Master Thesis

Applying and testing hybrid lean and agile planning operations

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Statutory Declaration

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Abstract

The last two decades witnessed the advent of two important production systems; agile production and lean production. Whilst the latter received much more attention in industry and research, its applicability in industrial companies has recently been the focus of controversy by authors, due to the highly volatile current markets. Agile production, on the other hand, has seen by so many recent publications as the panacea to lean's drawbacks in turbulent markets. Yet, it is unclear in research whether the direction in production should be towards developing the current lean system, shifting towards agile production or integrating the two paradigms "leagility ".
This has triggered a research project at the institute of Production Science and Management at TU Graz, Austria seeking to find answers to such questions. Literature in this area, however, lacks the operational depth, and emphasises primarily on the strategic aspect. This master's thesis focuses on the operational level of the two paradigms, and shows that the current market necessitates the reinforcement of the lean system with several agility aspects, and the tailoring of some of its contents to agility. This could be achieved through tailoring the planning and control operations, developing more flexible pulling systems, adopting the decoupling point approach, applying hybrid Make-to-Stock /Make-to-Order, and utilizing scenario-based simulation techniques as a supporting tool to reach optimal solutions. Additionally, the thesis involves interviews and case studies at four major companies in Europe, in the automotive and powered metallurgy branches. The aim is to further investigate the applicability of leanness, agility, and their integration in real world practices. Moreover, it contributes in solving a real-world problem at Miba Sinter plant in Slovakia, through a case study tackling the implementation of hybrid lean-agile production, based on simulation and a suggested framework. The main finding of the thesis is that in the current volatile production market, it is needed to have a well-planned and thought about integration of lean and agile production.

Acknowledgement

First, I would like to express my deepest gratitude to my supervisor Dipl.-Ing. Alexander Pointner for all the tremendous support, insights and motivation he offered during the thesis. I was also honoured to work with him in publishing a conference paper in the area of the research topic. In addition, I am so grateful to my professor and advisor Prof. Christian Ramsauer, for giving me this generous opportunity to conduct my research at the institute of Production Science and Management. It was absolutely a beneficial experience for me to be among such high calibre staff, which helped me widen my horizons, and intensify my knowledge in my field of interest.

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Respectfully,

Farouq Halawa

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1 INTRODUCTION

1.1 Initial situation

The evolution of manufacturing witnessed several paradigm shifts over the past decades, starting with craft production, followed by mass production, and later on by lean production. The most recent paradigm is called agile production, which is seen as the zenith of production advancement in our modern world (Hormozi 2001, p. 132,143). Today, many companies in industry face a volatile market characterized by a dynamic environment, high market competition, varied products, and high complexity which requires collaboration between firms, suppliers and customers (Vázquez-Bustelo et al. 2007, pp. 1312–1313). An example of such an environment can be seen through observing the market demand of China's automobile industry in the last twenty years, which was characterized by high uncertainties and fluctuations. Such uncertainties reached 70% of volatility in some years (Wang et al. 2013, p. 3).

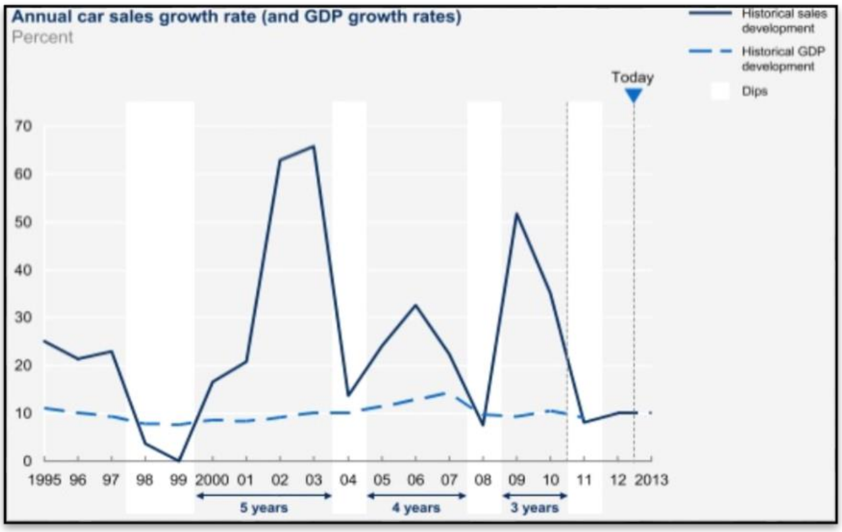


Figure 1: Erratic demand in china's automobile industry (Wang et al. 2013, p. 3)

Nowadays, customers require more personalization and superiority from their providers. Firms who are able to provide excellent services will thrive, and others who cannot, will ultimately fail. Thus, it is becoming the case in many industries that satisfying customers with high personalization is much more important than the traditionally brand awareness mentality (Wang, Koh 2010, p. 3). In response to all these challenges, agile production was seen as the panacea, as it enables the organization to thrive in a volatile environment, and adapt to dramatic increases and drops in customer demand. Thus, being agile enables the organization to boost its flexibility level to a wide spectrum

(Rabitsch, Ramsauer 2015, p. 5). Hence, lean is the choice of companies with cost leadership, and agile is the choice of companies with differentiation leadership (Hallgren, Olhager 2009b, p. 988). Although researchers do not agree about some aspects, there is much more agreement that agile production over performs lean production in terms of flexibility (Hallgren, Olhager 2009b, p. 988), (Narasimhan et al. 2006, p. 448). The aspect of flexibility and agility in lean production has been a focus of controversial discussion by authors over the last decade. The integration of lean and agile production has become one of the main elements of success in manufacturing enterprises, which in turn, attracted both manufacturers as well as researchers to find its distinguishing impact and applicability in all industrial sectors (Mukhopadhyay 2015, pp. 361–362).

1.2 Objectives of the thesis

This master thesis investigates the applicability of lean production and agile production, and focuses on how the lean system can be reinforced by agile production, from operational point of view.

1.3 Approach

In pursuit of this goal, first a comprehensive literature review was conducted to address both agile production and lean production separately as operational production systems. Then, light was shed on the differences and synergies of the two paradigms, and the integration of the two systems in accordance to literature. This, included studying the compatibility of the two systems from an operational point of view. Based on the literature review, several research gaps were highlighted. The next step was to validate the results of the literature, and to further investigate the research gaps empirically. This was done through conducting several interviews and a case study at a manufacturer in Europe. A case study was also conducted at Miba Sinter Slovakia, to tackle real-world problem. The thesis, culminates in a list of contributions and further research opportunities. All in all, the thesis attempted to bridge the gap between literature and practice in the area of leanness and agility, and show practically how the two systems can be employed for such volatile markets.

2 LITERATURE REVIEW

The following chapter encompasses seven sub-chapters that deal comprehensively with agile production, lean production, comparisons, compatibility analysis, and integration possibilities between the two paradigms, implementation frameworks, and finally, literature gaps.

2.1 Agile production

Agile manufacturing has recently gained lots of importance, and became a main strategy to face the fiercer market competition, characterized by market pull and shorter product lifecycle (van Assen et al. 2000, p. 2). The term "agility" was coined during early nineties by Iacocca Institute, and was believed to be the competitive strategy for the 21th century (Dove, Nagel 1991, p. 2).
"*Agility means using market knowledge and a virtual corporation to exploit profitable opportunities in a volatile market place*" (Ben Naylor et al. 1999, p. 108). However, several definitions of agility were presented in literature over the years, and it is important to understand the main characteristics of the agile system to form a holistic understanding of the paradigm. Agility is characterized by several key elements as shown in **Figure 4.** The first key characteristic of agility is "Proactive Preparation", which is materialized through possessing an early-warning system that can sense upcoming changes. It also means planning ahead of time to cope with these upcoming changes, and setting the right level of flexibility within the organization, which leads us to the second characteristic, namely "fast reaction". This part deals with processes and structures, which if planned effectively, would enable the organization to cope well with the change and achieve benefit out of them. The third main characteristic is the "optimized profitability". This part, targets achieving economic goals in different levers, such as increasing market share or return of investment, depending on the status quo of the organization. These characteristics cannot be reached without the existence of sound foundation that encompasses the workforce, corporate culture, coordination and cohesion in processes (Rabitsch, Ramsauer 2015, pp. 3–4).
Thus, agile manufacturing works such that all processes, tools and knowledge function actively together to enable the organization to respond swiftly to customer demand and market changes, taking into account the necessity to control cost and quality (Wang, Koh 2010, p. 3)**.**

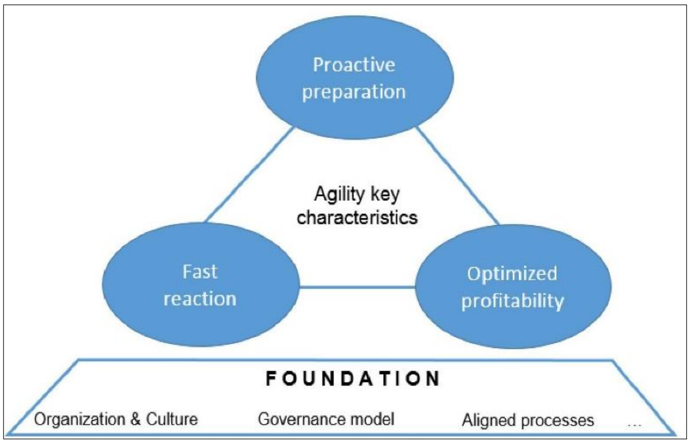


Figure 4: Key characteristics of agile production (Rabitsch, Ramsauer 2015, p. 4)

Being agile, enables the organization not only to adapt itself to dramatic increases in customer's demand, but also it mitigates risks in case of drops. It is worth mentioning, that agile organizations are noticeably more proactive to demand fluctuations than flexible organization from a definition point of view as seen in **Figure 5** (Rabitsch, Ramsauer 2015, p. 2).

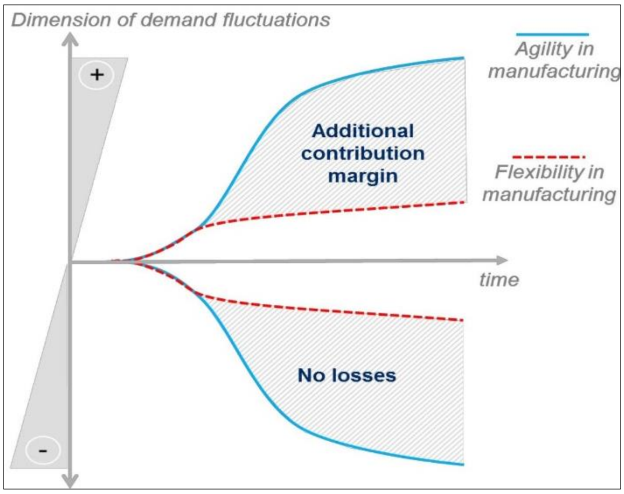


Figure 5: Agility and flexibility (Rabitsch, Ramsauer 2015, p. 2)

Customers nowadays, expect more personalization and superiority from their provider. Firms who are able to provide world-class services will thrive, and others who cannot, will ultimately fail. Consequently, satisfying customer needs have become more important than the traditional concept of brand loyalty (Wang, Koh 2010, p. 3). Hence, agile organizations function in an environment that have several characteristics, as described by (Vázquez-Bustelo et al. 2007, pp. 1312–1313):

- Relatively dynamic environment with unanticipated changes.
- Fears market competition.
- High complexity which requires high collaboration between firm, suppliers, customers and competitors as well.
- Varied products, customers, and markets.

Agility tools and practices

Several authors attempted to define the main tools and practices of agile production. A look at literature, however, makes it clear that there is no agreed operational model for agile production yet. What can be agreed upon is the existence of some common features and tools for the agile operational model. A model was developed by (Gunasekaran 1999, p. 1233), and altered by (Wang, Koh 2010, p. 3) shows that agility tools are categorized into technologies, systems, people, and strategies. The two authors agreed that the agile system should encompass several tools acting altogether to achieve mass customization, configurability, virtual enterprise and rapid partnerships. Another model was developed by (Vázquez-Bustelo et al. 2007, pp. 1312–1313) provided an expanded picture by including concurrent engineering and knowledge management in addition to the previously mentioned categorization of the agility tools. Hence, literature in agility is ripe with tools and practices. To conduct the research study, a model for agility is required. Thus, more than 65 different agility tools and practices were compiled as seen in **Figure 6**, compiling a literature review made by (Vázquez-Bustelo et al. 2007, p. 1309), in addition to several other sources such as (Nyman, Sarlin, p. 4195), (Baker 2008, pp. 18–19), (Rabitsch, Ramsauer 2015, p. 4), (Wang, Koh 2010, p. 159), (Gunasekaran, Yusuf 2002, p. 1376), (Jodlbauer et al. 2012, p. 46), (Ben Naylor et al. 1999, p. 114). The model is primarily based on (Vázquez-Bustelo et al. 2007) in many of the tools and categorization as well, as he made the effort to compile and categorize the agility practices from a wide range of literature. More detailed tools mapping is provided in Appendix E.

