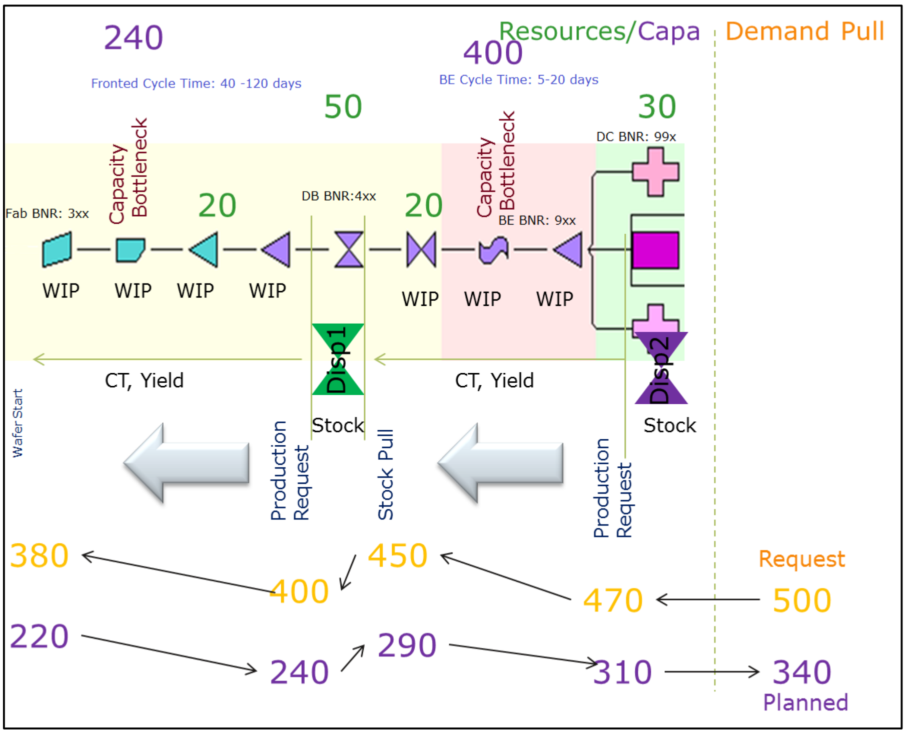

Figure 34: Demand Backwards - Supply Forward Calculation in the APS System (Source: Own Illustration based on Internal Document)

In this case, the APS will then try to compensate for the unfulfilled demand due to the capacity limitation in this specific week by checking the possibility of preproduction. If preproduction is not possible, the system will plan the missing quantities in a later week. Figure 35 demonstrates the processes of rescheduling the unfulfilled demand due to capacity limitation in a certain week. Building on the previous example, there is a deficit of 160 pieces to fulfill the aggregated demand of 500 pieces. In this case, the APS tries to schedule a preproduction for the 160 pieces in previous weeks, but succeeds to schedule only 60 of them due to a capacity limitation in those weeks as well. Accordingly, the APS has no other choice but to schedule the remaining 100 pieces in a later week.

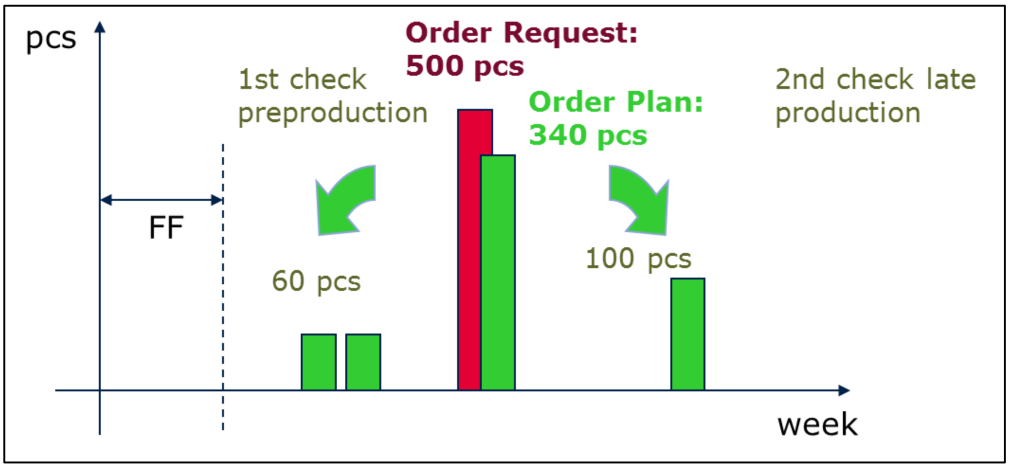

Figure 35: The APS Rescheduling of Unfulfilled Demand due to Capacity Limitation in a Certain Week (Source: Internal Document)

It is clear from the prior example that the demand propagates down the baunumber tree, starting from the DC baunumber till wafer start (fab baunumber). The APS considers the stock on the disposition baunumbers and the WIP on the other baunumbers in its calculations for the loading. The current disposition points are the DC, where the finished goods are stored, and the DB, where the fabricated wafers are stocked prior to packaging. FE production to DB usually follows a push approach as it is driven by forecast, while BE production usually pulls the chips from DB according to orders. It could be therefore assumed that the DB is the current decoupling point in the examined company's supply chain, as it is the point that separates the part of the supply chain driven by forecast (push) from the part driven by orders (pull). Another reason the DB could be considered the decoupling point in the company's supply chain, is that in case the same chip goes into different packages, diversification into different end products happens after DB. This allows demand aggregation of the different end products having the same chip's demands on the DB baunumber level, as they all share the same baunumber tree upstream from the DB baunumber as shown in Figure 32. The aggregation then follows the same logic used in the DC demand aggregation on the BE baunumber level explained in the above example.

However, an analysis of the company's products data shows that only 35% of its basic types (chip types) go into more than one package (end product), while around 65% of the basic types are used in only one end product. That means that for 65% of the cases, the end product is decided from the very beginning of the manufacturing cycle (wafer start), as there is no possibility of diversification at the DB. Taking into account the demand volatility the industry experiences, and the long manufacturing cycle time (especially for the FE process) that hinders the quick response required for the demand fluctuations, it makes sense to challenge the DB as a decoupling point and try to find an earlier decoupling point within the FE production process. This could allow diversification into different basic types after wafer start, as that the decision of which product into which the started wafer will be diversified could be delayed till a later stage in the supply chain compared to the current state where the end product is already decided from the very beginning in most of the cases.

It was accordingly decided to peruse a case study that aims at finding a possible way to introduce a decoupling point within FE production that could enable delaying product diversification till a later stage in production, instead of having the specific basic type that will be produced decided from the very beginning of the production cycle.

3.2.2 Case Study Methodology

In order to explore the possibility of introducing a decoupling point within FE production, a common platform should be found between different basic types that get differentiated in a late stage in the FE process. This was the main task of the case study; to find out a way to detect the latest differentiation point between different basic types by indicating the latest process step in FE production the two basic types share.

In order to do this, the processing steps of different basic types need to be compared in order to detect the latest possible process step they share, which should then be the location where the decoupling point could be introduced within the FE production. By identifying this, the common platform between the different basic types will then be the semi-finished wafer that was processed till the last shared step before differentiation. This will be mainly done via data analysis of the manufacturing data of FE production in the examined company, in order to find out the best way to detect the latest differentiation point

The next step would be to suggest changes in the company's planning system that would help realize the benefits of the decoupling point on the planning level. Finally, an example of basic types that share a long portion of the FE process will be given as a result of the used detection methodology introduced.

3.2.3 Case Study Execution

In this section, the execution of the identified case study will be explained in detail, starting by elaborating the developed methodology to detect the decoupling point between any two basic types, moving on to describing the recommended changes in the company's planning system. Finally, an example will be given where the methodology was applied to an actual case in the company.

3.2.3.1 Detection of the Possible Decoupling Point between two Basic Types

The examined company describes the wafer fabrication steps of its different basic types in FE in the form of work routes. A work route represents a sequence of process steps in manufacturing (mainly at wafer fab). Each process step has an ID, a name, a set of attributes and parameters. The work route also defines the base materials used in the wafer fabrication process. Any production lot of a certain basic type in FE passes through the sequence of operations defined by the work route. Each basic type has its own unique work route that defines its specific process steps, as well as the attributes associated to each step.

Accordingly, the work route data was considered the source for the needed comparison that would lead to finding out the latest shared process step between different basic types. The examined company has an IT platform where the work routes of two basic types can be browsed side by side. This is done via an online portal, where the user can select the two basic types he wants to browse, and their work routes will be then browsed on a web page. There is also the possibility to download the data to an excel file, where the data of the two work routes are documented in adjacent sets of cells.

The excel file containing the downloaded work routes' data was the starting point for the decoupling point detection process. Figure 36 shows a sample of the work routes data of two basic types after being downloaded to an excel file, which is the generic way the work routes' data are documented in excel format. It should be noted that the real data are erased in the figure, as it is only for demonstration purposes.

As shown in the figure, the names and data of the two basic types are written in the first row. Afterwards, the process steps and their specific attributes are listed starting from row number 4. The operation numbers and operation names are written in the cells colored in blue, while the attributes are listed in the white colored cells beneath. It could be noted that the data of the first work route is listed from column A till column E, while for the second work route, the data is listed from column H to column L.

The first step for any work route lists the base materials used in the attributes. In order to apply the decoupling point concept for two basic types, their base materials should be the same. They should also have the same processing steps and attributes for a large portion of the FE process, so that late diversification could be enabled. This will then take place after the last common process step they share. The modular platform for those two wafers will then be the semi-finished wafer that is processed up till this process step. But first, this last common process step should be detected.