Technologies

- Rapid Hardware
- 3D Printing technologies
- Enterprise resource planning (ERP)
- Material requirement planning (MRP)
- Robotics
- Automated guided vehicle systems (AGVSs); automated storage and retrieval systems (AS/RS)
- Computer numerically controlled (CNC) machines
- Rapid Hardware
- Modular assembly softwares
- Kanban, JIT
- Computer-aided design (CAD)/computer-aided manufacturing (CAM)
- Rapid prototyping tools
- Intranet, internet and world wide web
- Electronic data interchange (EDI)
- Electronic commerce
- Visual inspection
- Manufacturing cells
- Virtual reality software
- Flexible manufacturing systems (FMS)
- Group technology
- Computer-aided process planning (CAPP)
- Point-of-sales data collection (POS)
- Bar codes, automatic data collection
- Real-time
- communication/execution systems
- Design for manufacture/assembly

Organisational-internal &external

- Strategic alliances based on core/complementary competencies
- Annual cross functional planning
- Virtual firm/organization
- Integration of functions from purchasing to sales; firm-wide integration of functions
- Scenario planning, and market intelligence
- Global supply chain management
- Integrated supply chain; integrated and interactive partner relations
- Outsource off-site
- Hybrid MTS and MTO
- Postponement of differentiation
- Decoupling point
- Customer integrated processes for designing, manufacturing, marketing, and support
- Strategic relationship with customers, close relationship with suppliers; thrust-based relationship with customers/suppliers Internal and external cooperation
- Business process reengineering
- Rapid-partnership formation

Human

- Top management support and employee involvement and empowerment
- Team working, self-directed teams, cross-functional teams
- Job rotation, multifunctional workforce, job enrichment (responsibility on multiple tasks)
- Training and education, higher average skill levels, workforce skill upgrade, continuous training and development, cross-functional training
- Knowledge workers, IT-skilled workers
- Decentralised decision making
- Additional shifts
- Entrepreneurial firm culture Reward schemes to encourage innovation and
- based on both financial and non financial measures

Concurrent Engineering

- Formation of cross-functional product development teams
- Multidisciplinary team working environment
- Customer and supplier integrated multidisciplinary teams
- Early involvement of different agents in the product development process and concurrent execution of functions/activities
- Intelligent engineering design support system; groupware Collaborative work
- Concurrent design of products and processes

Knowledge management

- Global access to databases and information
- easy access to integrated data; open information/communication policy
- Knowledge based systems (KBS) , knowledge management systems
- Sensitive information protection
- Organizational structure that promotes innovation and training and education;
- learning organization
- Team-to-team learning
- Firm-wide integration of learning,
- continuous learning
- Knowledge acquisition from internal and external sources
- Core-competence management

Figure 6: Basic agile tools and practices based on literature review from (Vázquez-Bustelo et al. 2007, p. 1309),(Nyman, Sarlin, p. 4195), (Baker 2008, pp. 18–19), (Rabitsch, Ramsauer 2015, p. 4), (Wang, Koh 2010, p. 159), (Gunasekaran, Yusuf 2002, p. 1376), (Jodlbauer et al. 2012, p. 46), (Ben Naylor et al. 1999, p. 114)

Production planning in agile manufacturing

The production planning system has different characteristics in agile production. ERP system is a substantial technology as seen in several literature (Vázquez-Bustelo et al. 2007, p. 1309), (Wang, Koh 2010, p. 159), (Gunasekaran, Yusuf 2002, p. 1364). Thus the characteristics of the agile production system is described as follows:

Enterprise Resource Planning (ERP)

ERP systems depend on Internet, and integrate information within the organization and outside. ERP integrates several areas in the organization which are operations, finance, human resources and marketing. The advantage of such system is that it gets red of the separate programs, and it provides integrity and secure access through Internet. Usually ERP is done through a dedicated software such as SAP. Although ERP can provide significant advantages to an organization, its high cost diminishes its attractiveness, especially in small organizations. The elements of ERP system can be described as follows (Greasley 2009, pp. 373–378):

1. Demand profile: knowing final products required by the market or customer.
2. Aggregate Plan: production rate, workforce, subcontracts are specified.
3. Master Production Schedule (MPS): planning quantities to be produce on time periods
4. Rough-cut capacity plan (RCCP): assessing the feasibility of MPS in terms of capacity
5. Material Requirement Planning (MRP): Calculating the requirements of component material based on BOM and on hold inventory
6. Capacity Requirement Plan (CRP): calculating the workloads and number of workers based on MRP.

Recently the MRP was extended to include financial and market aspects to form the MRPII (Manufacturing Resource Planning). The system, however, faces problems with accuracy of information and complexity, which makes its usability not very wide.

Decentralized planning hierarchy

Achieving agility, necessitates changes in the traditional hierarchy of the planning and control activities in the organization, the top down based on a centralized unit. The agility approach fosters decentralized production planning and control centers in every stage, multi-disciplinary teams in all stages, and an Information Management System as an umbrella over the value creation processes. The central production planning and control unit - which in traditional supply chains has a bigger scope, is only responsible for handling customer order, and the long term planning decision. Each stage is controlled by a decentralized production planning and control unit that carries out order review, and activities controlling (Assen et al. 2000, pp. 6–8).

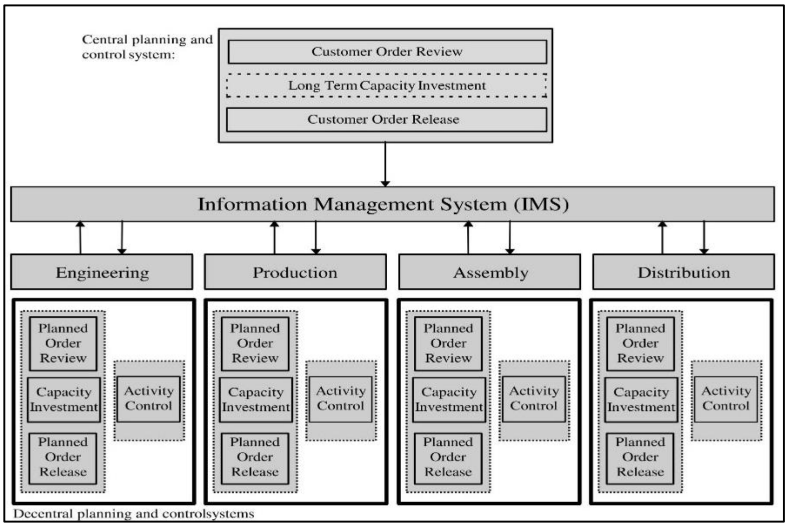


Figure 7: Production planning and control in agile production (Assen et al. 2000, p. 17)

Achieving such kind of production planning and control calls for the transformation from traditional hierarchy to flat organizational structure with decentralized units. Such organization empowers people for problem solving with the assistance of an efficient information system that provides the necessary linkage between the elements of the system (Assen et al. 2000, p. 17).

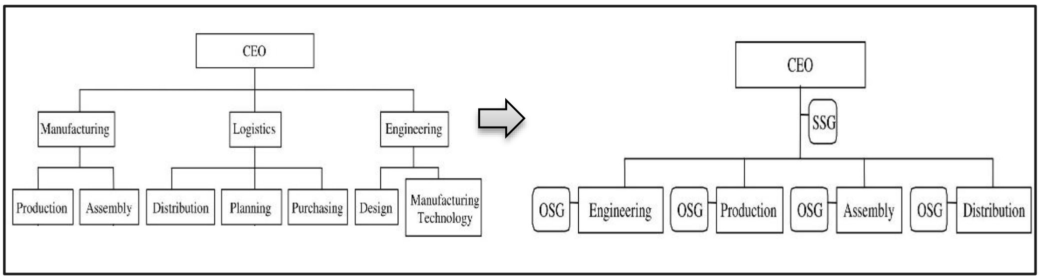


Figure 8: Hierarchy of an agile organization (Assen et al. 2000, p. 18)

The concept of decentralized planning was extended by (Wang, Koh 2010, p. 50), to include the whole supply network of a company. The system eliminates the central planning, and completely empowers each unit to have its own coordinating unit. Such system reduces the “bullwhip effect” in the network. The reason of this reduction is that it fosters a responsive pull system, where downstream operations coordinate with the upstream ones about the planned consumption on weekly, daily and shift basis. Forecasting is carried out in a generic form for strategic and tactical issues. These information is also transferred upstream, where the upstream company schedules the deliveries and communicates them back to the downstream company. This kind of planning is called collaborative production planning. Thus, the main role of the collaborative planning units is to communicate the results of the ERP with the upstream. This system, however, might pose some complexities in terms of the algorithms used. Furthermore, one of the key issues in this coordination is the transformation of information in almost real time. This necessitates the supplier to keep tracking orders and inventory levels, to produce up to date information, in addition to visualizing customer order status e.g. traffic light approach.

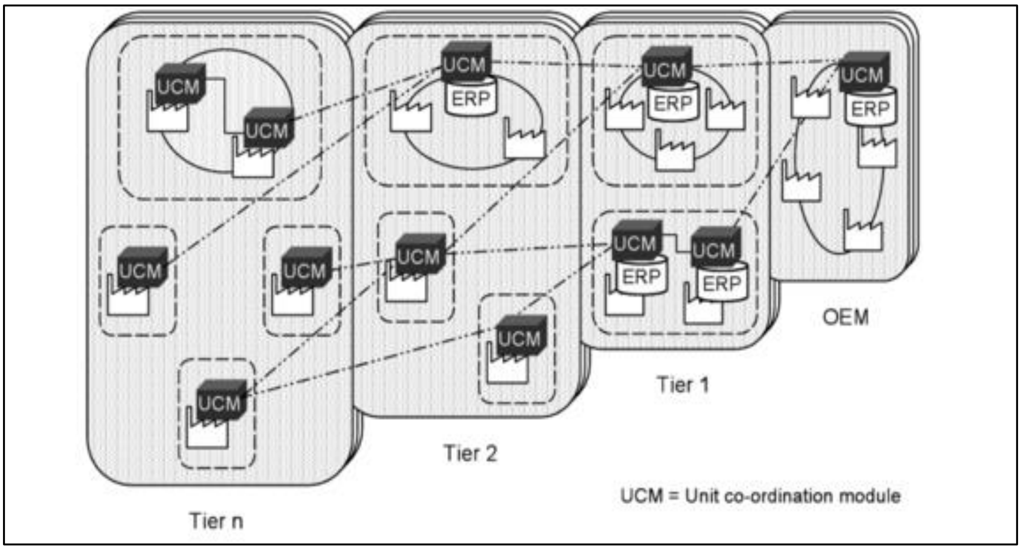


Figure 9: Decentred planning networks in agility (Wang, Koh 2010, p. 50)

2.2 Lean production

Lean production evolved from Toyota Production System (TPS), which was first published by Taiichi Ohno’s in the seventies, who spent three decades in Toyota Japan experimenting the TPS. His Just-in-time approach was influenced by Ford Production System and the American Supermarket. Lean production was first coined by (Krafcik 1988), and a couple of years later, it became global after publishing The machine that changed the world by (Womack et al. 1990), which presented the genesis and elements of leanness production. This was followed by several books e.g. (Womack, Jones 2003, pp. 16–19), (Drew et al. 2004, pp. 15–16) that tried to characterize lean production and expand its application span, however until present, there is a lack of clear definition and unanimously agreed measures of lean production in literature (Shah, Ward 2007, pp. 786–787). Lean production, is considered as a change platform that focuses on three main aspects. First is the operating system which deals with creating a smooth value stream of the product or service. Second is management infrastructure including the management system and applying performance management to have clear and measurable targets. The last one is the mindsets and behaviors of people involved including staff and managers. (Drew et al. 2004, pp. 18–20). Lean production aims at finding the source of losses and eliminating them. The loss sources are threefold: waste, variability and inflexibility. Waste is considered anything that adds no value but cost to the operations like overproduction, waiting time, transportation, over processing, inventory, motion and rework, in addition to losing the potential of using people's skills and contribution in improving processes. Leanness also attempts to eliminate variabilities, which are defined as deviations form standards. Additionally, leanness deals with inflexibility as a loss source to be eliminated, which will enable the organization to meeting changing customer requirements without causing additional costs (Drew et al. 2004, pp. 15–16). To achieve Leanness in an organization, five main principles should be understood thoroughly, as highlighted by (Womack, Jones 2003, pp. 16–19):

- **Value**: is the starting point of Leanness, and can be defined by the end customer. It is expressed with regard to specific products or services that should meet customer needs at a particular price and time through a dialogue with specific customers. Companies should define the value of their product from the eyes of their customers. The word “muda” is a Japanese word means waste, and the products that do not add a value are muda.

- **Value stream**: is defined as the set of all activities to be done in order to come up with a specific product or service. Three aspects to be involved in the value stream; the problem solving starting from the concept until start of production, the information management from receiving orders until delivery, and finally the physical transformation from raw material until the finished product. This has to be done for every product family. In creating the value stream, three types of actions are discovered, creating value activities, creating no value activities but inevitable with current technology and assets (type one muda), and finally creating no value and should be avoided (type two muda).
- **Flow**: Perhaps our instinct as humans leads us to batch and departmental thinking. However, these should be fought to achieve more efficiency. The principle of flow is that all activities from design, order, and production should happen in a continuous flow manner.
- **Perfection**: What stimulates perfection is transparency, where everyone at the work environment can see everything, and everyone is committed to continuously improve the work.
- **Pull**: The idea of pull, is that customer pulls the product from the manufacturer whenever needed. The contrary to this thinking is the push one where the manufacturer produces producers which often would be unwanted, and would be scraped afterwards. It is worth mentioning that the literature review shows non agreement degrading using the terms pull and push, and this will be discussed in a separate chapter.

Lean tools and practices

There are several tools and practices that are highly connected to lean production, and they have been recently combined in what was called “House of Lean”, which is an effective way to graphically present the contents of lean system in an organization as seen in **Figure 10**. It is worth mentioning that this house can be tailored to the needs of an organization, and thus every firm would have its own house of lean (Wilson 2010, p. 300).

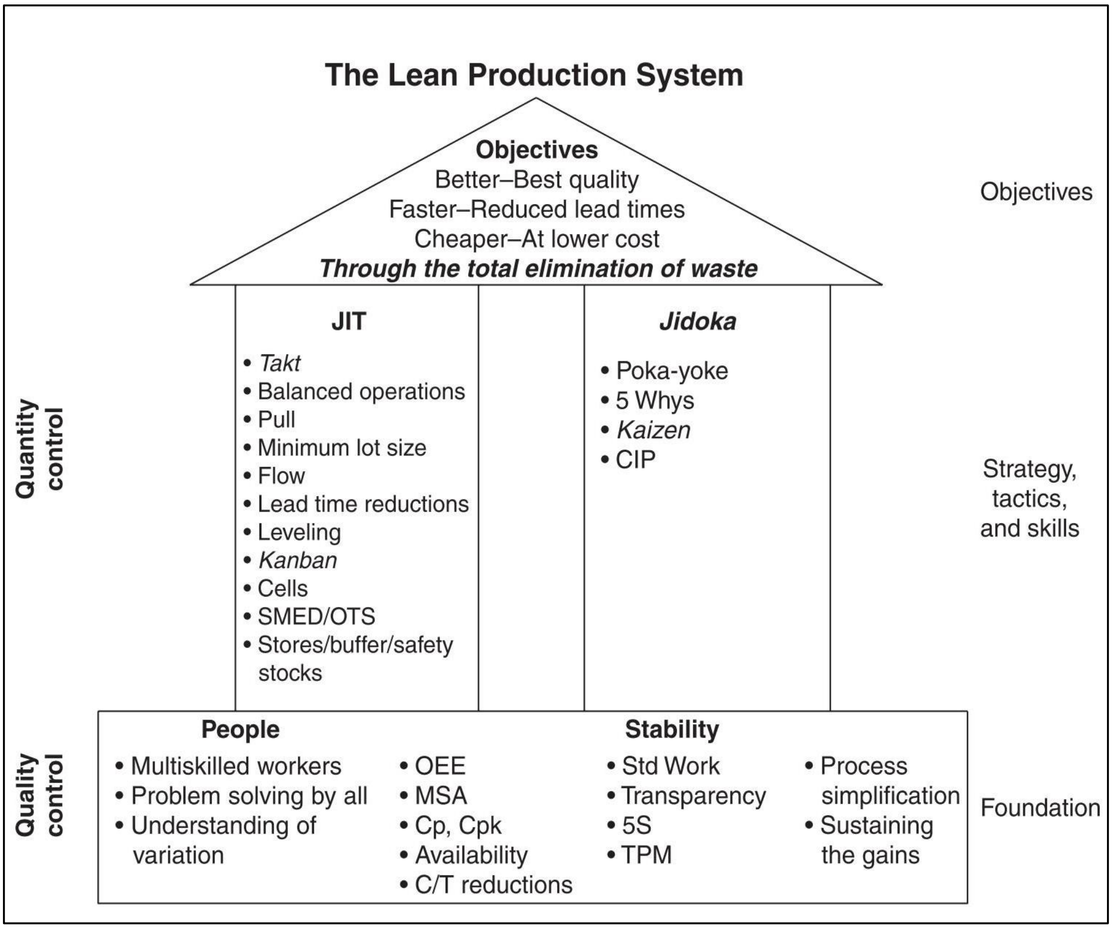


Figure 10 : House of lean production (Wilson 2010, p. 300)

2.3 Comparison between lean and agile production

This chapter will present the main similarities and differences between Lean and Agile production, and will present different views about the comparison between the two systems.

2.3.1 Different views

The debate between leanness and agility got famous after (Ben Naylor et al. 1999, p. 111) published a study calling for the integration of the two paradigms. The bottom line of the study was that Leanness and agility share common and similar characteristics. Yet, what distinguishes the two approaches the most is that agility strives for robustness and benefiting from demand fluctuation, whereas leanness calls for stability and smoothing of production. **Table 1** shows the comparison and the taxonomy that was highlighted by (Ben Naylor et al. 1999, p. 111).

Table 1: Leanness vs agility from literature by (Ben Naylor et al. 1999, p. 111)

Characteristics with equal importance in leanness and agility	Characteristics of similar importance	Main difference characteristics
Use of market knowledge, where the end user is highly emphasized and the supply chain in responsive. Existence of integrated supply chain, value stream or virtual corporation Reduction of Lead-time	Elimination of waste “muda”. e.g. non value added activities Rapid reconfiguration	Robustness, characterized by taking advantage of fluctuating demand in the case of agility Leanness avoids robustness through calling for stable demand and production levelling and smoothing.

Other researchers built on Naylor’s approach and expanded it to include the topics of market winner and market qualifier in relation to leanness and agility. The advocates of this approach (Mason-Jones et al. 2000, p. 55) show that the market winner for lean supplies is cost, where other factors such as quality, service level and lead time are considered as market qualifiers. In the case of agility, however, service level distinguishes itself as a market winner while cost, quality and lead time are market qualifiers.

The comparison of Leanness and Agility is very intense in literature, this is evident through a literature review done by (Agarwal et al. 2006, p. 212), that puts together all previous comparisons in literature in one table (**Figure 11**). The table shows that the two approaches are quite different in terms of market demand, product variety, product lifecycle, market winning strategy and forecasting mechanism. Yet, they share several parameters like seeking quality, reduced lead-time, and attempting to eliminate waste. The study also shows that a merge between the two approaches would harvest the benefits of both. This merge will be the focus on the next chapter.

Distinguishing attributes	Lean supply chain	Agile supply chain	Leagile supply chain
Market demand	Predictable	Volatile	Volatile and unpredictable
Product variety	Low	High	Medium
Product life cycle	Long	Short	Short
Customer drivers	Cost	Lead-time and availability	Service level
Profit margin	Low	High	Moderate
Dominant costs	Physical costs	Marketability costs	Both
Stock out penalties	Long term contractual	Immediate and volatile	No place for stock out
Purchasing policy	Buy goods	Assign capacity	Vendor managed inventory
Information enrichment	Highly desirable	Obligatory	Essential
Forecast mechanism	Algorithmic	Consultative	Both/either
Typical products	Commodities	Fashion goods	Product as per customer demand
Lead time compression	Essential	Essential	Desirable
Eliminate muda	Essential	Desirable	Arbitrary
Rapid reconfiguration	Desirable	Essential	Essential
Robustness	Arbitrary	Essential	Desirable
Quality	Market qualifier	Market qualifier	Market qualifier
Cost	Market winner	Market qualifier	Market winner
Lead-time	Market qualifier	Market qualifier	Market qualifier
Service level	Market qualifier	Market winner	Market winner

Figure 11: Comparison of lean, agile and leagile production by Agarwal, Shankar et al (Agarwal et al. 2006, p. 212) based on (Naylor et al. (1999), Mason-Jones et al. (2000), Olhager (2003), Bruce et al. (2004).

Furthermore, a comparative study conducted by (Shahram et al. 2011, p. 55) concludes that both leanness and agility has pros and cons. Whilst lean supply chain focuses on satisfying customer’s demand with the lowest price, agility calls for flexibility, promptness and innovation as well. Thus, the starting point to achieving agility is being lean. This shows congruence with what was proposed by (Christopher, Towill 2001), that Lean underpins the implementation of agile strategy, and it is a pre-requisite to being agile.

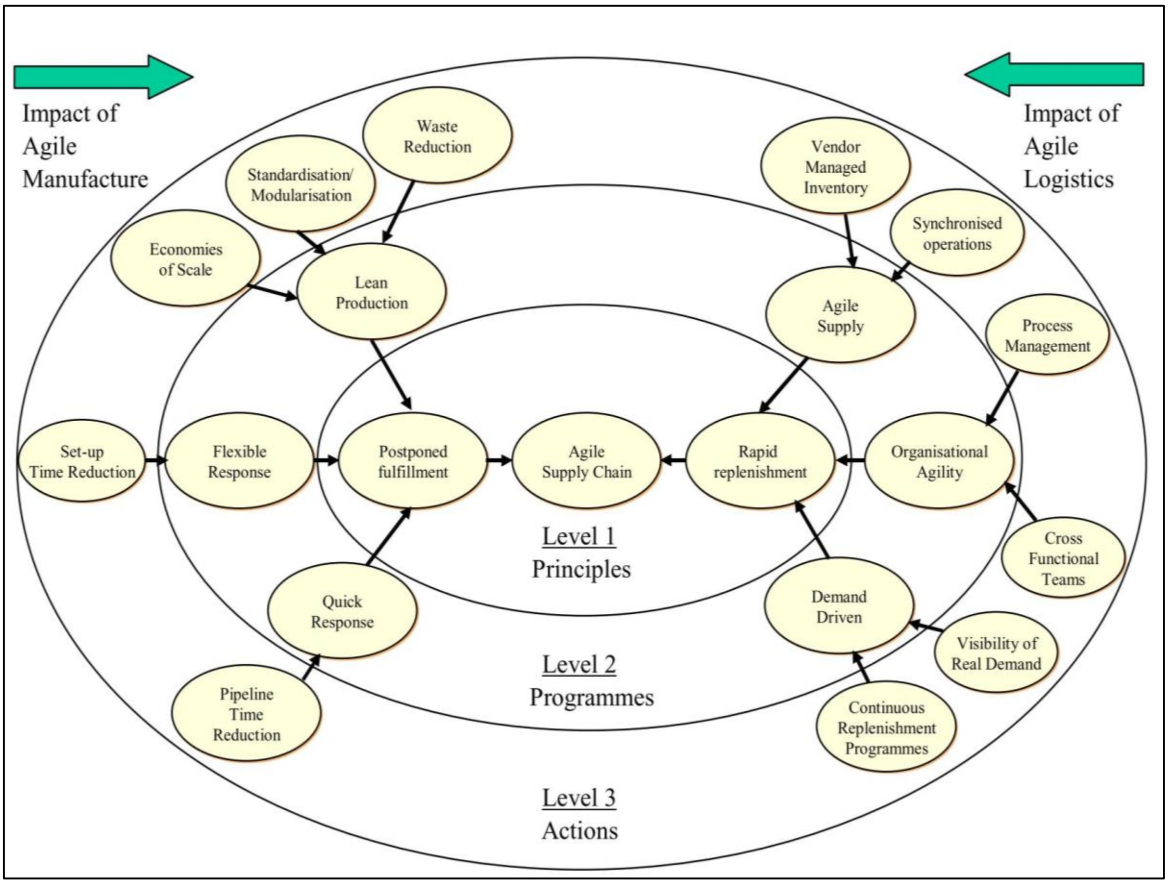


Figure 12: Leanness is contributor to agility (Christopher, Towill 2001)

Lean production in literature is seen to be antecedent to agile production, as pointed out by (Narasimhan et al. 2006, p. 444). The researcher sought to compare the performance of companies who implement Leanness, and others who are completely agile in terms of performance dimensions i.e. cost, flexibility, delivery time and quality, in many US companies. The results of her study came in accord with what other researchers have suggested, that flexibility and lead time are the distinguishing factors of agile firms. In fact, agile companies showed a noticeable advancement rates in these two factors as compared to lean ones, while resemblance in performance was observed in other factors such as quality. Still, cost was the distinguishing factor in Leanness.

The results obtained by (Narasimhan et al. 2006, p. 444) were further investigated by (Hallgren, Olhager 2009b, p. 991) through a survey study that focused on European companies in Austria, Germany , Sweden and other international ones. The results of the study show that flexibility and cost were the major distinguishing factors of the two paradigms, in terms of companies' performance; agile companies outperform their lean counterparts in product and volume mixes, although leanness has a positive effect on flexibility. Nevertheless, lean companies showed superiority in cost-wise than the agile ones.