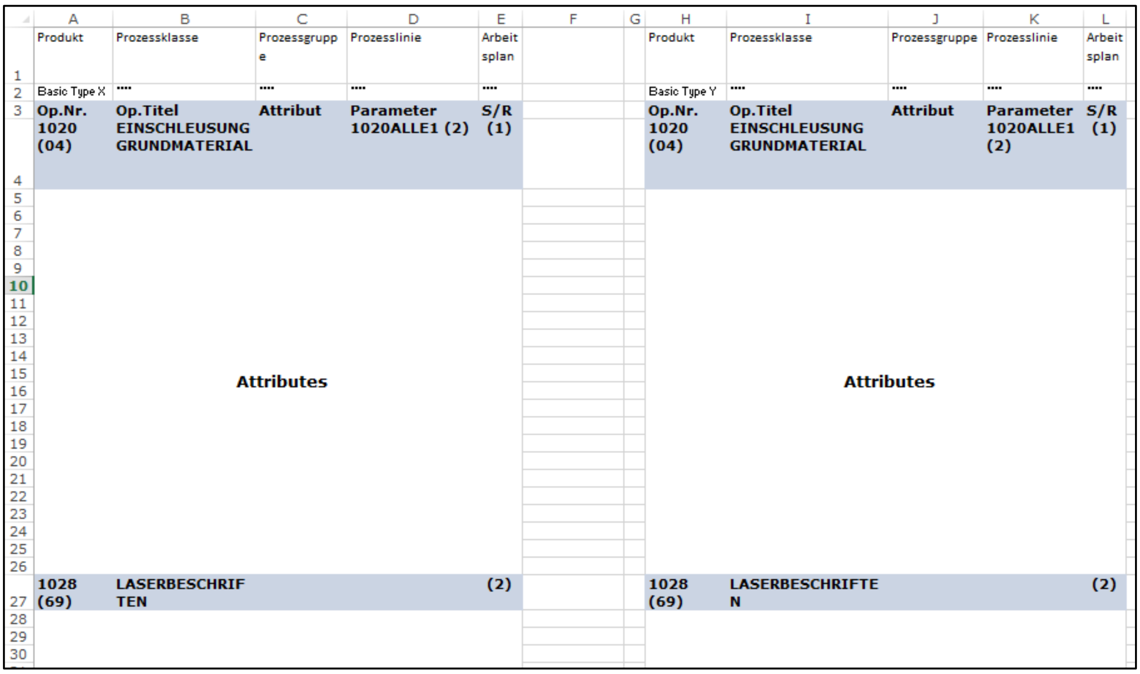

Figure 36: The Work Routes' Data of Two Basic Types on Excel (Source: Modified Internal Document)

Based on the excel extraction of the work routes data, and the data listing pattern explained above, it was decided to create a program that could automatically detect the latest common processing step between any two basic types by comparing their respective work routes on excel. The aim of the program would be to return back the last common process step between the work routes of two basic types being compared, and to highlight the first different process step in which the two basic types get differentiated.

Visual Basic for Applications (VBA) is the programming language used in Microsoft excel, with which a program could be written to execute a certain algorithm for a data set on excel. It was accordingly used for coding the program that could be applied on any work routes' data of two basic types extracted from the online portal, in order to detect their latest differentiation point. Appendix 1 contains the code of the program which was written to perform the above mentioned task, written in VBA.

The program compares the data of the two routes listed in the excel file extracted from the company's IT platform. It is based on the data listing pattern explained above and depicted in Figure 36, as this is the generic layout for any two routes extracted from the platform. The algorithm basically conducts a cell by cell crosscheck between the two work routes based on the positions of the rows and columns stated above, in order detect the first different step, attribute, or parameter between the two work routes, and accordingly return the last common process step, which is the step before the one that contains the different element. The details of the algorithm's logic will be elaborated in the following paragraphs.

The first step executed by the program is to compare the first process step of the two work routes, which lists the base materials used for the wafer fabrication process. The program goes through the material names listed in the white cells of the first work route, and compares them to their corresponding attributes and parameters in the other work route, which are seven columns apart. The program crosschecks the five cells in which the attributes/parameters are stored for each work route, and the moves to the next row. If any cell in one work route is different that its corresponding cell in the other work route, this means that the base materials of those two basic types are different, and accordingly the decoupling point concept could not be applied. If the program detects such a difference, it returns back the statement "no decoupling possible, base materials are different" and terminates. If the crosscheck runs without detecting any differences, the program moves to checking the next process step. The process steps are detected via cell colors; i.e. as long as the cell colors are white, the program understands that it is comparing the attributes inside a certain step. Once the color changes to be blue, the program realizes that this is a new process step.

After checking the first process step that lists the base materials, the program moves on to check the next process steps with the same logic. The last similar step number is saved as a variable. Once the program finds any difference in any attribute, parameter, or step name between the two routes, it colors the two different cells with a red color, and returns back the step number of the last similar step it had saved after completing a successful crosscheck for. Figure 37 shows the result of the program for a case where the process steps' IDs and names were different after having exactly the same process steps for the previous part of the work routes. Since the different step ID was the first detected difference, the program colored the different cells in red, and terminated afterwards. This means that this step colored in red is the first process step that differentiates the two basic types, as all the process steps before are exactly the same for them.

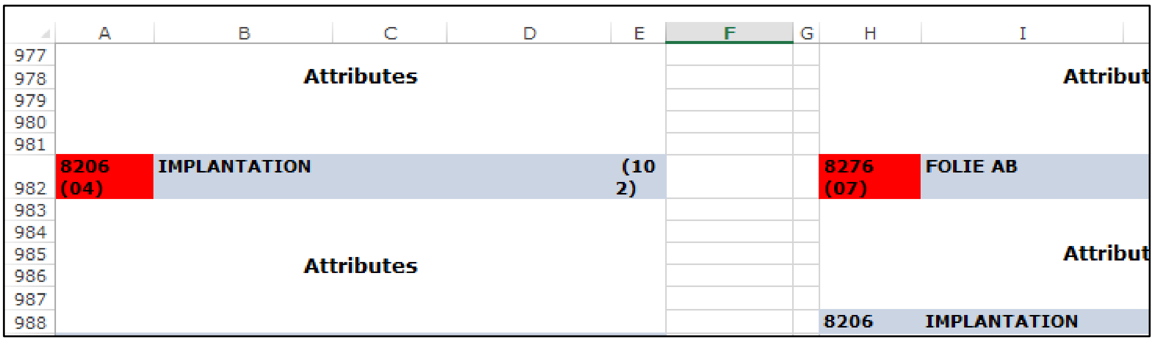

Figure 37: Different Cells Highlighted in Red by the Program: (Source: Modified Internal Document)

The last common process step between the two basic types could be then considered the potential decoupling point for them, as it separates the part of the process that manufactures the modular semi-finished wafer that both basic types share, from the part where both basic types get customized to their final form.

After detecting the potential decoupling point, the next step is to find out the portion of the FE process the two basic types share. This is done by calculating the process cycle time till the last common process step, and comparing it to the total manufacturing cycle time of each basic type in FE. The rationale of doing so is that it only makes sense to introduce a decoupling point if the shared portion of the process is relatively large, as this makes it closer to the customer and accordingly reduces the time to needed to deliver the customized basic types ordered by the customer.

The total cycle time for any process in the examined company is composed of two components; raw process time, and queueing time. The raw process time is the average time needed for the part to undergo the process step in the line, including the average amount of failure time, setup time, and other non-value-added time that happens during processing. The queuing time however, is the time which the part spends in the queue while waiting to get processed. The cycle time for a certain process step is the sum of both, the raw process time and the queueing time.

The examined company has another IT platform that reports the cycle time for a certain process, defined by the baunumber. By entering the baunumber, the respective process steps defined by the work route are listed, with the raw process time and queueing time for each step. Figure 38 depicts an example of the report for a random baunumber, showing the process step number (OPERATION), and its respective raw process time (PDLZ) and queuing time (QUEUE_TIME). The time is measured in days in this report. By downloading the report as an excel file, the cycle time of all the process steps before the decoupling point can be summed and divided by the total cycle time of the whole FE process. The result will be the percentage of the shared cycle time between both basic types. A high percentage represents a more effective decoupling point, as this indicates that the two basic types share a big portion of the process, and the decoupling point will accordingly be closer to the customer.

OPERATION	OPERATION_DESC	OPERATION_SEQUENCE	PHL	PDLZ	QUEUE_TIME
			7	8,621	12,93
1020	SCHEIBEN-EINLAUF	1	N	0,012	0,046
1028	EINGANGSKONTROLLE	2	N	0,066	0,154
1045	ERSTOXID	3	N	0,479	0,442
1300	EOX-DAM-IMPLANTATION	4	N	0,038	0,07
2010	FT-BELACKEN	5	N	0,029	0,059
2011	FT-BELICHTEN	6	Y	0,072	0,107

Figure 38: Cycle Time Report in the Examined Company (Source: Internal Document)

The final step that should be done in order to ensure the benefit of introducing a decoupling point between any two basic types is checking the demand situation for each basic type. It makes little sense to introduce a decoupling point for two basic types if only one of them is a high runner with an active demand from the customers, while the other one has a rather low demand or is ramping down. In this case since the demand is rather predictable, the finished wafers could be produced to stock on die bank right away, as the chance for demand swings between the two basic types is rather low.

3.2.3.2 Suggested Changes to the Examined Company's Planning System

In order to apply the decoupling point methodology and realize its benefits in the examined company's supply chain, certain changes have to be applied to its planning system. As explained in section 3.2.1, the baunumber system used in the examined company is a unique identification system, where each product has its own unique baunumber tree. As mentioned, the possible unification of baunumber trees of different end products happens only on the DB baunumber level, if different end products use the same basic type. In this case, their demand will be aggregated on the DB baunumber, and wafer starts in FE for the needed basic type will be triggered for the aggregated demand of the different end products using it, in order to deliver the needed wafers to the DB. In a nutshell, the current setup of the baunumber system only allows differentiation after DB. Before DB, the targeted basic type is decided from wafer start, which gives no possibility for further diversification. This is due to the fact that before DB, the baunumber trees of the basic types are always unique. Figure 39 illustrates the baunumber structures for two basic types having the same process steps till a late stage in FE. In spite of that, they have different baunumbers from the very beginning of the supply chain.

Due to the previously explained setup of the planning system in the examined company, the harmony between the basic types sharing the same process steps till a late stage in FE production is not realized. The reason for that is that the system regards the two basic types as totally different and non-interchangeable products due to having different baunumber trees from the very beginning of the supply chain. Accordingly, no demand aggregation could take place on any level for them. Interchangeability between the targeted basic types is also not possible, even if they are in the stage in which they share the same process before differentiation, as the uniqueness of the baunumber system implies the decision of the basic type to be produced from wafer start.

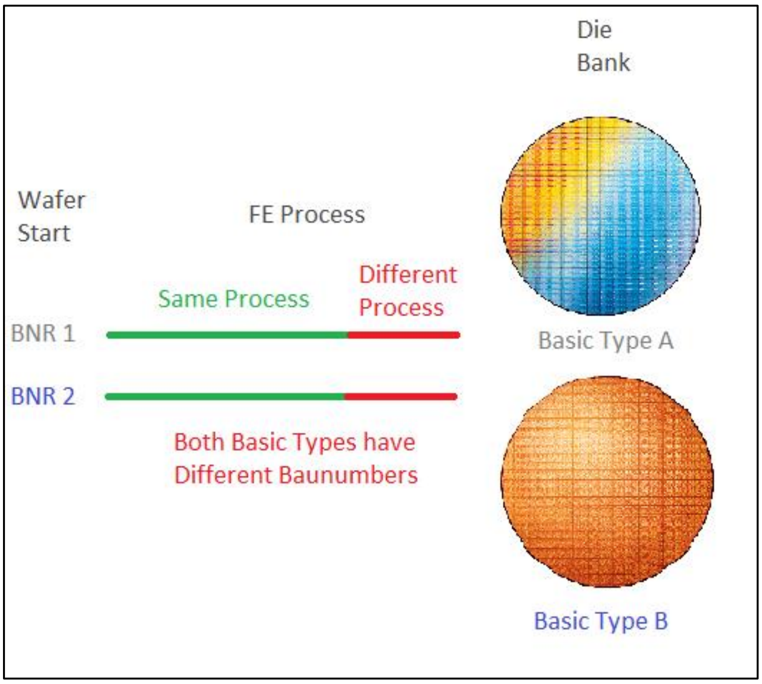

Figure 39: Different Baunumber Structures for Basic Types that have the Same Process Steps in FE (Source: Own Illustration)

This current setup of the planning system does not help quick response to the inevitable demand fluctuations the semiconductor industry faces as a consequence of the volatile nature of its supply chain. Figure 40 illustrates an example demonstrating that. In the example there are two basic types, A and B, that have the same process steps till a late stage in FE production. It is assumed that there is an urgent demand rise for a product using basic type B, and that there is no FE WIP on any of its FE baunumbers. On the other hand, there are two lots of 50 wafers of WIP on the fab baunumber of basic type A, and the lots are still in the part of the FE process which is common between the two basic types. In this case, since the system is not able to realize that the lots are still interchangeable (due to the different baunumber trees the two basic types have), it will have to start new lots for basic type B, despite having lots on the fab baunumber of basic type A that could be theoretically interchanged with basic type B.

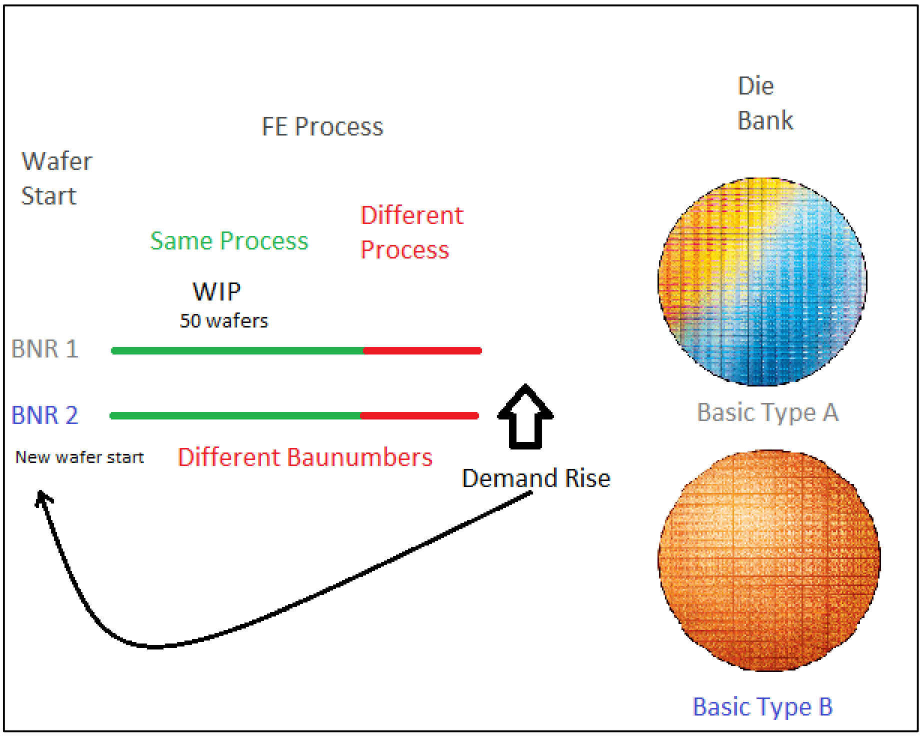

Figure 40: An Example Showing the Planning System's Behavior in Case of a Demand Rise for a Basic Type that Shares the Same FE Process Steps with Another Basic Type (Source: Own Illustration)

This means that the customer order will be fulfilled in a longer time, as instead of using the lots already in WIP on the baunumber for basic type A (which have already undergone some processing steps and won't need the whole FE cycle time), new lots will be started. These lots will have to undergo the lengthy process from the very beginning, and the fulfillment of the urgent customer demand will be delayed compared to what is theoretically possible if the system allows interchangeability of lots in the common part of the FE process.

The previous example epitomizes the need for restructuring the planning system in a way that could enable benefiting from the modularization and decoupling point concepts. After detecting the decoupling point using the method described in subsection 3.2.3.1, the next step is to suggest changes in the planning system that will help realizing the benefits of the concept.

As explained in section 3.2.1, the APS only considers the WIP assigned to any of the baunumbers in the baunumber tree of the requested product in its demand backwards-supply forward calculation. As also mentioned, demand aggregation for different end products could only happen in case there is a Y-link in the baunumber trees of those products, which - according to the current setup of the baunumber system- could only happen on the DB baunumber level, if more than one end product is based on the same basic type. After DB, the chips are pulled according to the received orders to be produced in BE, and the decision of which end product to be produced is delayed till that point in the supply chain.

It could be therefore deduced that in order to realize the benefit of the detected decoupling point with FE production, a Y-link has to be created in the baunumber tree that would enable branching to the different basic types that are differentiated after the decoupling point, and aggregate the demand of those basic types before it on a common baunumber. This common baunumber will have a work route that ends with the last common process step between the two basic types as detected by the excel program, which results in the modular semi-finished wafer that the differentiated basic types are based on. After the common baunumber, each basic type will have its unique work route, consisting of the remaining process steps in the fab process. This will accordingly imply having different baunumber trees from that point onwards till DB.

This unification of the baunumbers before the decoupling point will enable demand aggregation of the basic types based on this modular platform on the common baunumber, and wafer starts for those basic types could accordingly be consolidated. This will also lead to fewer changeovers in the costly FE production process, resulting in better capacity utilization. Additionally, the common baunumber will enable interchangeability between the two basic types as long as the lots are in WIP on it, as the decision of which basic type is to produce will be delayed till the decoupling point, instead of having it decided from the very beginning of the cycle. Faster and more flexible responses to sudden demand fluctuations could be accordingly enabled. The started lots on the common baunumber could be reassigned to the basic type having the urgent demand rise instead of having to start new lots for it, while (possibly) having interchangeable lots as FE WIP on the fab baunumber of another basic type having the same process steps, as explained in the previous example.

The next step would be to introduce a strategic stocking point at the decoupling point. The rationale of doing so is to enable the push-pull approach recommended in the literature. This implies that the semi-finished wafers defined by the common work route will be stored in a strategic stocking point within the FE production facility. The production of the semi-finished wafers to the strategic stocking point will be according to forecast and the latest demand picture will then trigger pulling the semi-finished wafers from it, and customizing them according to the ordered product.

Figure 41 depicts a schematic showing the suggested changes to the planning system of the examined company after introducing the decoupling point. The effect of the decoupling point could be noted from the beginning of the supply chain, as the wafer starts for the two basic types with the common platform are unified. This is due to the common baunumber they share till the decoupling point. Each product will afterwards have its own baunumber tree till the end of the supply chain. After producing the semi-finished wafers to stock according to forecast, they will afterwards get pulled to DB according to the latest order picture.

Another important advantage of the decoupling point in FE is that it allows a short time to market, benefiting from the strategic stocking point within production. By ensuring appropriate stock levels of the semi-finished wafers in the strategic stocking point, the time needed to respond to customer demand could be significantly reduced. Instead of having to wait for the entire semiconductor manufacturing process cycle time in case of demand rises, the semi-finished wafers could be pulled from the strategic stocking point, which is ideally positioned at the end of the FE process, reducing the time to market for sudden demand rises to be the cycle time from the decoupling point till the end of the process. This could be considered a relatively big reduction, since the FE process is the lengthiest part of the semiconductor supply chain.

An additional potential benefit of the decoupling point concept is potentially reducing the risk of stock obsolescence. The decoupling point enables holding more generic inventory of semi-finished wafers in the strategic stocking point within FE production, which could be later on customized based on customer orders and pulled to DB. This is a better alternative compared to holding inventory of finished wafers and products, which could turn out to be useless in case of unexpected customer demand drops. The general stock levels throughout the entire supply chain could accordingly be reduced by enabling the customizability of the held inventory.

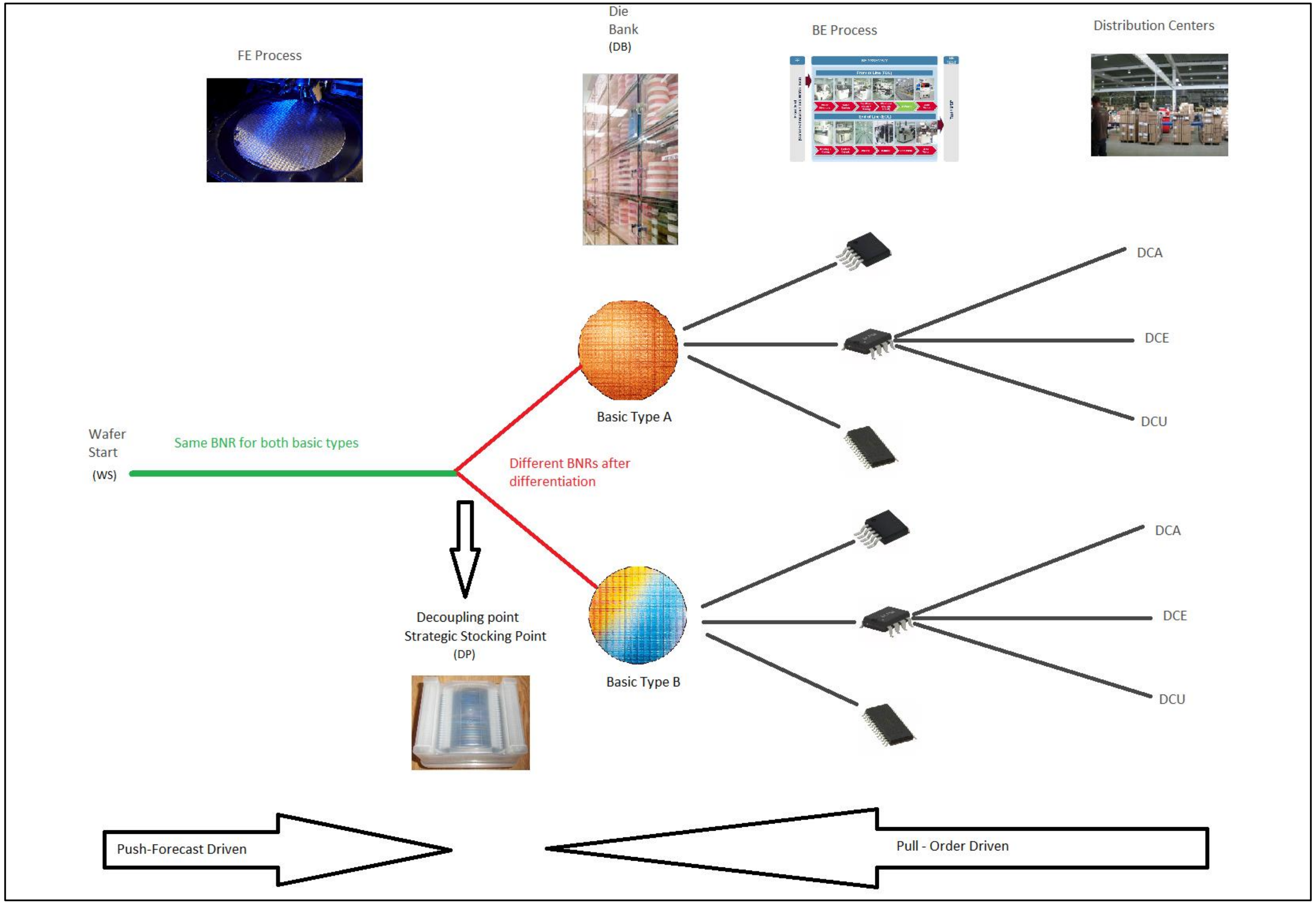

Figure 41: Suggested Changes to the Planning System after Introducing the Decoupling Point (Source: Own Illustration)

3.2.3.3 An Example to Demonstrate the Application of the Suggested Methodology

In the previous two subsections, a methodology to detect a potential decoupling point within FE production was introduced, and subsequent changes that would facilitate applying the concept within the examined company's planning system were proposed. In this subsection, an example to demonstrate the application of the previously explained decoupling point detection methodology was applied for two basic types in the company will be given, and the suggested changes to the planning system will be demonstrated.