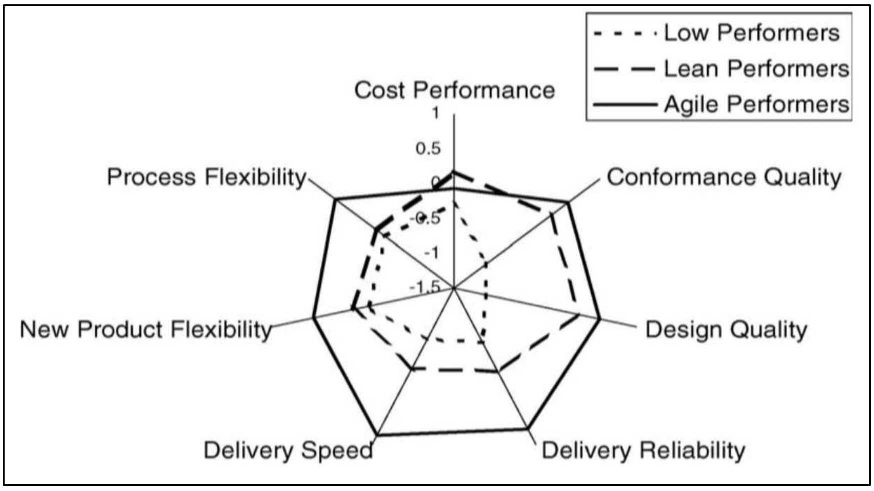


Figure 13: Performance of lean and agile companies in the US (Narasimhan et al. 2006, p. 448)

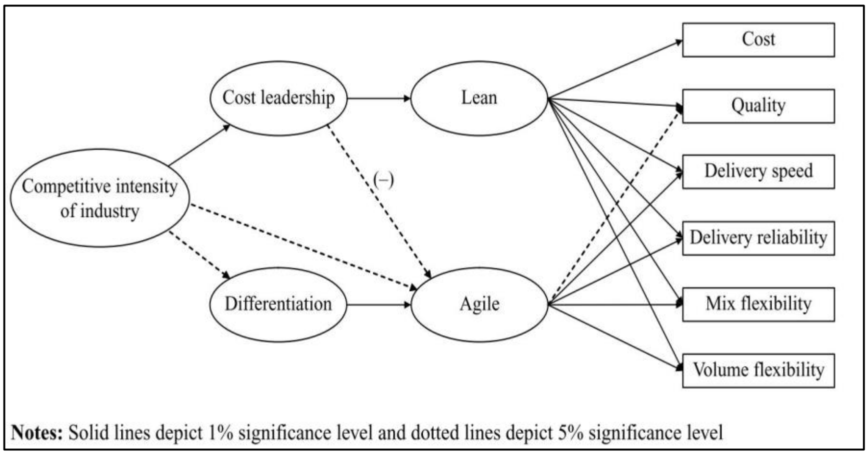


Figure 14: Drivers and impact of lean and agile on companies (Hallgren, Olhager 2009, p. 988)

With all these variations between Leanness and Agility, the steppingstone of settling on the right supply chain strategy should be based on the type of product to be produced. A study done by (Vonderembse et al. 2006, p. 230) shows three types of products in relation to Lean, Agile and Leagile production.

- **Standard Products**: These products have stable market, and demand for these can be accurately forecasted. Such products have high cycle time. The environment of operations will not encounter lots of variations, and the company have long term relations with suppliers. This kind of products is highly associated with Lean mindset. E.g. small appliances and tools for home uses.

- **Innovative Products**: *"are new products that require sophisticated design and/or manufacturing capabilities. They often represent breakthrough in design".* Such products should be dealt with through agile mindset. However, when the demand of these products surges, and competitors manage to imitate, then they should be done in a lean way e.g. IBM products.
- **Hybrid products:** Such products encompass both standard products and complex ones. Automobile is a good example of that. In such environments both Lean and Agile approaches should be present, through a combination called leagility.

The choice to opt for leagility in a company is driven by the desire of the firm to be both cost efficient and flexible performer, for instance, if a company wants to combine lower cost and differentiation strategies, then leagile is vital (Hallgren, Olhager 2009b, p. 992). Other authors show that, every supply chain has lean and agile interaction, due to the existence of several important synergies between the two mindsets as highlighted by (Mukhopadhyay 2015, p. 367). For instance:

- Agility strives for customer enrichment, which can be obtained through value identification of Leanness.
- Agility calls for enhanced competitiveness, which can be obtained through perfecting the flow of material and info.
- Agility utilizes IT and technology, which help improve communication within the organization and divisions as required by Leanness.
- Agility strives for leveraging employees and information, which can be achieved by utilizing employees' skills through Leanness.

The coexistence between leanness and agility can also be applied in multi-unit corporate enterprise, where a decoupling point will exist within the company boundaries to separate lean and agile parts (Krishnamurthy, Yauch 2007, p. 599).

In this chapter, different views on leanness and agility were reviewed, and it was observed the two systems hold similarities and contradictions as well. This will be summarized in the following two tables:

2.3.2 Summary of the comparative study

To provide a comprehensive comparison between leanness and agility, literature was analyzed, the result was that the two systems share several common characteristics, but also share several differences. **Table 2** summarizes the main differences between leanness and agility, and **Table 3** presents the main similarities between the two paradigms.

Table 2: Differences between leanness and agility based on literature

Characteristics	Differences
Robustness	Agility calls for robustness characterized by taking advantage of fluctuating demand, while leanness avoids robustness by calling for stable demand and production levelling and smoothing (Ben Naylor et al. 1999, p. 111).
Market winners and qualifiers	The market winner for lean supply chain is cost, while other factors such as quality, service level and lead time are considered as market qualifiers. In the case of agile production, however, service level distinguishes itself as a market winner, while cost, quality and lead time are market qualifiers (Mason-Jones et al. 2000, p. 55).
Demand nature	Demand is predictable in leanness, while in agility it is volatile and non-predictable. In addition, agile organizations should be more sensitive to customer demand (Hormozi 2001, p. 132,143), (Agarwal et al. 2006, p. 212).
Handling variations	Agile supply has superior flexibility performance in handling situations of mixed volumes and products (Hallgren, Olhager 2009b, p. 991), (Ben Naylor et al. 1999, p. 111).
Product nature	Leanness is suitable for standard products, lower varieties, with stable market and high cycle time, while agility is suitable for new innovative products (Mason-Jones et al. 2000, p. 56), (Vonderembse et al. 2006, p. 230).
Product development	Product development in agile production is significantly shorter than in lean production; it takes weeks rather than months as is the case with leanness (Sharp et al. 1999, p. 157).
Cost	The dominant cost in agile production is the marketable cost, while the dominant one in leanness is the physical cost (Agarwal et al. 2006, p. 212).
Companies' cooperation	The degree of cooperation between companies is very high in agile production, while it is considered low in leanness (Hormozi 2001, p. 132,143).

Suppliers	Leanness establishes long term relations with fewer suppliers, while agility involves a high number of suppliers with short term relations (Sharp et al. 1999, p. 157).

Table 3: Synergies and similarities between leanness and agility based on literature

Characteristics	Synergies and Similarities
Market knowledge	Both paradigms call for the use of market knowledge, with high emphasis on the end user and the supply chain responsiveness (Ben Naylor et al. 1999, p. 111).
Integration of supply chains	The existence of integrated supply chain, value stream or virtual corporation is vital in both paradigms, although agility calls for virtual collaboration which makes it possible to access global resources(Ben Naylor et al. 1999, p. 111), (Yusuf, Adeleye 2002, p. 4560)
Lead time reduction	Reduction of lead time has equal importance by both paradigms (Hormozi 2001, p. 132,143),(Ben Naylor et al. 1999, p. 111), (Agarwal et al. 2006, p. 212)
Waste elimination	Elimination of waste (non-value added activities), is essential in leanness and desired in agility (Hormozi 2001, p. 132,143)(Ben Naylor et al. 1999, p. 111) ,(Agarwal et al. 2006, p. 212).
Rapid reconfiguration	Rapid reconfiguration is important in both paradigms, although it is more desired in agility (Hormozi 2001, p. 132,143),(Ben Naylor et al. 1999, p. 111).
Communication	Both paradigms call for leveraging employees, using IT for enhancing communication (Mukhopadhyay 2015, p. 367), (Mason-Jones et al. 2000, p. 56).
Employees' skills	Both paradigms exhibit the need for skilled employees, although in agility the need is greater (Hormozi 2001, p. 132,143).
Organizational structure	Both paradigms call for flat organization, although in agility, organizations should also be nimble and empowered to change in response to several situations (Sharp et al. 1999, p. 157,163).
Material flow	Both paradigms strive for perfecting flow of material to achieve enhanced competitiveness (Mukhopadhyay 2015, p. 367).
Shared methods and tools	This involves the extensive use of similar concepts like Kaizen (Continues Improvement), TPM (Total Productive Maintenance) , TQM (Total Quality Management) with equal importance, in addition to the use of JIT, concurrent engineering, quick changeover, cross functional teams by both paradigms (Lotfi et al. 2013, p. 3)(Katayama, Bennett 1996, p. 22).

2.4 Compatibility study of lean and agile production

The aim of this chapter is to investigate the compatibility of leanness and agility, and the possibility to integrate the two approaches from a literature point of view. First, the agility of the lean production will be investigated and analysed according to lean literature, then, several applicable agile tools with leanness will be illustrated.

2.4.1 Analysis of lean tools in supporting agility

Flexibility is seen as an integral part of agility, and achieving high degree of flexibility is the main focus of the agile system (Rabitsch, Ramsauer 2015, p. 4). The aspect of flexibility and agility in lean production has been the subject of controversy between researchers during the last decade. Whilst some researchers (Drew et al. 2004, p. 41), (Hayes, Pisano 1996, p. 36),(Boyle, Scherrer-Rathje 2009, p. 349) advocate that leanness can support agility, others (Purvis et al. 2014, p. 102), (Ben Naylor et al. 1999, p. 112), (Chahal 2012, p. 407,408) show the opposite, and that the lean system should be enhanced with other strategies or systems. This sub-chapter will focus on lean tools that support agility. Therefore, the contents of the house of lean will be investigated to know which tools support agility, and which ones should be tailored for agility. A question can be raised here of what types of flexibility as part of agility, exist in manufacturing and how leanness contributes to them. (Gerwin 1993) categorized four types of manufacturing flexibilities: “Banking”, which means holding extra stock in case of emergencies, “Adaptation” based on customer demand, “Reduction” through reducing uncertainty by better forecasting or long-term relations with supplier, and finally “Redefinition”, which calls for creating the need of flexibility as a means of competitive advantage. Although the type “Banking” was seen by (Boyle, Scherrer-Rathje 2009, p. 363) as a common flexible tool that is not aligned with leanness, the house of lean affirms that having stocks and buffers is in congruence with leanness (Wilson 2010, p. 300).

Gerwin's strategy	Tools and techniques
Adaptation	Multifunctional employees
Adaptation	Focused factory
Adaptation	Reduced setup times
Adaptation	Kanban
Banking	Overcapacity
Adaptation	Group technology
Adaptation	TPM
Reduction	Communication improvement
Reduction	Forecasting
Adaptation	Kaizen
Banking	Capacity variation
Adaptation	One piece flow
Adaptation	Total quality control
Adaptation	Quality circles
Banking	Stock building
Adaptation	Just-in-time purchasing
Adaptation	5S
Adaptation	Value stream mapping
	Rest
	Sum

Figure 15 : Most used tools for manufacturing flexibility by companies (Boyle, Scherrer-Rathje 2009, p. 362)

To investigate the issue of flexibility and agility in lean production, the house of Lean (chapter 2.2) was referred to, and its contents were investigated in response to flexibility. Five categories were identified for each item in the house of lean; agility supportive, pre-requisite, should be tailored to agility in accordance to literature, neutral, and negatively effect on agility.

Lean basic tools that support agility:

The house of lean contains several tools and practices that support agile production, due to their positive impact on flexibility. These tools and practices are described as follows:

- Supermarket: Supermarket is "intermediary stocks needed to buffer production, and must be defined in terms of their location, quality, and replenishment method". It is an inventory to be replenished by the upstream operations. (Wilson 2010, p. 307). Supermarket is used, and achieves flexibility when customer lead time is shorter than the product lead time (Drew et al. 2004, p. 16,41). It is categorized as banking flexibility (Boyle, Scherrer-Rathje 2009, p. 357).
- Over capacity: Categorized as banking flexibility (Boyle, Scherrer-Rathje 2009, p. 357).

- Visual management, andon, and 5S: Ensuring transparency and the effective movement of staff, which makes it less complicated to move people from one workplace to another (Drew et al. 2004, p. 16,41), and categorized as adaptation flexibility (Boyle, Scherrer-Rathje 2009, p. 357).
- Standardization: Standards should be seen as a way to ensure training and continuous improvement. As processes are improved, standards need to be updated, and the process continuous. Standardization makes it easier to implement flexible labour system because where employees can be switched between different tasks or working cells, which facilitates companies' prompt responsiveness to fluctuations in customer demand (Drew et al. 2004, p. 16,41). It is categorized as adaptation flexibility (Boyle, Scherrer-Rathje 2009, p. 357).
- Lead time reduction: Reducing the lead time enables the company to respond faster to abnormalities, for instance, when changing the product mixes. For instance, if it takes a company 6.2 days to ship a product before adopting lean, and 1.2 days after adoption. If the customer decides to change the product mix. In the case of high lead-time, customer should first wait the items that are in production until they finish, then changing the mix and produce and ship the new mix. Altogether, this would take 14.4 days, and due to higher changes of uncertainty in non-lean systems, you would add another day for safety issues, so customer is told 15 days. On the other hand, in lean system customer would receive the new mix only in 2.4 days, and you would not need to add time for safety as in non-lean situation. This type of flexibility called "ability to respond to abnormalities more quickly" (Wilson 2010, pp. 74–75). (Wilson 2010, pp. 74–75). It is categorized as adaptation flexibility (Boyle, Scherrer-Rathje 2009, p. 357).
- SMED (Single Minute Exchange of Dies): Reduction of set up time using SMED is categorized as adaptive flexibility (Boyle, Scherrer-Rathje 2009, p. 357)
- Multifunctional Employees: Employees should be trained to perform a variety of tasks/jobs and they are cross-trained so that they can fit to other tasks if necessary (Forza 1996, p. 51). This achieves adaptation flexibility (Boyle, Scherrer-Rathje 2009, p. 357),(Hallgren, Olhager 2009a, p. 6).
- Total Productive Maintenance (TPM): TPM contributes in increasing the availability and reducing uncertainties, and helps be flexible to changes in production volumes (Hallgren, Olhager 2009a, p. 6,7). It is categories as adaptation flexibility (Boyle, Scherrer-Rathje 2009, p. 357).

- One piece flow, minimum lot size: Is considered the key to flexibility, and prompts responsiveness; when reducing the lead time for the a lot or piece, discovering mistakes becomes faster (Wilson 2010, p. 67). It is categories as adaptation flexibility (Boyle, Scherrer-Rathje 2009, p. 357).
- Kaizen and communicating improvements: It is categories as adaptation flexibility (Boyle, Scherrer-Rathje 2009, p. 357).
- Poka-Yoke: It supports mistake proofing, and thus, enhances the robustness of processes (Wilson 2010, p. 65). It is categories as adaptation flexibility (Boyle, Scherrer-Rathje 2009, p. 357).
- Cellular manufacturing: The use of cellular manufacturing is important in leanness to achieve higher level of flexibility necessarily for today's production. To ensure achieving flexibility and responsiveness, Value Stream Mapping and Simulation can be used to investigate the current situation, and find the optimal cell design. Thus, cellular manufacturing when incorporated with Leanness can give more flexibility to the system in case of demand changes. Consequently, planning the workforce on site will be easier and faster, and less amount of employees will be required (Charoensiriwath 2011, p. 325). The big advantage of cell is that it lowers down the walking distance, and that people can be used for various activities in an assembly cell, which will allow to cope with more demand variations. Of course, this will necessitate multi-functional workers (Wilson 2010, p. 69). **Figure 16** shows a layout for a cell, where only two workers are required to manage 7 stations, through a circular movement.

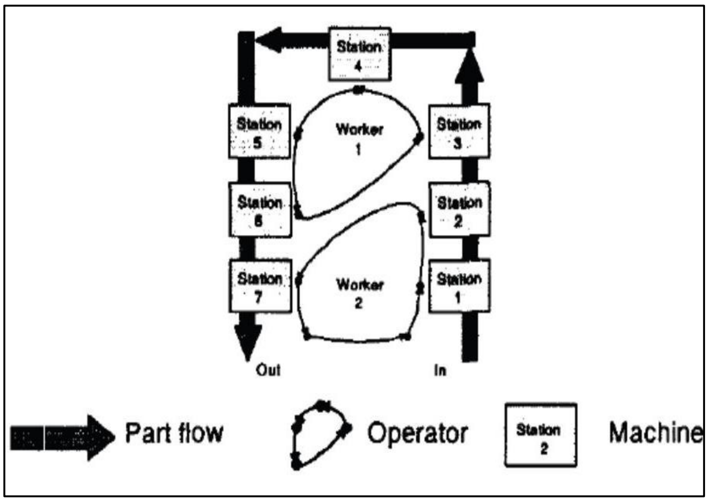


Figure 16 : Lean manufacturing cell (Charoensiriwath 2011, p. 323)

Pre-requisite lean tool for agile production

Although many tools within the house of lean support agility, other tools are pre-requisites since they support achieving the other tools, but not directly associated with agility according to literature. For example, machines and resources should be available to carry out lean tools. Furthermore, “understanding the variation” is the base for responding to problems; if managers and employees who are response for these problems, do not understand problems, the solution will not be prompt what so ever. Same goes for “problems solving by all”; if the change culture was not practiced by all, neither leanness, nor agility can be realized (Wilson 2010, p. 60).

Neutral leanness contents

These tools could not be directly linked to agility through literature, and thus they were classified as neutral. Such tools are Process capabilities (Cp, Cpk), sustaining the gains, 5 Whys, MSA (Measurement System Analysis), and OEE (Overall Equipment Efficiency).

Lean basic tools that should be tailored to agility

The analytical study of the lean tools that should be tailored for agility can be described as follows:

- Towards carful elimination of waste:

One of the traditional lean concepts is the elimination of waste as shown in house of lean (Wilson 2010, p. 300). In flexible lean supplies, the aim to eliminate waste should still be emphasized. However, careful consideration of capacities and stocks should be examined to have a robust system susceptible to changes in customer demand (Ben Naylor et al. 1999, p. 111). Thus, in this master thesis we suggest the name carful elimination of waste.

- Towards scenario based takt-time and line balancing:

Due to the variations in demand, the planning system should enable the operational takt-time to be recalculated on weekly basis, or more frequent basis, and in case of changes due to increases in demand, swift reallocations can be undertaken e.g. planed addition of a worker to the cell. This should be supplemented by the right level of supermarket to cope with short term fluctuations (Bell 2006, p. 126). Hence, different scenarios should be planned beforehand (Rabitsch, Ramsauer 2015, p. 4). Furthermore, the uncertainties that exist in flexible environments call for using models that are more robust in line balancing, the reason why some researchers developed scenario based planning techniques based on the worst case analysis (Xu, Xiao 2011, p. 313) to achieve some agility.

- Towards adaptive level production:

Usually levelling production aims at finding a fixed pattern over the leveling period. Nevertheless, changes in demand mixes are more common nowadays, and thus the system should be robust enough to react to such changes. This means, working pattern should be adapted. In such situations, forecasting is important to decide the patterns and their periods (Bohnen et al. 2011, p. 250). One of the key issues to facilitate this adaptation is to have set-up friendly production facilities such as CNC or flexible manufacturing systems, this would enable the company to modify the production sequence more easily e.g. A,B,E,D,C to A,A,D,E (Schönsleben 2007, pp. 317-315).

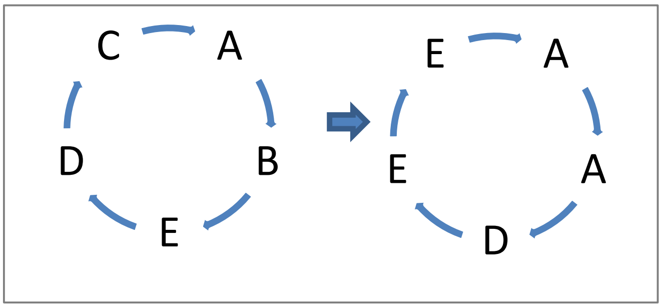


Figure 17 : Adaptive cyclic production

- Towards group technologies in production cells:

Although cellular manufacturing is supportive to agility, in some cases, it is difficult to transfer from a functional layout to product oriented layout. For example, in the case of having huge machines, or product nature that is totally unstable, or even when it is hard to have multi-skilled operators. The solution is to use group technology where the physical layout does not change in response to the change in products. This is done through assigning products to machines using bar codes and IT technologies, thus changes in products can easily be reconfigured with a virtual rout (Prince, Kay 2003, p. 312,306). Hence, virtual cells are seen as temporary cells, used when the resources i.e. people, machines, and handling can't be group in one cell (Nomden et al. 2005, p. 41). A conceptual model of a virtual production cell can be seen in **Figure 18.** The figure shows how MPS(Master Prodution Schedule), and MRP(Material Requirement Planning), and SFC(Shop Floor Control) and interconnected top down and bottom up.

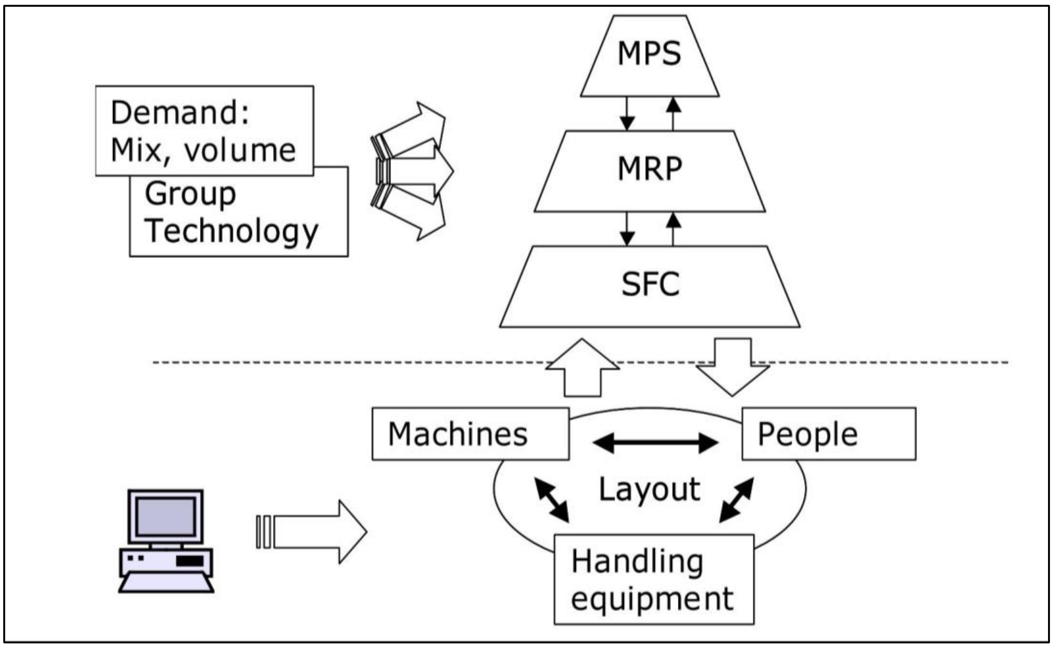


Figure 18: Virtual production cell (Nomden et al. 2005)

- Towards tailored Kanban e.g. BK-CONWIP:

Kanban is one of the most common ways companies rely on to improve flexibility in leanness as presented earlier (**Figure 15)**. The demand variability in multi-stage lean production systems, if failed to be tackled with the right pull strategy, would lead to a high WIP and lower throughput. The bottom line of this sub chapter is that different pull system strategies emerged during the last two decades (see **Figure 19**). Some extensive simulation and modeling studies proved that the hybrid strategies can achieve higher amount of flexibility in multistage and multi product situations, as seen in (Onyeocha et al. 2015, p. 465).

Table 4: Comparison between pull systems

Pull system	Advantage	Disadvantage
Kanban	Control the number of parts in a stage (Liberopoulos, Dallery 2000, p. 335).	if demand and flow was not constant, poor performance in fluctuated demand situations (Dallery, Liberopoulos 2000, p. 370).
CONWIP	Better than Kanban as it can be applied in a broader variety of	Accumulation of parts before the bottleneck, low performance in

	production situations (Spearman et al. 1990, p. 883).	long production line (Geraghty, Heavey 2005, p. 438).
BaseStock	Demand is responded rapidly (Liberopoulos, Dallery 2000, p. 333)	More WIP, and poor coordination between stages (Takahashi, Nakamura 2000, p. 244).
Hybrid Strategies e.g. BK CONWIP	Achieve higher flexibility in multistage and multi product situations (Onyeocha, Geraghty 2012).	Complexity and high Optimization, applicability. (Source: Expert Interviews, personal correspondences with the creator of the method)

The figure bellow classifies the pull strategies according to the number of control parameters they contain based on literature from (Onyeocha, Geraghty 2012), (Boonlertvanich), (Baynat et al. 2010, p. 4231), (Dallery, Liberopoulos , George 2000), (Takahashi, Nakamura 2000, p. 249), (Bonvik, Gershwin 1996), (Karrer 2012a, p. 21):

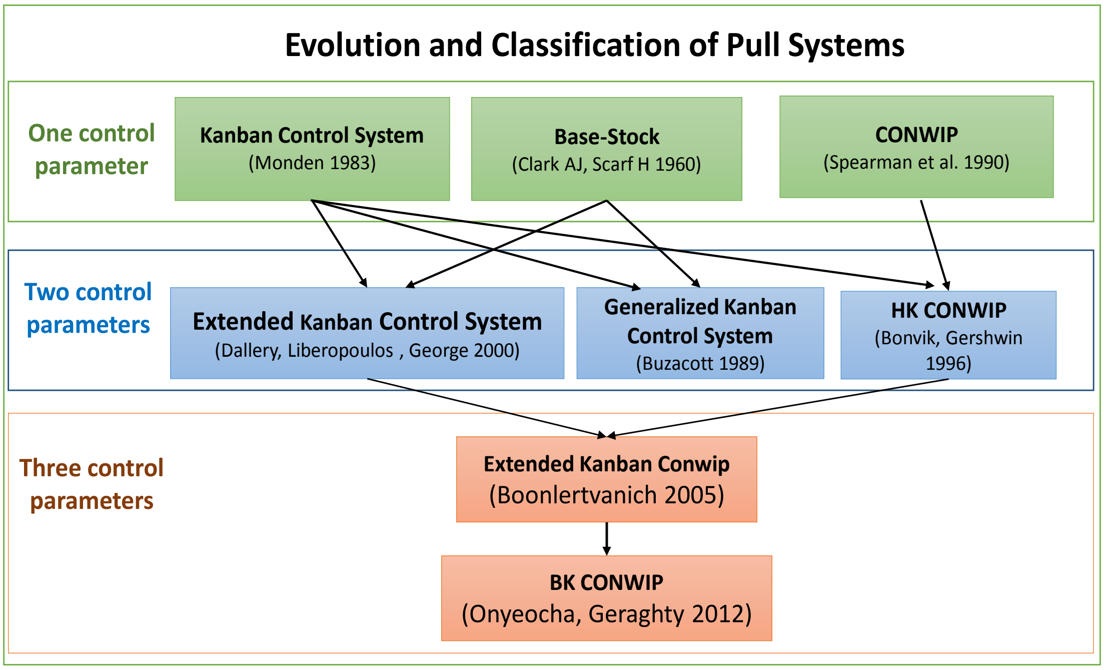


Figure 19: Evolution and classification of pull control systems (own illustration)

To explain the notion, each control strategy will be studied details based on literature.