In order to identify the potential basic types to which the decoupling point concept could be applied, an expert interview with the head of FE production and logistics planning for a major FE manufacturing site of the examined company was carried out. The purpose of the interview was to gather information from the interviewee's expertise that would help identifying the basic types that could be used as an example for the application of the concept. The interviewee pointed out that many of the basic types manufactured in the fab he is responsible for are differentiated from the very beginning of the fab process. Thus, the application of decoupling point does not make much sense in such cases, as the decoupling point will be rather upstream and far from the customer, which is against what is recommended in the literature. However, he also pointed out that there is a group of basic types that belong to a certain business unit in the company, which usually share a big part of the fab process and get differentiated at the end of the line, mainly in the implantation process. For this process, every basic type in this group has different attributes (for example different thicknesses), based on the design of the wafer according to the application of the final product.

It was accordingly decided to pursue the example for the case study based on the recommendations of the interviewed expert. The next step was to carry out trials that would lead to finding out 2 suitable basic types out of this group for which the proposed methodology could be applied. After trying out many combinations of different basic types from the recommended product group, a suitable case was found, where two basic types that share a big portion of the fab process in FE and get differentiated in the very end of the process.

The two basic types discussed in the example will be referred to as basic type "X" and basic type "Y". The first step, was browsing the work routes of the two basic types on the examined company's mentioned IT platform, and downloading the excel file in which they are listed side by side. Later on, the decoupling point detection program was run for the two work routes on excel. As explained in subsection 3.2.3.1, the aim of the program is to find out the latest possible diversification point between any two basic types, which could then become the potential decoupling point between them.

Appendix 2 shows the work routes of the examined basic types on excel after running the decoupling point detection program. The real process attributes are also hidden in the appendix, as the work routes in the appendix are shown only for demonstration purposes. The two basic types have a wafer size of six inches, and both have 60 chips per wafer. Each basic type undergoes 113 process steps in the fab process in FE, and they are both manufactured in the same site, to be notated in this thesis as fab A. After running the decoupling point detection program for those two basic types, it was found out that the last common process was the 101st process for both basic types. Starting from the 102nd process, each basic type has a different sequence of process steps and different attributes for each step till the end of its work route. This was revealed as a result of running the program, as clear from Appendix 2.

As seen in the appendix, the program returned back the process step ID of the last common process step between the two basic types, which is process 8570 (12), and it also highlighted the first difference between the two work routes in red as seen later in the work route. It could be noted that basic type X moves from process step 8570 (12), which is (NASSCHEM. REINIGEN YIELD-UP), where the wafers are dried from the etching process undergone before, to process step 8206 (04) (Implantation) where the metal gets implanted in the wafer according to specific process attributes for this basic type. After implantation, the wafers move to 8276 (07) (FOLIE AB) where the foil placed on the wafers in an earlier step gets removed after implantation. On the other hand, basic type Y moves from the same process step 8570 (12) (NASSCHEM. REINIGEN YIELD-UP), to process step 8276 (07) (FOLIE AB), in which the foil layer is removed. Afterwards, it undergoes the implantation process, but with different attributes than those of basic type X. The resulting wafer structure in the two basic types is then different for each of them, as basic type X undergoes the implantation process with the foil layer on, while in basic type Y, the layer is removed at first, then the implantation process takes place. Additionally, the implantation process has different attributes for each basic type.

The semi-finished wafer processed from first process step in the work route till the 101st process step “8570 (12)” - (NASSCHEM. REINIGEN YIELD-UP), in which the wafer drying takes place, could be then considered the modular platform both basic types are based on. The differentiation happens afterwards in the last 12 process steps, as the process steps that take place have different attributes and order for each basic type according to the end product’s application and its implication on the wafer design. Accordingly, the potential decoupling point for those two basic types could be positioned after process step "8570 (12)" - (NASSCHEM. REINIGEN YIELD-UP), as it is the last common step before they get differentiated.

As clear from the above discussion, the two basic types share a rather huge portion of the fab process, as 101 out of 113 process steps are exactly the same for both of them. In order to quantify the shared portion in terms of cycle time, the cycle time data for both basic types have been checked as explained in subsection 3.2.3.1. The total cycle time of the FE process for those basic types is rather low, as their wafer size is considered small (6 inch diameter). For basic type X, the total cycle time of the fab process is approximately 22.2 days, and for the sort process, it is around 0.8 day. That means that the total FE cycle time for it is around 23 days. On the other hand, basic type Y has a cycle time of 22.3 days for the fab process, and 0.8 days for the sort process, which adds up to a total FE cycle time of 23.1 days. The cycle time for the common 101 process steps was found to be 20.1 days. This means that the two basic types share approximately 87% of their processing cycle time in the FE process, and only 13% of the process is different (in terms of cycle time).

The previous analysis of the cycle times shows that if a strategic stocking point is introduced after the differentiation point (process step "8570 (12)"), then the cycle time needed to deliver the finished wafer to DB after this point will be approximately 3 days only, which is considered a rather low time in the world of semiconductors. This means that the response time needed to deliver finished wafers to DB in response to sudden demand rises could be reduced to from 23 days, which is the whole FE process cycle time, to 3 days only, if the modular semi-finished wafers are pulled from the strategic stocking point and customized based on the received orders.

The next step was to check the demand situation of both basic types, in order to ensure that both of them have regular demand. The check revealed that the both basic types were actively demanded by the customers. The average demand for basic type X is around 50 wafers per week, while for basic type Y, it was around 63 wafers per week. Considering the bullwhip effect phenomena that the semiconductor industry is plagued with, the demand for such high runner products tends to be volatile. Demand swings are mostly unpredictable and inevitable, as customers can multiply their orders without any previous notice. This is why it makes sense to postpone the customization to the latest possible point in production, in order to respond to the latest demand picture. Table 4 summarizes the different attributes of the two basic types discussed in the example.

	Basic Type X	Basic Type Y
Chips/Wafer	60	60
Wafer Size (inch)	6	6
Manufacturing Location	Fab A	Fab A
FAB Process CT (days)	22.21	22,28
Sort Process CT (days)	0.82	0.82
Total FE CT (days)	23.03	23.1
CT of Common Processes (days)	20.1	20.1
CT of processes after the DP till DB (days)	3.02	3.00
Number of Process Steps in the Fab Process	113	113
Percentage of Common process in terms of CT	87%	87%
Average Demand/Week (wafers)	50	63

Table 4: Different Attributes of the Basic Types Discussed in the Case Study Example

After successfully detecting the potential decoupling point between the two basic types, and assessing their demand situation in order to ensure its effectiveness, the next recommended step is to apply the changes in the planning system suggested in subsection 3.2.3.1, in order to realize the benefit of the concept for this case.

As mentioned, the two basic types have different baunumbers from the very beginning of their baunumber trees. The first disposition point in their supply chain is the DB. In order to apply the decoupling point concept for them, a new common baunumber should be introduced at the beginning of the baunumber tree for each of them. This baunumber defines the process of fabricating the modular semi-finished wafer both basic types are based on. A Y-link should be created after this common baunumber, to define the differentiating processes till the end of the process, and the rest of the supply chain till delivery to DCs. As explained, this will enable demand aggregation of both basic types' demands, which will accordingly trigger consolidated wafer starts. WIP interchangeability of both basic types will also be enabled as long they are on the common baunumber.

In order to activate the strategic stocking point in the company's planning system, a disposition point should be introduced after the common baunumber. This will enable storing the semi-finished modular wafers in it, and pulling them afterwards based on customer orders.

4 Conclusion and Recommendations for Future Research

After describing the case study undergone in the examined company in chapter 3, the work done will be summarized and concluded in chapter 4, and recommendations for the future research will be given.

4.1 Summary and Conclusion

In the case study undergone in this thesis, a methodology was proposed to apply an important concept of agility within the examined semiconductor company's supply chain. The case study focused on applying the decoupling point concept in the examined company's supply chain, as it is one of the most prominent concepts within the literature of agility. In the case study, a tool to detect the potential decoupling point within the wafer fabrication process of the examined company (the front end process) was formulated. Afterwards, changes were suggested to the company's planning system in order to apply the concept and benefit from its advantages. Finally, an example was given to demonstrate the application of the suggested methodology on a case where two basic types have late differentiation in the front end process.

The case study carried out could be considered an attempt to materialize an important concept emphasized in the literature of agility and supply chain agility into a practical tool that enables the application of the concept within the examined company's supply chain. The advantage of the developed methodology is that it is a sustainable tool that could be applied to any case within the examined company. The tool is based on a data extract from an existing IT platform in the company, and it accordingly enables detecting the potential decoupling point between any two basic types using an excel visual basic for applications (VBA) program that could be used in an efficient way.

The suggested changes to the company's planning system are based on an understanding of the system, and they accordingly aim at facilitating the application the decoupling point concept within it in a way that would help managing some of the challenges faced by a typical semiconductor manufacturer within his supply chain. The suggested setup of the production and planning system after introducing the decoupling point with front end production facilitates a prompter response to inevitable customer demand rises, and shortens the time required to deliver finished wafers to die bank by means of the strategic stocking point, which would help in overcoming the long cycle time of the front end process.

As mentioned in subchapter 2.3, Christopher (2000) claims that the decoupling point also helps in reducing the bullwhip effect, which is a phenomenon any typical semiconductor supply chain suffers from. The changes suggested in the examined company's planning system could potentially help in reducing the bullwhip effect by means of stocking the modular semi-finished wafers in the strategic stocking point, which could be customized to the ordered basic type in a late stage in front end and delivered quickly to die bank, and accordingly to customers. Additionally, unifying the baunumber tress before the decoupling point delays the definition of the target basic type to be produced. This enables the supply chain planners to react to urgent demand changes by freely booking the lots on the work in process of the common baunumber to the basic type that has the urgent demand rise.

4.2 Outlook and Recommendations for Future Research

The suggested methodology introduces a practical tool that could potentially increase the agility of the semiconductor supply chain. However, there are areas that should be further researched in the future in order to realize the full potential of the concept and its application within the examined company. Exploring the possibility of expanding the span of the IT platform used to compare the work routes to include more than two work routes in the comparison, and accordingly in the downloaded excel extract is highly recommended. This will enable the detection of the potential decoupling point between more than two basic types, thus expanding the benefit of the suggested methodology.

The case study undergone in thesis made use of the company's experts' knowledge in identifying the candidate basic types for exemplifying the application of the recommended methodology. As pointed out by the interviewed expert, there are groups of basic types which are differentiated rather early in the front end process, while others have late differentiation as shown in the example in subsection 3.2.3.3. It would be therefore recommended to develop a systematic approach to identify the candidate basic types for the application of the suggested methodology, and accordingly quantify the potential span of company-wide application of the concept. This could be done in close collaboration of the company's product designers and R&D departments, as they are the responsible parties for the work route's design within front end, which is the base of the application of the suggested methodology.

Another recommendation that would enhance the scope of this study would be to develop a simulation model that quantifies the benefits of the suggested methodology in terms of cost savings. The model should simulate different scenarios of demand fluctuations, and accordingly assess the effect of the decoupling point in terms of cost savings. It could be also extended to indicate the recommended stock levels of the stocks held in the strategic stocking point according to the simulated demand fluctuations of the basic types being differentiated afterwards.

The suggested setup of the planning system in this study recommends adding an extra disposition point within the supply chain of examined company, which is the strategic stocking point. The strategic stocking point is normally positioned at the differentiation point of the basic types that get differentiated in a late stage in the front end process. Since the processes after this point normally don't have a long cycle time till die bank (3 days in the case of the example given in the case study), it would be recommended to study the possibility of cancelling the disposition point at die bank for those basic types, enabling back end then to pull the wafers directly from the strategic stocking point without stopping in die bank.

The potential benefit of bypassing the die bank and pulling the wafers directly form the strategic stocking point would be decreasing the overall stocking costs, as the value of the stock held in the strategic stocking point is lower than that of the stock held in die bank. However, the wafer testing that happens during the sort process determines the amount of good chips on the wafer that could be promised to customer, which is not known in case the semi-finished wafers are only stored in the strategic stocking point. More research should be directed towards coming up with methodologies that would help overcoming such a hurdle.

Another issue that should be addressed is to study the feasibility of the strategic stocking point based on the possible storage time of the semi-finished wafers from the quality point of view. The possible storage time of a semi-finished wafer could be lower than that of the finished wafer, and it could vary based on the process step the wafers are being stored after. It is therefore recommended to study the optimal strategic stocking point according to the allowed storage time from the quality point of view.

A potential benefit of the decoupling point concept that needs to be further researched in the future is producing two basic types out of one lot, in case the two basic types have a low demand. The changes suggested in the case study enable interchangeability of the lots on WIP in the common part of the process by means of the common baunumber. However, the whole lot must be assigned to the target basic type, which might be more that what is actually needed. Splitting of one lot to produce two different basic types is not possible in the current planning and manufacturing system of the examined company. This is mainly due to the nature of the manufacturing process, as many of the costly machines used are designed to process a certain numbers of wafers at a time, which makes processing a lower number of wafers significantly more costly in terms of production cost per wafer.

Since the suggested methodology recommends positioning the decoupling point at a late stage within the front end process, the number of remaining processes to produce the finished wafers after it should be rather low, and they might not include the machines that are designed to process a certain numbers of wafers at a time. It is therefore recommended to establish a mathematical model that analyzes the cost vs. benefit of processing singular wafers instead of whole lots after the decoupling point. Based on the cost assessment of the processes succeeding the decoupling point and the demand situation of both basic types, the model should come up with a recommendation whether it would be better to produce singular wafers or whole lots after the decoupling point. The planning system should then be redesigned in a way that aggregates the demand of both basic types, and starts lots based on the possibility of splitting the same lot into different basic types. This can potentially decrease wafer starts and also finished wafer stocks on die bank as the surplus of unneeded wafers on stock due to lot size could be avoided.

List of References

Aelker, J., Bauernhansl, T. & Ehm, H., 2013. Managing complexity in supply chains: A discussion of current approaches on the example of the semiconductor industry. *Procedia CIRP*, Volume 7, pp. 79-84.

APICS, 2014. *SCOR - Supply Chain Operations Reference Model, Revision 11.0.,* s.l.: s.n.

Ballhaus, W., Pagella, A. & Vogel, C., 2009. *A Change of Pace for the Semiconnductor Industry,* s.l.: PricewaterhouseCoopers, Kohlhammer und Wallishauser GmbH, Druckerei und Verlag, Hechingen.

Braunscheidel, M. J. & Suresh, N. C., 2009. The Organizational Antecedents of a Firm's Supply Chain Agility for Risk Mitigation and Response. *Journal of Operations Management,* 27(2), p. 119–140.

Brown, S. & Bessant, J., 2003. The Manufacturing Strategy-Capabilities Links in Mass Customisation and Agile Manufacturing – an Exploratory Study. *International Journal of Operations & Production Management,* 23(7), pp. 707 - 730.

Carvalho, H., Duarte, S. & Machado, V. C., 2011. Lean, agile, resilient and green: divergencies and synergies. *International Journal of Lean Six Sigma,* 2(2), pp. 151 - 179.

Cho, Y.-C., Cheng, C.-T., Yang, F.-C. & Liang, Y.-Y., 2007. Evaluating alternative capacity strategies in semiconductor manufacturing under uncertain demand and price scenarios. *International Journal of Production Economics,* 105(2), p. 591–606.

Christopher, M., 2000. The Agile Supply Chain Competing in Volatile Markets. *Industrial Marketing Management,* 29(1), pp. 37-44.

Christopher, M. & Towill, D., 2001. An Integrated Model for the Design of Agile Supply Chains. *International Journal of Physical Distribution & Logistics Management,* 31(4), pp. 235 - 246.

Cohen, M. A., Ho, T. H., Justin Ren, Z. & Terwiesch, C., 2003. Measuring Imputed Cost in the Semiconductor Equipment Supply Chain. *Management Science,* December, Volume Vol. 49, pp. 1653-1670.

Dove, R., 1992. What Is All This Talk About Agility - The 21st Century Manufacturing Enterprise Strategy. *Prevision, Japan Management Association.*

Dove, R., 1994. The Meaning of Life and the Meaning of Agile. *Production Magazine,* 106(11), pp. 14-15.

Dove, R., 1996. Agile Supply-Chain Management. *Automotive Production,* 108(4), pp. 16-17.

Dubey, R. & Gunasekaran, A., 2015. Agile Manufacturing: Framework and its Empirical Validation. *International Journal of Advanced Manufucturing Technology,* 76(21), p. 2147–2157.

Elkins, D. A., Huang, N. & Alden, J. M., 2004. Agile Manufacturing Systems in the Automotive Industry. *International Journal of Production Economics,* Volume 91, p. 201–214.

Fliedner, G. & Vokurka, R. J., 1997. Agility: Competitive Weapon of the 1990s and Beyond?. *Production and Inventory Management Journal,* 38(3), pp. 19-24.

Geng, N. & Jiang, Z., 2009. A review on strategic capacity planning for the semiconductor manufacturing industry. *International Journal of Production Research,* 47(13), p. 3639–3655.

Goldman, S. L. & Nagel, R. N., 1993. Management, Technology and Agility: the Emergence of a New Era in Manufacturing. *International Journal of Technology Management,* 8(1/2), pp. 18-38.

Guisinger, A. & Ghorashi, B., 2004. Agile Manufacturing Practices in the Specialty Chemical Industry. *International Journal of Operations & Production Management,* 24(6), pp. 625 - 635.

Gunasekaran, A., 1998. Agile Manufacturing: Enablers and an Implementation Framework. *International Journal of Production Research,* 36(5), pp. 1223-1247.

Huang, Y.-Y. & Li, S.-J., 2009. Tracking the Evolution of Research Issues on Agility. *Asia Pacific Management Review,* 14(1), pp. 107-129.

Internal Document, 2008b. *Plan: Production Management and Inventory Handling,* Munich: s.n.

Internal Document, 2008. *Make - Introduction and Overview.* Munich: s.n.

Internal Document, 2009. *Plan: Order Management,* Munich: s.n.

Internal Document, 2012. *Plan: Supply Planning,* Munich: s.n.

Internal Document, 2013a. *Make - Backend: Introduction to Backend Manufacturing,* Munich: s.n.

Internal Document, 2013b. *Make - Backend: BE Manufacturing Front of Line,* Munich: s.n.

Internal Document, 2013c. *Make - Backend: BE Manufacturing End of Line,* Munich: s.n.

Internal Document, 2013d. *Make - Backend: BE Manufacturing Test and Mark Scan Pack,* Munich: s.n.

Internal Document, 2014a. *Plan - General Introduction to Planning,* Munich: s.n.

Internal Document, 2014b. *Plan: Introduction to Demand Planning,* Munich: s.n.

Internal Document, 2014c. *Plan: Introduction to Capacity Planning,* Munich: s.n.

Internal Document, 2015a. *General Introduction SCOR Model.* Munich: s.n.

Internal Document, 2015b. *Source,* Munich: s.n.

Internal Document, 2015c. *Deliver and Return - Focus Topic: Distribution Logistics ,* Munich: s.n.

Internal Document, 2015d. *Plan: Introduction to the Company's Planning Processes,* Munich: s.n.

Izadpanah, N. & Yaghoubipoor, A., 2012. Agility Reaching in Governmental Organizations and their Achievements. *Life Science Journal,* 9(4), p. 3763–3769.

Kidd, P., 1994. *Agile Manufacturing: Forging New Frontiers.* 1 ed. s.l.:Addison-Wesley.

Kidd, P., 1995. *Agile Corporations: Business Enterprises in the 21st Century - An Executive Guide.* s.l.:Cheshire Henbury.

Kidd, P. T., 1995. Agile Manufacturing: A Strategy for the 21st Century. *Agile Manufacturing (Digest No.1995/179), IEE Colloquium on IET,* pp. 1/1 - 1/6.

Lambert, D., Cooper, M. & Pagh, J., 1998. Supply Chain Management: Implementation Issues and Research Opportunities. *TheIinternational Journal of Logistics Management,* 9(2), pp. 1-20.

Lee, H. L., 2004. The Triple-A Supply Chain. *Harvard Business Review,* 82(10), pp. 102-113.

Losleben, P., 1990. *Semiconductor Manufacturing in the 21st Century: Capital Investment vs. Technological Innovation.* Washington DC, IEEE, pp. 3-11.