Kanban Control Strategy KCS:

Kanban strategy works such that production is authorized when a part leaves the inventory. In other words, inventory is replenished once part is removed from inventory. Thus, the only control parameter is the number of Kanbans per loop. Kanban control strategy is illustrated in **Figure 20**. The disadvantage of Kanban is that it does not work properly if demand and flow were not constant. For instant, one would require high number of Kanbans to respond to surges in demand, and in the same time, low number of Kanban cards to reduce inventory cost. This leads to poor performance in fluctuated demand situations (Dallery, Liberopoulos , George 2000, p. 370). Other disadvantage of Kanban is that when customer demand arrives, it is not transmitted immediately to the whole system, and thus the system does not respond directly to the demand, since the coordination happens only between one stage and the previous one. In Kanban strategy, the products, the production authorization and Kanbans are all coupled. On the other hand, the advantage of Kanban is that the number of parts in a stage is limited to the number of Kanban cars in that particular stage. This controls the WIP in that stage(Liberopoulos, Dallery 2000, p. 335).

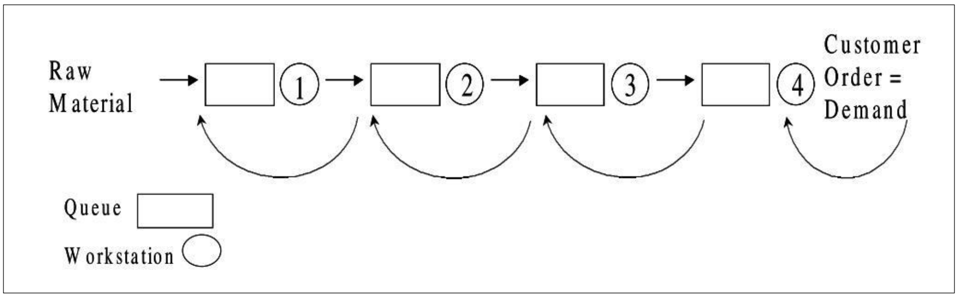


Figure 20 : Kanban strategy as explained by (Marek et al. 2001)

CONWIP control strategy:

Several alternatives to Kanban were proposed in pulling systems, one of these called CONWIP (Spearman et al. 1990, p. 883), which can be applied in a broader variety of production situations. The difference between Kanban and CONWIP can be shown through looking at the control strategy of CONWIP (**Figure 21**). In Kanban, WIP is controlled between every two stations such that Kanban cards constitute an authorization of production, while in CONWIP only the overall system WIP is controlled and from its name (Constant Work in Process), the overall WIP will not exceed a pre-defined value. Controlling WIP is crucial in production systems, and when large amount of WIP exists in the system, certain degree of flexibility is lost in the system (Marek et al. 2001, p. 922). Controlling work in process in a line through CONWIP is achieved as follows: when an order arrives for a finished product, the replenishment happens such that an order is sent back to the first stage of the line, then the flow of material is initiated from the first stage of the line (Villa, Taurino 2013,

p. 958). In CONWIP, if a stage failed, number of parts going downstream will decrease, and some parts will accumulate before the failed stage until there are not CONWIP cards in COWIP buffer any more, then the system stops (Boonlertvanich, p. 32). A disadvantage of such system, is that when the production line is too long, the response of such system will be slow, since information is transferred directly to the first stage. In addition, there is loose communication between stages and the accumulation of parts prior to the bottleneck compromises its benefits (Geraghty, Heavey 2005, p. 438).

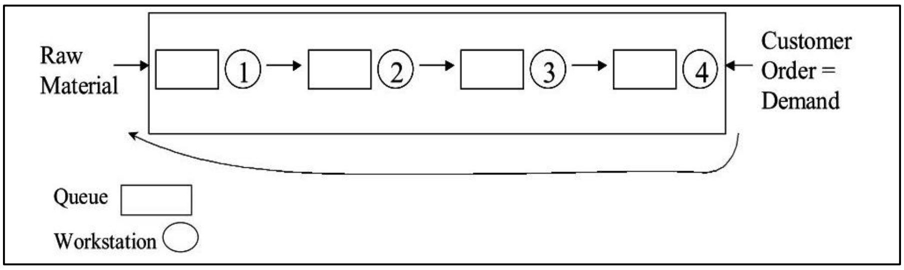


Figure 21: CONWIP strategy as explained by (Marek et al. 2001)

Nevertheless, a study conducted by (Geraghty, Heavey 2010), shows that CONWIP outperforms Kanban control strategy in the case of variable demand, and it achieves lower inventory and shorter lead time. The same study, however, shows better performance in the case of hybrid strategies than CONWIP, which will be discussed next.

Basestock control strategy:

One of the oldest pulling system strategies called Basestock, it was coined by Clark AJ, Scarf H (1960), and it works such that when the demand arrives, demand cards are sent to every stage in the line to authorize production in the same time. In addition, the inventory level in all stages are initialized to a predefined numbers (Villa, Taurino 2013, p. 437, 450). The advantage of this strategy is that demand is responded rapidly. On the other hand, it does not control the amount of items entering the system, and poor coordination between stages was observed as well (Liberopoulos, Dallery 2000, p. 333). In other words, it causes more WIP in stages (Takahashi, Nakamura 2000, p. 244).

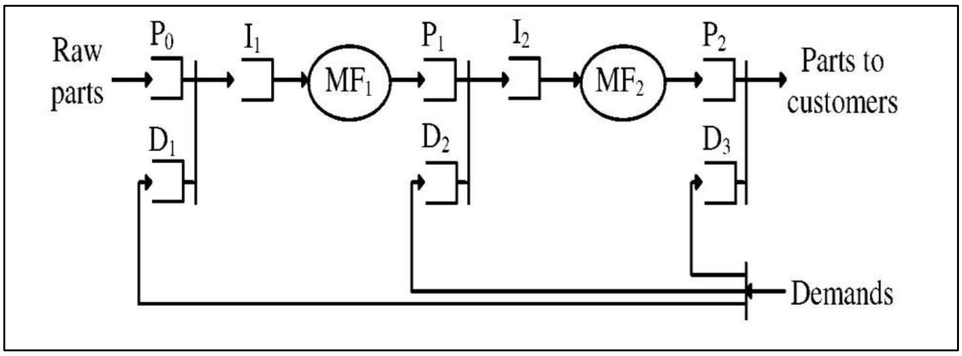


Figure 22: Base stock strategy (Liberopoulos, Dallery 2000, p. 332)

A study was conducted by (Takahashi, Nakamura 2000, p. 246,247) addressed the base stock control, which they referred to as "concurrent ordering", in comparison to Kanban. The result of a simulation study shows that to react to unstable demand, the best solution is to switch between Kanban and Basestock to decrease total WIP and keep waiting time constant. The reason of their suggestion was that both Kanban and Basestock showed superiority in some demand interarrival mean conditions. Hence, they suggested a system which transfers between Kanban and Basestock to achieve the best performance in response to demand data as shown in **Figure 23**.

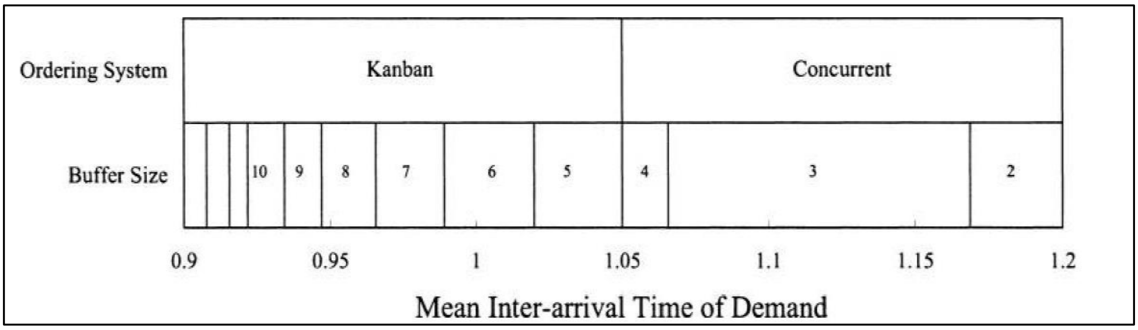


Figure 23: Agile changing order system based on demand (Takahashi, Nakamura 2000, p. 250)

One important point that should be raised here, is that in all the basic systems we presented, the existence of buffers was evident, although we have seen that leanness considers inventory as a waste, supporting JIT means that buffers should be used to absorbed changes in demand, even in stable demand conditions. Indeed, the amount of buffer should be as minimal as possible, and trade-offs should always be made when allocating the system parameters (Takahashi, Nakamura 2000, pp. 245–247).

In the above mentioned situations, we saw that only one approach dominates, even in the suggestion of (Takahashi, Nakamura 2000, p. 248), only one approach is applier at a point of time depending on mean inter arrival time of demand to achieve agility. However, other researchers merged different approaches to come up with a superior system in case of volatile demand (eg. BK CONWIP).

Hybrid Control Strategies (HK CONWIP, BK CONWIP, EKCS):

Some hybrids were suggested in literature which provide better inventory performance, one of these is the hybrid Kanban and Base Stock, called EKCS (Extended Kanban Control System) by (Dallery, Liberopoulos , George 2000, p. 370), which depends on Basestock - target inventory of finished parts in every stage, where demand is transferred to all stages, and Kanban cards as well. However, in the EKCS, Kanbans are only used to allow the transfer of finished parts downstream, and is not involved in the transfer of demands upstream, as in classical Kanban. The author of this method suggests that the method allows more flexibility and robustness than traditional Kanban.
Another older method was also proposed called, Generalized Kanban Control Strategy GKCS, coined by Buzacott, 1989 which also depends on both base stock and Kanban. These two variants of Kanban differs than traditional KCS in the fact that demand and Kanban move back separately to the input of the stage. The difference between the two emerged systems is that in GKCS the release of a Kanban happens just when the part enters the output buffer of a stage, while in Classical Kanban Control and Extended Kanban Strategy, the release of Kanban happens only when a finished part at a stage is sent to the next one. (Baynat et al. 2010, p. 4227).
Furthermore, there are two types of cards allocation in Kanban called Dedicated Kanban “D Kanban” and Shared Kanban ”S Kanban”. The former dedicates cards according to the kind of product to be produced, and the latter share the Kanbans between different parts. Shared Kanban cannot be applied on classical Kanban Strategy. However, when applying shared Kanban Strategy on the two variants of Kanab (GCKS, EKCS), the two systems show different behavior, and more flexibility (Baynat et al. 2010, p. 4247). In this thesis, the main focus in this chapter will not be on the shared and dedicated Kanban, but we aimed to show different Kanban types existed in literature, and what variations do they embody in terms of flexibility.