Lu, C.-C., Tsa, K.-M., Chen, J.-H. & Lee, W.-T., 2013. Mitigating the Bullwhip Effect in the Supply Chain of Semiconductor Assembly and Testing Through an Inter-Business Information Platform. *International Journal of Electronic Business Management,* 11(3), pp. 202-211.

Mason-Jones, R., Naylor, B. & Towill, D. R., 2000. Engineering the Leagile Supply Chain. *International Journal of Agile Management Systems,* 2(1), pp. 54 - 61.

Masson, R., Iosif, L., MacKerron, G. & Fernie, J., 2007. Managing Complexity in Agile Global Fashion Industry Supply Chains. *The International Journal of Logistics Management,* 18(2), pp. 238 - 254.

McCann, J., Selsky, J. & Lee, J., 2009. Building Agility, Resilience and Performance in Turbulent Environments. *People & Strategy,* 32(3), pp. 44-51.

McKinsey & Company , 2011. *McKinsey on Semiconductors,* s.l.: McKinsey & Company Industry Publications.

Mercier, P., Sirkin, H. & Bratton, J., 2010. 8 Ways to Boost Supply Chain Agility. *Supply Chain Management Review,* 14(1), pp. 18-25.

Moore, G. E., 1965. Cramming More Components onto Integrated Circuits. *Electronics,* 38(8), p. 114–117.

Moore, G. E., 1975. Progress in Digital Integrated Electronics. *Electron Devices Meeting,* Volume 21, pp. 11-13.

Nagel, R. & Dove, R., 1991. *21st Century Manufacturing Enterprise Strategy.* Bethlehem: Iacocca Institute, Lehigh University.

Nagel, R. N. & Bhargava, P., 1994. Agility: The Ultimate Requirement for World-class Manufacturing Performance. *National Productivity Review,* 13(3), p. 331–340.

Narasimhan, R., Swink, M. & Kim, S. W., 2006. Disentangling Leanness and Agility: An Empirical Investigation. *Journal of Operations Management,* Volume 24, p. 440–457.

Naylor, J. B., Naim, M. M. & Berry, D., 1999. Leagility: Integrating the Lean and Agile Manufacturing Paradigms in the Total Supply Chain. *International Journal of Production Economics,* 62(1), pp. 107-118.

Neshati, R., 2013. *A Statistical Model to Analyze the Complexity of Semiconductor Manufacturing.* San Jose, CA, IEEE, pp. 2757 - 2764.

Rabitsch, C. & Ramsauer, C., 2015. Towards a Management Approach for Implementing Agility in the Manufacturing Industry. *Proceedings International Conference Management of Technology – Step to Sustainable Production,* pp. 1-8.

Richards, C. W., 1996. Agile Manufacturing: Beyond Lean?. *Production and Inventory Management Journal,* 37(2), pp. 60-64.

Sanchez, L. M. & Nagi, R., 2001. A review of agile manufacturing systems. *International Journal of Production Research,* 39(16), pp. 3561-3600.

Sanchez, L. M. & Nagi, R., 2001. A review of agile manufacturing systems. *International Journal of Production Research,* 39(16), pp. 3561-3600.

Semiconductor Industry Association, 2014. *Industry Statistics: Global Sales Report.* [Online]
Available at:
http://www.semiconductors.org/news/2014/12/02/global_sales_report_2014/global_semiconductor_sales_increase_in_october_substantial_growth_projected_for_2014/

Sharifi, H., Colquhoun, G., Barclay, I. & Dann, Z., 2001. Agile Manufacturing: a Management and Operational Framework. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture,* 215(6), pp. 857-869.

Sharifi, H. & Zhang, Z., 2001. Agile manufacturing in practice - Application of a methodology. *International Journal of Operations & Production Management,* 21(5/6), pp. 772 - 794.

Sherehiy, B., Karwowski, W. & Layer, J. K., 2007. A Review of Enterprise Agility: Concepts, Frameworks, and Attributes. *International Journal of Industrial Ergonomics,* 37(5), p. 445–460.

Sheridan, J. S., 1993. Agile manufacturing: stepping beyond lean production. *Industry Week,* Volume 242, pp. 30-46.

Sherin, B. & Bartolett, S., 2000. Taiwan's 921 Quake and what it means to the Semiconductor Industry. *available at http://www.semiconductorsafety.org/proceedings00/sherinbrian.pdf*.

Sun, C., Rose, T., Ehm, H. & Heilmayer, S., 2015. Complexity Management in the Semiconductor Supply Chain and Manufacturing Using PROS Analysis. *Information and Knowledge Management in Complex Systems,* Volume 449, pp. 166-175.

Towill, D., 2005. Decoupling for Supply Chain Competitiveness. *Manufacturing Engineer,* 84(1), pp. 36-39.

Youssef, M. A., 1992. Agile Manufacturing: A Necessary Condition for Competing in Global Markets. *Industrial Engineering,* 24(12), pp. 18-20.

Yusuf, Y., Sarhadi, M. & Gunasekaran, A., 1999. Agile Manufacturing: The Drivers, Concepts and Attributes. *International Journal of Production Economics,* 62(1-2), pp. 33-43.

Yusuf, Y. Y. & Gunasekaran, A., 2002. Agile Manufacturing: A Taxonomy of Strategic and Technological Imperatives. *International Journal of Production Research,* 40(6), pp. 1357-1385.

Appendix 1

The program in this appendix is written in Visual Basic for Applications (VBA). The algorithm is designed to detect the latest common point within the FE manufacturing process of any two basic types in the examined company.

Program:

```
Sub Decoupling()


Dim i As Long 'main row counter
i = 4
Dim j As Long 'main column counter
j = 1
Dim k As Long 'row counter for second loop
k = 0
Dim a As String 'true/false indicator for cells comparison
a = "y"
Dim d As String ' stores the latest common process step
d = "no decoupling possible, base materials are different "
Dim d2 As String 'in case there are 2 blue cells for 1 step
Do While Left(ActiveSheet.Cells(i, 1), 4) <> "9999" And a = "y" 'main loop, ends with the end of the data set or with the latest common process step
  a = "y"

  Do While j <= 5 And a = "y" '1st row comparison
    If ActiveSheet.Cells(i, j) = ActiveSheet.Cells(i, j + 7) Then
      a = "y"
    Else
      a = "n"
      ActiveSheet.Cells(i, j).Interior.ColorIndex = 3
      ActiveSheet.Cells(i, j + 7).Interior.ColorIndex = 3
    End If
    j = j + 1
  Loop

  j = 1
```

```
 k = 0
 If ActiveSheet.Cells(i + 1, 1).Interior.ColorIndex = 24 Then 'check for the color of the
second cell in the step to avoid exiting the loop if there are two blue cells in the beginning
    Do While j <= 5 And a = "y" '2nd row comparison in case second row is also blue
       If ActiveSheet.Cells(i + 1, j) = ActiveSheet.Cells(i + 1, j + 7) Then
          a = "y"
       Else
          a = "n"
          ActiveSheet.Cells(i + 1, j).Interior.ColorIndex = 3
          ActiveSheet.Cells(i + 1, j + 7).Interior.ColorIndex = 3
       End If
       j = j + 1
    Loop

 i = i + 1
 End If
 If a = "y" Then
    j = 1
    k = 1
    Do While ActiveSheet.Cells(i + k, j).Interior.ColorIndex <> 24 And a = "y" 'main check
inside the step, stops as soon as next step starts
          If ActiveSheet.Cells(i + k, j) = ActiveSheet.Cells(i + k, j + 7) Then
             a = "y"
          Else
             a = "n"
             ActiveSheet.Cells(i + k, j).Interior.ColorIndex = 3
             ActiveSheet.Cells(i + k, j + 7).Interior.ColorIndex = 3
          End If
       j = j + 1
       If j = 5 Then
          j = 1
          k = k + 1
       End If
    Loop
    If a = "y" Then
```

```
            d = ActiveSheet.Cells(i, 1)
            d2 = ActiveSheet.Cells(i - 1, 1)
        End If
        i = i + k

    End If
Loop
ActiveSheet.Cells(4, 6) = d2
ActiveSheet.Cells(5, 6) = d
End Sub
```

Appendix 2

The work routes of the two basic types in the example, listing the process steps of each basic type withing FE production.

Basic Type X	****	****	****	****		Basic Type Y	****	****	****	****
Op.Nr.	**Op.Titel**	**Attribut**	**Parameter**	**S/R**		**Op.Nr.**	**Op.Titel**	**Attribut**	**Parameter**	**S/R**
1020 (04)	**EINSCHLEUSUNG GRUNDMATERIAL**		**1020ALLE1 (2)**	**(1)**	**8570(1 2)**	**1020 (04)**	**EINSCHLEUSUNG GRUNDMATERIAL**		**1020ALLE1 (2)**	**(1)**
		Attributes						**Attributes**		
1028 (69)	**LASERBESCHRIFTE N**			**(2)**		**1028 (69)**	**LASERBESCHRIFTE N**			**(2)**

Attributes

1045 (48)	**OXIDATION ERSTOXID 1300 nm**	**1045S700 (1)**	**(3)**

Attributes

Attributes

1045 (48)	**OXIDATION ERSTOXID 1300 nm**	**1045S700 (1)**	**(3)**

Attributes

1300 (04)	**IMPLANTATION EOX-DAMAGE**			**(4)**

Attributes

2010 (34)	**BELACKEN ERSTOXID**	**NA-VC-OF12 / 1026 / 2010**		**(5)**

Attributes

2011 (12)	**BELICHTEN ERSTOXID**	**NA-VC-OF12 / 1026 / 2010**	**STEPPERALL E3 (7)**	**(6)**

Attributes

2012 (51)	**ENTWICKELN ERSTOXID**	**NA-VC-OF12 / 1026 / 2010**		**(7)**

Attributes

1300 (04)	**IMPLANTATION EOX-DAMAGE**			**(4)**

Attributes

2010 (34)	**BELACKEN ERSTOXID**	**NA-VC-OF12 / 1026 / 2010**		**(5)**

Attributes

2011 (12)	**BELICHTEN ERSTOXID**	**NA-VC-OF12 / 1026 / 2010**	**STEPPERALL E3 (7)**	**(6)**

Attributes

2012 (51)	**ENTWICKELN ERSTOXID**	**NA-VC-OF12 / 1026 / 2010**		**(7)**

Attributes

2013 (24)	FOTOKONTROLLE ERSTOXID	NA-VC-OF12 / 1026 / 2010		(8)

Attributes

2015 (03)	MESSEN-LACKMASS ERSTOXID	NA-VC-OF12 / 1026 / 2010	2015M711 (1)	(9)

Attributes

2096 (03)	PLASMAAETZEN O2-FLASH			(10)

Attributes

2160 (84)	NASSCHEM. AETZUNG ERSTOXID			(11)

Attributes

2013 (24)	FOTOKONTROLLE ERSTOXID	NA-VC-OF12 / 1026 / 2010		(8)

Attributes

2015 (03)	MESSEN-LACKMASS ERSTOXID	NA-VC-OF12 / 1026 / 2010	2015M711 (1)	(9)