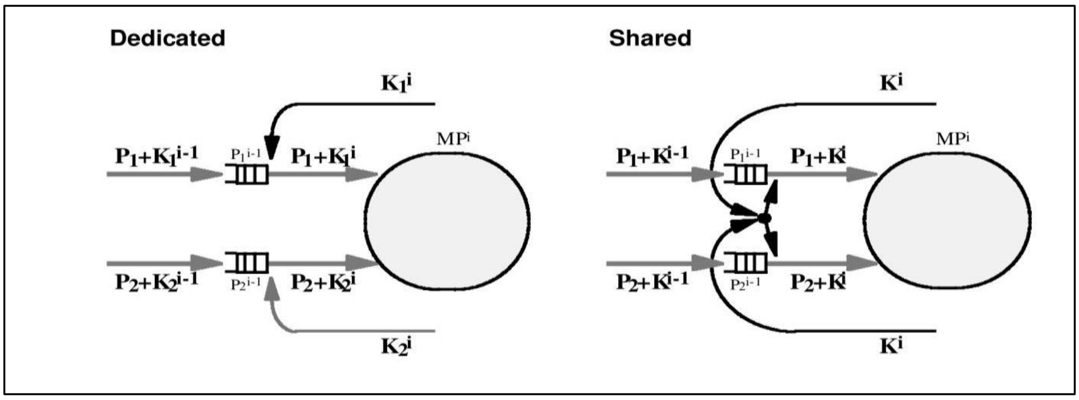
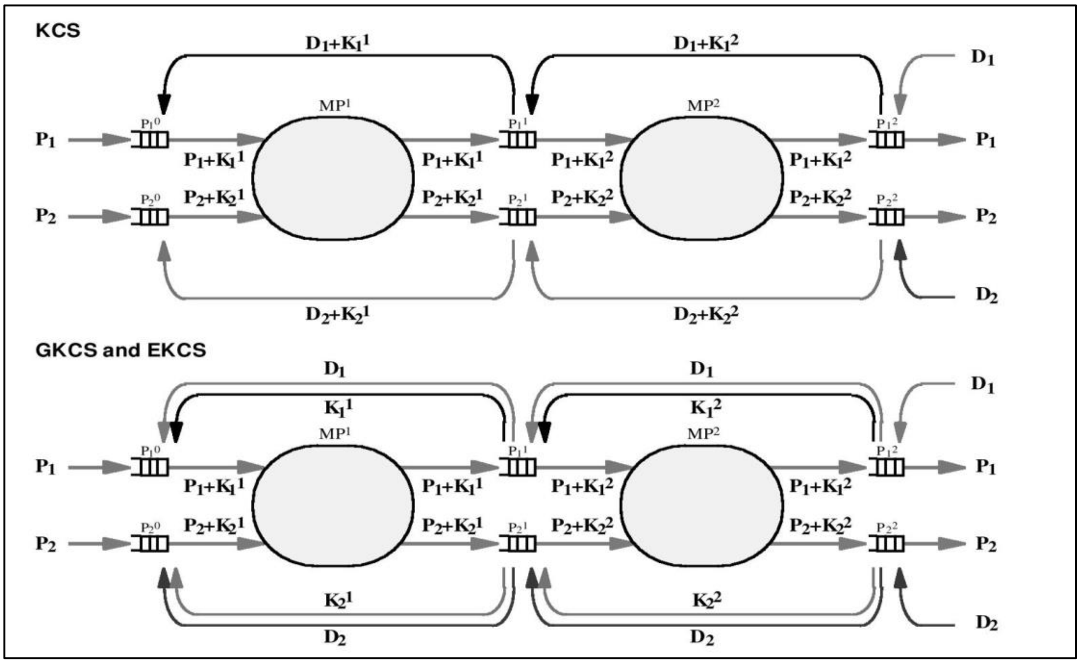


Figure 24: Shared and dedicated Kanban cards (Baynat et al. 2010, p. 4229)



D: represents the demand, K: Kanban, P: Product, MP: Manufacturing Process

Figure 25 : Two products one stage (Baynat et al. 2010, p. 4231)

Another common hybrid called, HK-CONWIP (Hybrid Kanban CONWIP) was introduced by (Bonvik, Gershwin 1996), and was believed to achieve better performance than the one approach strategy. The HK-CONWIP has been recently modified by (Onyeocha, Geraghty 2012), to cope with multi product with shared production authorization cards, a strategy that is considered better than the one approach, to cope with demand variations, such as a decline of demand in part A and an increase of demand in part B. The authors of the modified strategy were inspired by a PhD thesis by (Boonlertvanich,2005) who came up with a new method that combined Basestock, CONWIP and Kanban for a single product. The newly modified method was called BK-CONWIP, see **Figure 26,** and is characterized by the following:

- Demand information is decoupled from Kanban cards.
- Demand information is globally sent to all stages in real-time.
- Final good buffer has push production control strategy (non-controlled inventory).
- Kanban and Basestock distributions provide local inventory control at a workstation and the CONWIP and Demand Cards provide global inventory control and coordination of work authorisations for the system.

The newly developed Basestock–Kanban-CONWIP (BK-CONWIP) is capable of reducing WIP, while maintaining low backlog and achieve volume flexibility (Onyeocha et al. 2015, p. 465). This was proven from a simulation study that included several pull systems including Kanban, CONWIP, HK-CONWIP etc. **Figure 26** shows BK CONWIP on three stages with two product situation.

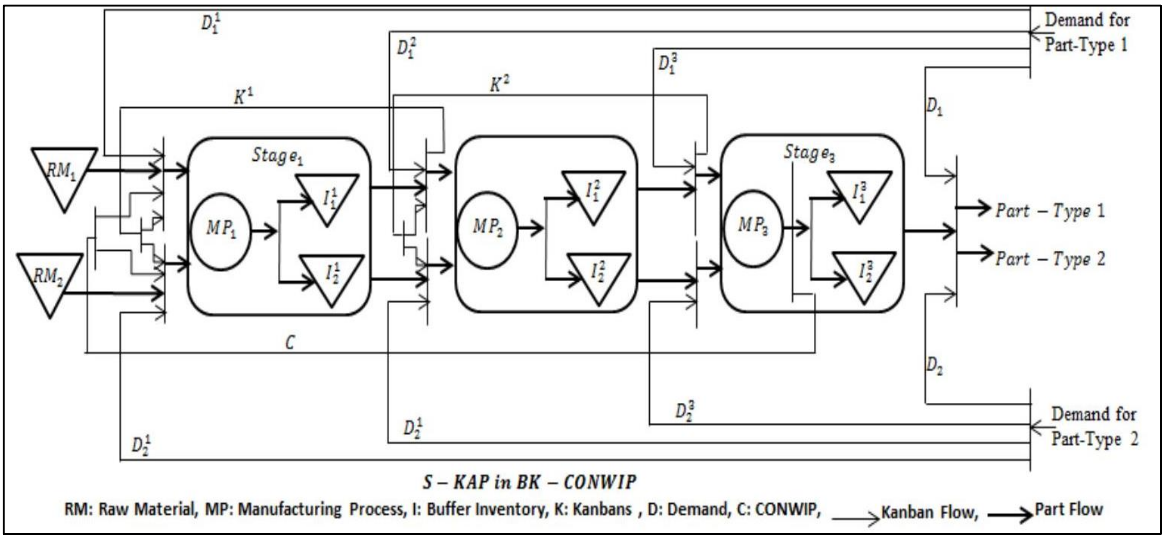


Figure 26: BK-CONWIP control strategy (Onyeocha, Geraghty 2012)

Several studies were conducted to compare BK-CONWIP to the other hybrid strategies, and in all studies, the strategy achieved superior performance in inventory level and WIP as well, as shown in **Figure 27**.

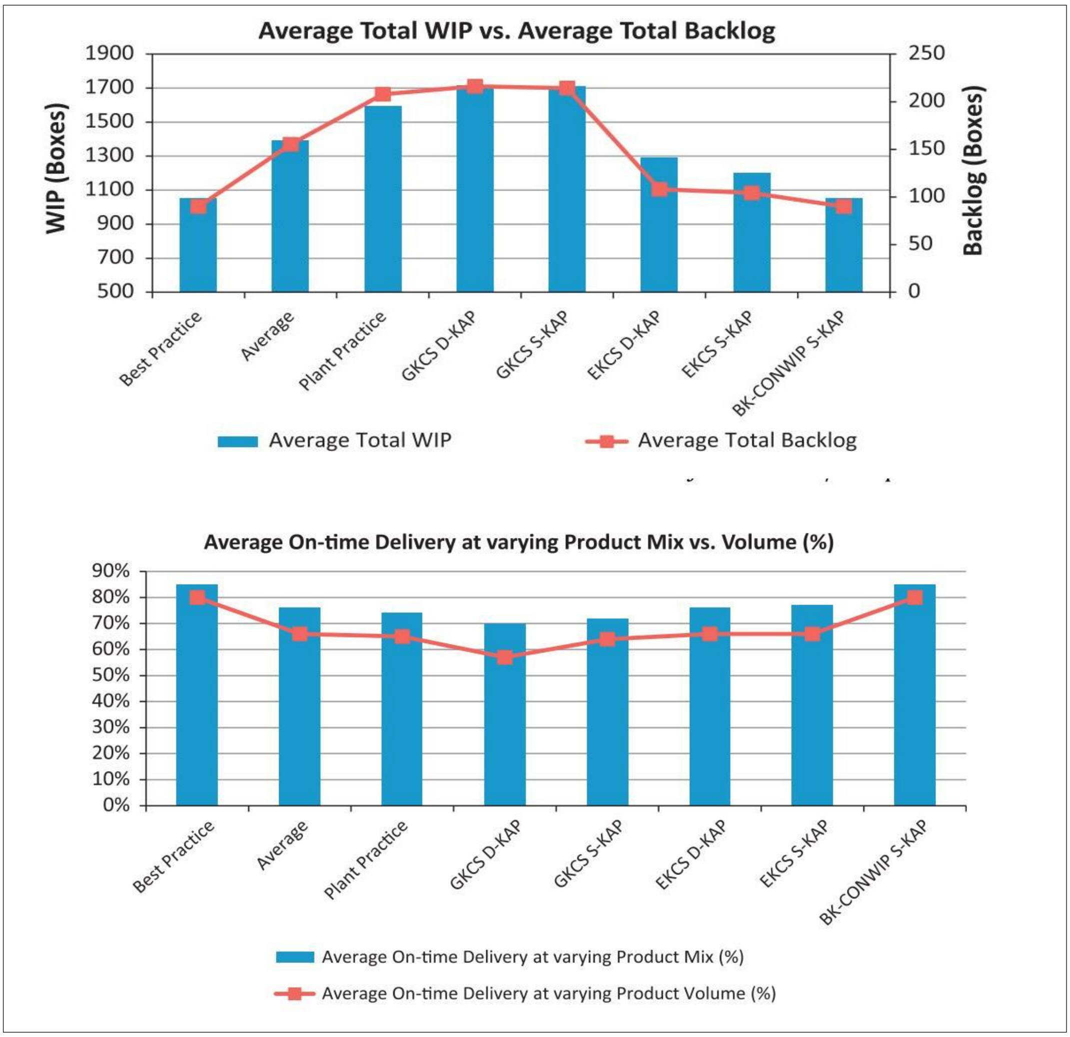


Figure 27: Comparison, pulling systems (Onyeocha et al. 2015, pp. 476–477)

To facilitate the understanding of the BK CONWIP for a two product, multi stage situation, it was depicted as flow chart next page (Onyeocha, Geraghty 2012).

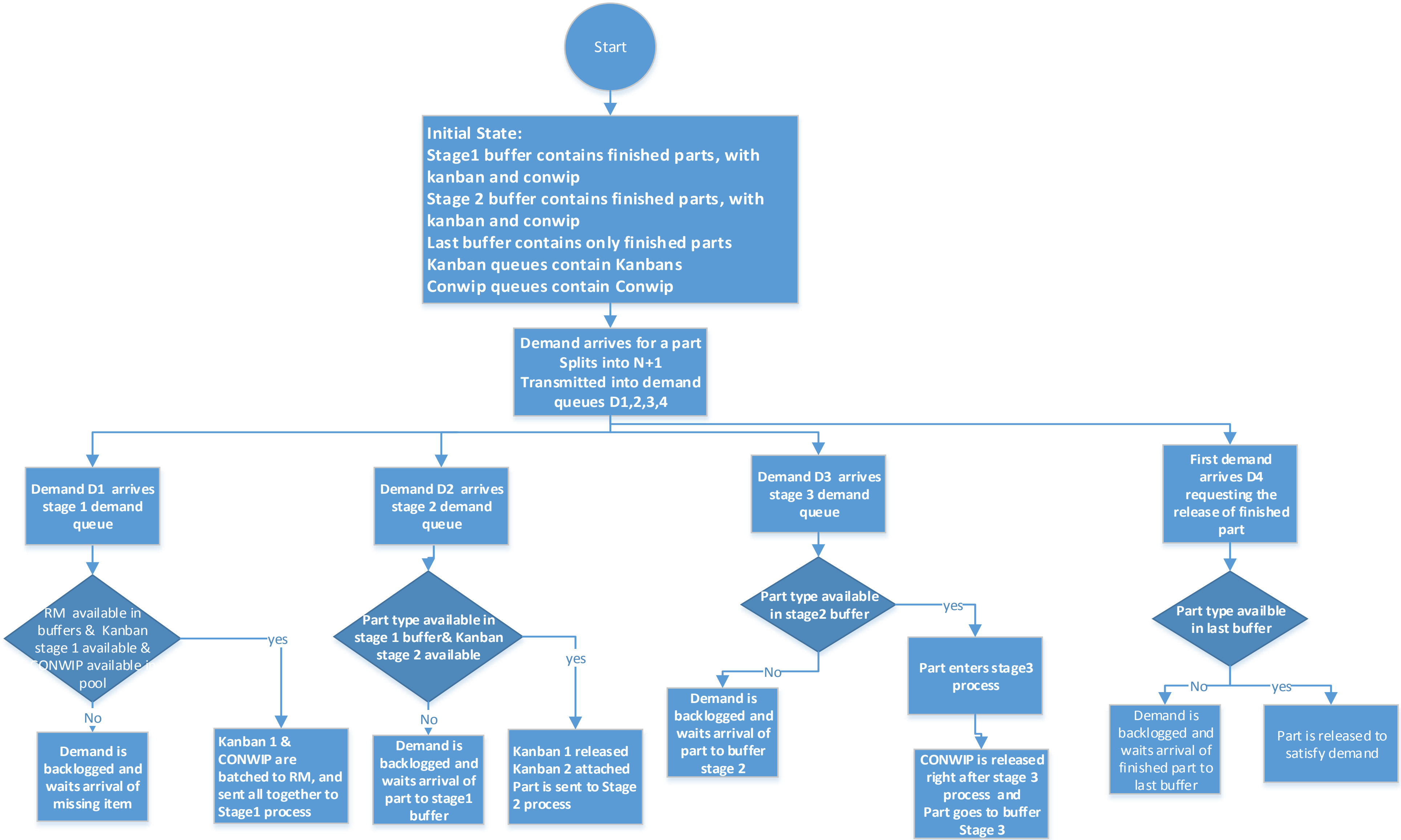


Figure 28: Flow chart of BK CONWIP control strategy based on (Onyeocha, Geraghty 2012)

2.4.2 Analysis of agile tools in supporting leanness

The literature in agile tools is ripe with methods and tools as shown in chapter 2.1. In this thesis, a focus is placed on the ones that are common and mentioned by the industry. Hence, this part is done retrospectively in response to results of the empirical analysis. The tools are studied in literature whether they support leanness, or are against.