Attributes

2096 (03)	PLASMAAETZEN O2-FLASH			(10)

Attributes

2160 (84)	NASSCHEM. AETZUNG ERSTOXID			(11)

Attributes

2540 (19)	NASSCHEM. LACKABLOESEN		(12)

Attributes

2171 (06)	MESSEN AETZMASS EOX	2171S711 (1)	(13)

Attributes

2240 (77)	OXIDATION GOX	2240F701 (5)	(14)

Attributes

2540 (19)	NASSCHEM. LACKABLOESEN		(12)

Attributes

2171 (06)	MESSEN AETZMASS EOX	2171S711 (1)	(13)

Attributes

2240 (77)	OXIDATION GOX	2240F701 (5)	(14)

Attributes

3164 (87)	**ABSCHEIDUNG POLY**	**3164S735 (4)**	**(15)**

Attributes

3270 (08) opt. (LTA020 P)	**DD-MONITORING**	**(16)**

Attributes

3164 (87)	**ABSCHEIDUNG POLY**	**3164S735 (4)**	**(15)**

Attributes

3270 (08) opt. (LTA020 P)	**DD-MONITORING**	**(16)**

Attributes

3272 (38)	DOPE-DRIVE-IN POLY		(17)

Attributes

3272 (38)	DOPE-DRIVE-IN POLY		(17)

Attributes

3510 (48)	BELACKEN POLY	NA-VC-OF05 / 1026 / 3510	(18)

Attributes

3510 (48)	BELACKEN POLY	NA-VC-OF05 / 1026 / 3510	(18)

Attributes

3511 (25)	BELICHTEN POLY	NA-VC-OF05 / 1026 / 3510	STEPPERALL E3 (7)	(19)

Attributes

3512 (07)	ENTWICKELN POLY	NA-VC-OF05 / 1026 / 3510		(20)

Attributes

3513 (14)	FOTOKONTROLLE POLY	NA-VC-OF05 / 1026 / 3510		(21)

Attributes

3511 (25)	BELICHTEN POLY	NA-VC-OF05 / 1026 / 3510	STEPPERALL E3 (7)	(19)

Attributes

3512 (07)	ENTWICKELN POLY	NA-VC-OF05 / 1026 / 3510		(20)

Attributes

3513 (14)	FOTOKONTROLLE POLY	NA-VC-OF05 / 1026 / 3510		(21)

Attributes

3515 (09)	**MESSEN-LACKMASS POLY**	**NA-VC-OF05 / 1026 / 3510**	**3515S711 (1)**	**(22)**

Attributes

3642 (15)	**PLASMAAETZEN POLY**		**3642S737 (3)**	**(23)**

Attributes

3644 (07)	**NASSCHEM. LACKABLOESEN**			**(24)**

Attributes

3646 (14)	**PLASMAAETZEN LACKABLOESEN**			**(25)**

Attributes

3515 (09)	**MESSEN-LACKMASS POLY**	**NA-VC-OF05 / 1026 / 3510**	**3515S711 (1)**	**(22)**

Attributes

3642 (15)	**PLASMAAETZEN POLY**		**3642S737 (3)**	**(23)**

Attributes

3644 (07)	**NASSCHEM. LACKABLOESEN**			**(24)**

Attributes

3646 (14)	**PLASMAAETZEN LACKABLOESEN**			**(25)**

Attributes

3652 (18)	**NASSCHEM. LACKABLOESEN**	**(26)**

Attributes

3657 (06) opt. (LTA020 P)	**DD-MONITORING**	**(27)**

Attributes

3652 (18)	**NASSCHEM. LACKABLOESEN**	**(26)**

Attributes

3657 (06) opt. (LTA020 P)	**DD-MONITORING**	**(27)**

Attributes

3675 (06)	**BELACKEN P+WANNE**	**NA-VC-OF01 / 1026 / 3675**		**(29)**

Attributes

3676 (06)	**BELICHTEN P+WANNE**	**NA-VC-OF01 / 1026 / 3675**	**STEPPERALL E3 (7)**	**(30)**

Attributes

3677 (25)	**ENTWICKELN P+WANNE**	**NA-VC-OF01 / 1026 / 3675**		**(31)**

Attributes

3681 (07)	**FOTOKONTROLLE P+WANNE**	**NA-VC-OF01 / 1026 / 3675**		**(32)**

3675 (06)	**BELACKEN P+WANNE**	**NA-VC-OF01 / 1026 / 3675**		**(29)**

Attributes

3676 (06)	**BELICHTEN P+WANNE**	**NA-VC-OF01 / 1026 / 3675**	**STEPPERALL E3 (7)**	**(30)**

Attributes

3677 (25)	**ENTWICKELN P+WANNE**	**NA-VC-OF01 / 1026 / 3675**		**(31)**

Attributes

3681 (07)	**FOTOKONTROLLE P+WANNE**	**NA-VC-OF01 / 1026 / 3675**		**(32)**

Attributes

3678 (11)	MESSEN-LACKMASS P+WANNE	NA-VC-OF01 / 1026 / 3675	3678M712 (1)	(33)

Attributes

3679 (02)	IMPLANTATION P+ WANNE	(34)

Attributes

3688 (03)	PLASMAAETZEN LACKABLOESEN	(35)

Attributes

3700 (19)	NASSCHEM. LACKABLOESEN	(36)

Attributes

Attributes

3678 (11)	MESSEN-LACKMASS P+WANNE	NA-VC-OF01 / 1026 / 3675	3678M712 (1)	(33)

Attributes

3679 (02)	IMPLANTATION P+ WANNE	(34)

Attributes

3688 (03)	PLASMAAETZEN LACKABLOESEN	(35)

Attributes

3700 (19)	NASSCHEM. LACKABLOESEN	(36)

Attributes

3740 **(17)**	**IMPLANTATION KANAL**		**(37)**

Attributes

3776 **(07)**	**PLASMAAETZEN REOX**		**(38)**

Attributes

3850 **(33)**	**DIFFUSION BOR**	**3850R737** **(1)**	**(39)**

Attributes

4010 **(06)**	**IMPLANTATION SOURCE**		**(40)**

3740 **(17)**	**IMPLANTATION KANAL**		**(37)**

Attributes

3776 **(07)**	**PLASMAAETZEN REOX**		**(38)**

Attributes

3850 **(33)**	**DIFFUSION BOR**	**3850R737** **(1)**	**(39)**

Attributes

4010 **(06)**	**IMPLANTATION SOURCE**		**(40)**

Attributes

4344 (49)	ABSCHEIDUNG SPACEROXID	4344S735 (6)	(41)

Attributes

4405 (02)	AUSHEILEN N2		(42)

Attributes

4620 (27)	PLASMAAETZEN SPACER	4620R735 (7)	(43)

Attributes

Attributes

4344 (49)	ABSCHEIDUNG SPACEROXID	4344S735 (6)	(41)

Attributes

4405 (02)	AUSHEILEN N2		(42)

Attributes

4620 (27)	PLASMAAETZEN SPACER	4620R735 (7)	(43)

Attributes

4700 (03)	AUSHEILEN	(44)

Attributes

5300 (03)	IMPLANTATION P+	(45)

Attributes

5850 (03)	IMPLANTATION SOURCE-2	(46)

Attributes

4700 (03)	AUSHEILEN	(44)

Attributes

5300 (03)	IMPLANTATION P+	(45)

Attributes

5850 (03)	IMPLANTATION SOURCE-2	(46)

Attributes

6040 (16)	**NASSCHEM. REINIGUNG**	**(47)**

Attributes

6046 (04) opt. (LTA020 P)	**DD-MONITORING**	**(48)**

Attributes

7012 (04) opt. (LTA501 P)	**TOOLMONITORIN G PRE MEASUREMENT**	**(49)**

Attributes

6040 (16)	**NASSCHEM. REINIGUNG**	**(47)**

Attributes

6046 (04) opt. (LTA020 P)	**DD-MONITORING**	**(48)**

Attributes

7012 (04) opt. (LTA501 P)	**TOOLMONITORIN G PRE MEASUREMENT**	**(49)**

Attributes

3680 (42)	ABSCHEIDUNG USG	3680SS74 (1)	(50)

Attributes

4402 (80)	ABSCHEIDUNG ZWOX	4402HZT (1)	(51)

Attributes

6072 (08)	AUSHEILEN ARSEN		(52)

3680 (42)	ABSCHEIDUNG USG	3680SS74 (1)	(50)

Attributes

4402 (80)	ABSCHEIDUNG ZWOX	4402HZT (1)	(51)

Attributes

6072 (08)	AUSHEILEN ARSEN		(52)

Attributes	Attributes
6160 (08) opt. (LTA020P) **DD-MONITORING** **(53)**	**6160 (08) opt. (LTA020P)** **DD-MONITORING** **(53)**

Attributes	Attributes
7013 (14) **(54)**	**7013 (14)** **(54)**

opt. (LTA501 P)	TOOLMONITORIN G POST MEASUREMENT		

Attributes

6110 (17)	ABSCHEIDUNG NITRID	6110S601 (3)	(55)

Attributes

6220 (36)	ABSCHEIDUNG POLSTER		(56)

Attributes

opt. (LTA501 P)	TOOLMONITORIN G POST MEASUREMENT		

Attributes

6110 (17)	ABSCHEIDUNG NITRID	6110S601 (3)	(55)

Attributes

6220 (36)	ABSCHEIDUNG POLSTER		(56)

Attributes

6240 (02)	**VERDICHTEN POLSTER 1**			**(57)**

Attributes

6340 (02)	**IMPLANTATION POLSTER**			**(58)**

Attributes

6380 (06)	**BELACKEN POLSTER**	**NA-VC-OF01 / 1026 / 6380**		**(59)**

Attributes

6381 (03)	**BELICHTEN POLSTER**	**NA-VC-OF01 / 1026 / 6380**	**STEPPERALL E3 (7)**	**(60)**

Attributes

6240 (02)	**VERDICHTEN POLSTER 1**			**(57)**

Attributes

6340 (02)	**IMPLANTATION POLSTER**			**(58)**

Attributes

6380 (06)	**BELACKEN POLSTER**	**NA-VC-OF01 / 1026 / 6380**		**(59)**

Attributes

6381 (03)	**BELICHTEN POLSTER**	**NA-VC-OF01 / 1026 / 6380**	**STEPPERALL E3 (7)**	**(60)**

Attributes

6382 (20)	**ENTWICKELN POLSTER**	**NA-VC-OF01 / 1026 / 6380**	**(61)**	**6382 (20)**	**ENTWICKELN POLSTER**	**NA-VC-OF01 / 1026 / 6380**	**(61)**
	Attributes				**Attributes**		
6383 (15)	**FOTOKONTROLLE POLSTER**	**NA-VC-OF01 / 1026 / 6380**	**(62)**	**6383 (15)**	**FOTOKONTROLLE POLSTER**	**NA-VC-OF01 / 1026 / 6380**	**(62)**
	Attributes				**Attributes**		
6410 (23)	**NASSCHEM. AETZUNG POLSTER**		**(63)**	**6410 (23)**	**NASSCHEM. AETZUNG POLSTER**		**(63)**
	Attributes				**Attributes**		
6414 (15)	**NASSCHEM. LACKABLOESEN**	**NA-PSG-6Z / 1063 / 6220**	**(64)**	**6414 (15)**	**NASSCHEM. LACKABLOESEN**	**NA-PSG-6Z / 1063 / 6220**	**(64)**
	Attributes				**Attributes**		

6416 (22)	**NASSCHEM. AETZUNG NITRID**	**6416E735 (4)**	**(65)**

Attributes

6416 (22)	**NASSCHEM. AETZUNG NITRID**	**6416E735 (4)**	**(65)**

Attributes

6556 (70)	**BELACKEN KONTAKTLOCH**	**NA-VC-OF01 / 1026 / 6556**	**(67)**

Attributes

6556 (70)	**BELACKEN KONTAKTLOCH**	**NA-VC-OF01 / 1026 / 6556**	**(67)**

Attributes

6557 (04)	**BELICHTEN KONTAKTLOCH**	**NA-VC-OF01 / 1026 / 6556**	**STEPPERALL E3 (7)**	**(68)**

Attributes

6558 (22)	**ENTWICKELN KONTAKTLOCH**	**NA-VC-OF01 / 1026 / 6556**		**(69)**

Attributes

6559 (24)	**FOTOKONTROLLE KONTAKTLOCH - E**	**NA-VC-OF01 / 1026 / 6556**		**(70)**

Attributes

6562 (13)	**MESSEN-LACKMASS KONTAKTLOCH**	**NA-VC-OF01 / 1026 / 6556**	**6562S722 (2)**	**(71)**

Attributes

6557 (04)	**BELICHTEN KONTAKTLOCH**	**NA-VC-OF01 / 1026 / 6556**	**STEPPERALL E3 (7)**	**(68)**

Attributes

6558 (22)	**ENTWICKELN KONTAKTLOCH**	**NA-VC-OF01 / 1026 / 6556**		**(69)**

Attributes

6559 (24)	**FOTOKONTROLLE KONTAKTLOCH - E**	**NA-VC-OF01 / 1026 / 6556**		**(70)**

Attributes

6562 (13)	**MESSEN-LACKMASS KONTAKTLOCH**	**NA-VC-OF01 / 1026 / 6556**	**6562S722 (2)**	**(71)**

Attributes

6618 (79)	**PLASMAAETZEN KONTAKTLOCH**		**(72)**

Attributes

6631 (45)	**PLASMAAETZEN LACKABLOESEN**		**(73)**

Attributes

6770 (04)	**NASSCHEM. LACKABLOESEN**		**(74)**

Attributes

6790 (04)	**PLASMAAETZEN KL/GRABEN**	**6790E737 (4)**	**(75)**

Attributes

6618 (79)	**PLASMAAETZEN KONTAKTLOCH**		**(72)**

Attributes

6631 (45)	**PLASMAAETZEN LACKABLOESEN**		**(73)**

Attributes

6770 (04)	**NASSCHEM. LACKABLOESEN**		**(74)**

Attributes

6790 (04)	**PLASMAAETZEN KL/GRABEN**	**6790E737 (4)**	**(75)**

Attributes

6791 (08)	MESSEN AETZMASS	6791S722 (2)	(76)

Attributes

6884 (02)	NASSCHEM. REINIGUNG		(77)

Attributes

6887 (68)	SPUTTERN METALL AlSiCu		(78)

Attributes

6791 (08)	MESSEN AETZMASS	6791S722 (2)	(76)

Attributes

6884 (02)	NASSCHEM. REINIGUNG		(77)

Attributes

6887 (68)	SPUTTERN METALL AlSiCu		(78)

Attributes

6980 (62)	**BELACKEN METALLISIERUNG**	**NA-VC-AE01 / 1025 / 6980**		**(79)**

Attributes

6981 (10)	**BELICHTEN METALLISIERUNG**	**NA-VC-AE01 / 1025 / 6980**	**STEPPERALL E3 (7)**	**(80)**

Attributes

6980 (62)	**BELACKEN METALLISIERUNG**	**NA-VC-AE01 / 1025 / 6980**		**(79)**

Attributes

6981 (10)	**BELICHTEN METALLISIERUNG**	**NA-VC-AE01 / 1025 / 6980**	**STEPPERALL E3 (7)**	**(80)**

Attributes

6982 (10)	ENTWICKELN METALLISIERUNG	NA-VC-AE01 / 1025 / 6980		(81)
Attributes				
6983 (38)	FOTOKONTROLLE METALLISIERUNG	NA-VC-AE01 / 1025 / 6980		(82)
Attributes				
6985 (01)	REM-MESSEN-LACKMASS METALLISIERUNG	NA-VC-AE01 / 1025 / 6980	6985S711 (1)	(83)
Attributes				
7059 (08)	PLASMAAETZEN O2-FLASH			(84)
Attributes				

6982 (10)	ENTWICKELN METALLISIERUNG	NA-VC-AE01 / 1025 / 6980		(81)
Attributes				
6983 (38)	FOTOKONTROLLE METALLISIERUNG	NA-VC-AE01 / 1025 / 6980		(82)
Attributes				
6985 (01)	REM-MESSEN-LACKMASS METALLISIERUNG	NA-VC-AE01 / 1025 / 6980	6985S711 (1)	(83)
Attributes				
7059 (08)	PLASMAAETZEN O2-FLASH			(84)
Attributes				

7075 (40)	**NASSCHEM. AETZUNG METALLISIERUNG**	**7075AETZ1 (1)**	**(85)**

Attributes

7075 (40)	**NASSCHEM. AETZUNG METALLISIERUNG**	**7075AETZ1 (1)**	**(85)**

Attributes

7087 (23)	**PLASMAAETZEN Si-GRIESZ/LAB**	**(86)**

Attributes

7087 (23)	**PLASMAAETZEN Si-GRIESZ/LAB**	**(86)**

Attributes

7099 (06)	**MESSEN AETZMASS METALISIERUNG**	**7099S700 (1)**	**(87)**

Attributes

7110 (22)	**NASSCHEM. REINIGUNG US-DMF**		**(88)**

Attributes

7660 (10)	**TEMPERN-H2N2**		**(89)**

Attributes

7750 (56)	**ABSCHEIDUNG PASSIVIERUNG**		**(90)**

Attributes

7099 (06)	**MESSEN AETZMASS METALISIERUNG**	**7099S700 (1)**	**(87)**

Attributes

7110 (22)	**NASSCHEM. REINIGUNG US-DMF**		**(88)**

Attributes

7660 (10)	**TEMPERN-H2N2**		**(89)**

Attributes

7750 (56)	**ABSCHEIDUNG PASSIVIERUNG**		**(90)**

Attributes

8288 (59)	BELACKEN IMID	NA-IMINTC / 1034 / 8288	(91)

Attributes

8288 (59)	BELACKEN IMID	NA-IMINTC / 1034 / 8288	(91)

Attributes

8289 (40)	BELICHTEN IMID	SVGALLE3 (4)	(92)

Attributes

8289 (40)	BELICHTEN IMID	SVGALLE3 (4)	(92)

Attributes

8290 (48)	ENTWICKELN IMID	(93)

Attributes

8900 (17)	FOTOKONTROLLE IMID	(94)

Attributes

8291 (02)	OFEN ZYKLISIEREN IMID	(95)

Attributes

8295 (01)	FARBTONKONTRO LLE IMID	(96)

Attributes

8290 (48)	ENTWICKELN IMID	(93)

Attributes

8900 (17)	FOTOKONTROLLE IMID	(94)

Attributes

8291 (02)	OFEN ZYKLISIEREN IMID	(95)

Attributes

8295 (01)	FARBTONKONTRO LLE IMID	(96)

Attributes

8520 (37)	**PLASMAAETZEN PASSIVIERUNG**	**TEGALAETZ (1)**	**(97)**

Attributes

8274 (14)	**FOLIE AUFZIEHEN**	**FOLIE (5)**	**(98)**

Attributes

8202 (43)	**DUENNSCHLEIFEN**	**8202S000 (1)**	**(99)**

Attributes

8520 (37)	**PLASMAAETZEN PASSIVIERUNG**	**TEGALAETZ (1)**	**(97)**

Attributes

8274 (14)	**FOLIE AUFZIEHEN**	**FOLIE (5)**	**(98)**

Attributes

8202 (43)	**DUENNSCHLEIFEN**	**8202S000 (1)**	**(99)**

Attributes

8280 (35)	**RS-SUBSTRATAETZUNG**	**8280M711 (1)**	**(100)**

Attributes

8570 (12)	**NASSCHEM. REINIGEN YIELD-UP**		**(101)**

8280 (35)	**RS-SUBSTRATAETZUNG**	**8280M711 (1)**	**(100)**

Attributes

8570 (12)	**NASSCHEM. REINIGEN YIELD-UP**		**(101)**

Attributes

8206 (04)	IMPLANTATION		(102)

Attributes

8276 (07)	FOLIE AB	FOLIE2 (3)	(103)

Attributes

8916 (07)	KONTROLLE		(104)

Attributes

8834 (03)	PLASMAAETZEN O2-FLASH		(105)

Attributes

Attributes

8276 (07)	FOLIE AB	FOLIE2 (3)	(102)

Attributes

8206 (39)	IMPLANTATION		(103)

Attributes

8916 (07)	KONTROLLE		(104)

1097 (02) **NA-WARTEN AUF KAPAZITAET** **(106)**

Attributes

8287 (08) **AETZUNG** **(107)**

Attributes

8575 (48) **RS-METALLISIERUNG** **(108)**

Attributes

Attributes

8834 (03) **PLASMAAETZEN O2-FLASH** **(105)**

Attributes

1097 (02) **NA-WARTEN AUF KAPAZITAET** **(106)**

Attributes

8287 (08) **AETZUNG** **(107)**

Attributes

8575 (48)	**RS-METALLISIERUNG**	**(108)**

Attributes

8825 (31)	**TEMPERN**	**(109)**

Attributes

8825 (31)	**TEMPERN**	**(109)**

Attributes

8645 (01)	**ENDKONTROLLE SCHEIBENFERTIGUNG**	**(110)**

Attributes

8650 (73)	**PARAMETERMESSUNG**	**NAPROLOS / 8955 / 8650**	**(111)**

Attributes

9990 (01)	**ALF-BEWERTUNG**	**(112)**

Attributes

9999 (02)	**LIEFERN**	**(113)**

Attributes

8645 (01)	**ENDKONTROLLE SCHEIBENFERTIGUNG**	**(110)**

Attributes

8650 (73)	**PARAMETERMESSUNG**	**NAPROLOS / 8955 / 8650**	**(111)**

Attributes

9990 (01)	**ALF-BEWERTUNG**	**(112)**

Attributes

9999 (02)	**LIEFERN**	**(113)**

Attributes