Agile tools that are in line with leanness

Several typical agile tools and in harmony with leanness from literature point of view, and are described below:

Flexible manufacturing systems

As seen in **Figure 6** of chapter 2.1, Flexible Manufacturing Systems (FMS) are considered part of the agile paradigm. Yet, this approach does not exist in the house of lean of chapter 2.2. *"FMS is defined as a group of workstations (mostly comprising of NC and CNC machine tools), interconnected by means of an automated material handling and storage system, and controlled by computer integrated manufacturing system(CIM)*" (Chahal 2012, p. 406). The current lean approach has a limited amount of flexibility, and incorporating flexible manufacturing systems and tools with Lean is viable and achieves more operational flexibility and customer satisfaction (Chahal 2012, p. 407,408). Moreover, FMS helps in achieving adaptive production leveling, since such systems have set-up friendly production facilities which enable the company to modify the production sequence more easily when needed (Schönsleben 2007, pp. 317-315).

Leagile tools

The term leagility was suggested and promoted by several authors (Purvis et al. 2014, p. 102),(Ben Naylor et al. 1999, p. 112), (Christopher, Towill 2001) as a solution to the inability of the lean system to cope with high mixes, high volume flexibilities, and high sourcing flexibility (switching between sourcing firm swiftly). The idea of leagility is to having a mixture of leanness and agility through a decoupling point between the make to stock items and the make to order ones. This is associated with postponing the differentiations or assemblies until real order is made. Leagility , also means using Pareto chart 20/80 or Surge and Base demands to separate between products made through lean(MTS) and agile(MTO) (Christopher, Towill 2001). This will be the focus of chapter 2.5.

ERP systems

ERP systems are considered as substantial technologies in agile paradigms as shown and described in chapter 2.1 . To study the system's ability to coexist with leanness, a study conducted by (Piazolo, Felderer 2013, pp. 13–18) shows that companies which implement ERP along with leanness, do this to overcome some of the lean cons. When production lead time is high, and when the company has multi-sites, the use of some forecasting is deemed necessary, and the Kanban applicability between company boarders is difficult. Additionally, leanness requires IT tools to support the data visualization, and to construct a database necessary for the continuous improvement. Nowadays, ERP software encompasses lean management. Yet, the use of lean production along with ERP is a niche market that has the potential for further investigation in research in accordance to the realization aspect (Piazolo, Felderer 2013, pp. 13–18).

MRP tools

The MRP arose in 1975 by Joseph Orlicky, which is a computer-based system aimed at calculating both quantities and processes starting times. The planning is done by a central unit, and thus production orders are "pushed" into the system. The idea of the MRP is that from the demand info(real and forecast), the raw material requirements and sub assembly requirements are determined based on the Bill of Material "BOM" (Karrer 2012a, p. 9). The master programing schedule provides the necessary quantities and times of orders as required. The software goes through the components of BOM to determine total number of components for each product. Thus, any mistakes of BOM would jeopardize the MRP calculation. Note that when quantities are decided, this will not be transferred into demand unless inventories are checked. Based on these three components, the MRP report is created which include the quantities of each item that should be ordered at the moment or the future (Greasley 2009, pp. 380–384).

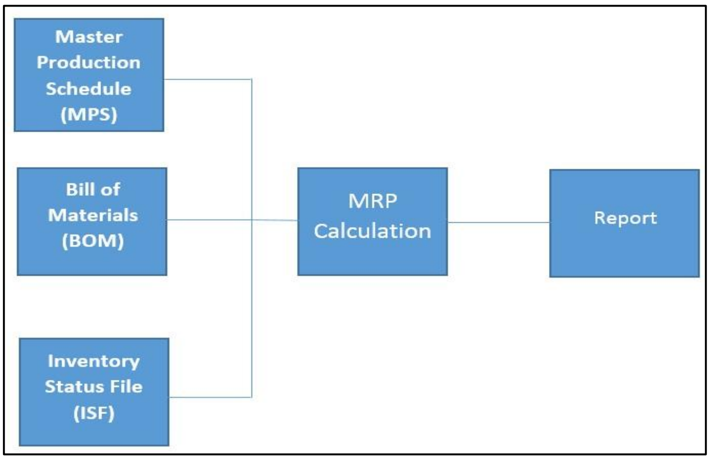


Figure 29 : MRP (Greasley 2009, p. 379)

It is worth mentioning though, that the MRP holds different problems in operational level, and throughout a literature review done by (Ho, Chang 2001, p.175), the main sources of MRP problems are pin pointed as follows:

- The lead time is hard to be predicted due to uncertainties within the lead time. Lead time combines processing time, set up time, waiting time and idle time. The latter is the easiest to predict, such that the cooling down of a part, whilst the others are more difficult to predict, which would eagre companies to set loose lead time to be in the safe side.
- The hardship to decide the optimal lot size EOQ “Economical Order Quantity”.
- MRP determines starting date and finishing dates, but it does not provide a deterministic schedule for the shop floor operations
- Capacity planning is not often done accurately.

The differences between the MRP and JIT are outlined in **Table 5.**

Table 5 : MRP vs JIT (Ho, Chang 2001, p. 177)

Characteristic	MRP	JIT
Main focus	Computerized information system	Shop-floor physical operations
Main function	Parts scheduling without regard to capacity	Operations scheduling
Shop-floor work authorization	Push system	Kanban pull system
Rates of outputs	Variable or level schedule	Level, stable schedule
Capacity required	Capacity requirement planning	Visual
Forms of control	Middle management	Shop-floor, line workers

Although the subject of MRP and JIT is highly controversial in literature, since they are considered as two opposing systems, the combination of the two approaches would achieve higher flexibility in production. The integration of the two approaches would utilize MRP for long term capacity planning, and JIT for daily production control. The proponents of this approach argue that MRP is ineffective for controlling production, thus MRP is used for planning and scheduling, while Kanban is used for control (Benton, Shin 1998, pp. 424–429). Thus, the use of MRP along with Kanban is essential for inventory planning. A conceptual model was presented by (Bell 2006, p. 150) showing how MRP is used along with Kanban for effective planning and controlling of production. While MRP is used for planning for long lead time requirements and final assembly supermarkets and raw materials, Kanban is used for daily production and final assemblies.

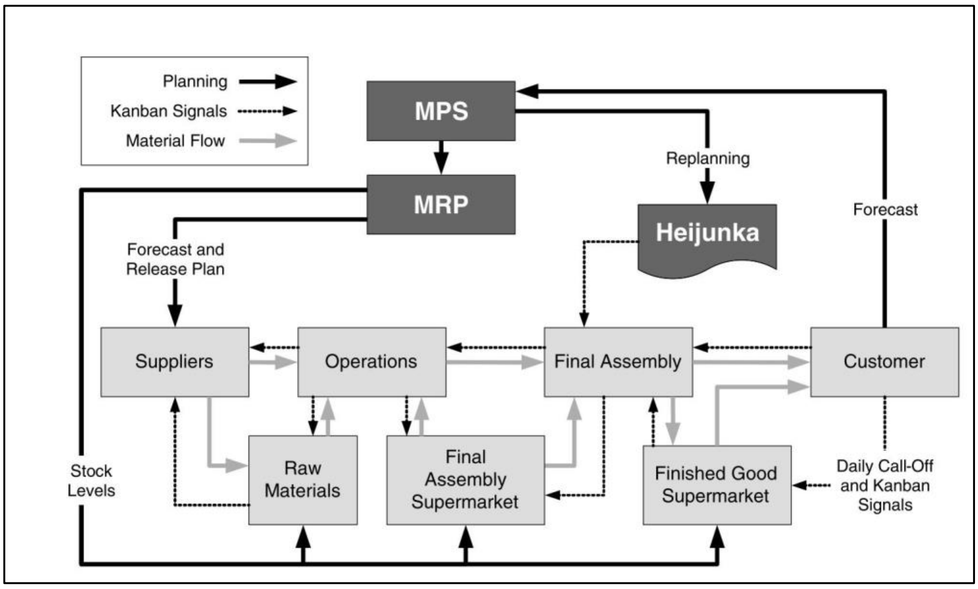


Figure 30: MRP and Kanban (Bell 2006, p. 150)

Outsourcing at non differentiation level

A study conducted by (Mohammed et al. 2008, p. 357,381) shows that outsourcing supports both the leanness, agility and flexible manufacturing approaches. Particularly when adopting outsourcing at "undifferentiated product" stage. This will give the possibility for the partner to optimize processes, and give the chance for the mother company to focus on the core competences, and work to master the non-core competences as well. The study shows that outsourcing has a positive effect on cost, and responsiveness as well.

Additional agile tools

There are other agile tools and practices, which were not seen directly aligned to leanness. These tools may possess some characteristics that support leanness, but still research has not focused on the applicability of these approaches within leanness.

- **3D printing**: Is considered a new agile technology that has high potential in supply chains. The 3D printing technologies are considered among the additive manufacturing paradigm. Although this technology may support leanness in some aspects, it currently yields in higher amount of unit cost, and negligible economy of scale. Thus, the company will not benefit from the cost advantage of mass produced items of the lean paradigm. Thus, currently 3D printing is more applicable to agility (Nyman, Sarlin, p. 4195).
- **Peak shaving**: To handle some volume variations, some companies opt to utilize the supplier liaison and cross-functional planning to outsource certain activities such assembling some parts (Baker 2008, p. 18–19, 35). Literature does not show direct liaison of this method with leanness, which was the reason for considering this method as non-supportive.
- **Extra shifts:** Volume variations could also be handled through extra shifts with overtime and weekends as an agile method (Baker 2008, pp. 18–19). This means that additional costs would be incurred, due to working at overtime rates. Although this method, is a good way to handle insufficient capacities, it does not go in-line with leanness, as *“insufficient capacity is considered to be an imbalance on the line”*(Hobbs 2011, p. 195).

2.5 Leagile production

As seen in chapter 2.4, some of the traditional lean tools support agility, and others should be tailored. On the other hand, several agile tools are in congruence with lean production, and others are yet to be decided. The following chapter will focus on a more recent approach that calls for integrating lean and agile production into one supply chain.

2.5.1 Overview

A group of researchers show that leanness might be able to operate low amount of mix flexibility, but it fails to operate high volume flexibility, high mix flexibility, and high sourcing flexibility (switch between sourcing companies with short term relations). The proponents of this approach support integrating the agile approach in lean supply chains, in what was called as “leagility ” to achieve higher amount of flexibility, and reap the benefits of both systems (Purvis et al. 2014, p. 102), (Ben Naylor et al. 1999, p. 112), (Christopher, Towill 2001), (Olhager 2010, p. 867). There is consensus in recent literature that this approach will have significant benefits to leanness, particularly in the area of automotive, where lead time is high.
The hybrid of Lean and Agile paradigms was first proposed by (Ben Naylor et al. 1999, p. 117), using the term “leagility ” which aimed at harvesting the benefits of the two approaches with the existence of a decoupling point in between. The idea of this approach is that the two systems “lean and agile” are separated through a decoupling point. Leanness is implemented upstream the decoupling point, where demand is stable, with what was described as a “push plan pull execution”. Agile approach, on the other hand, exists downstream the decoupling, with higher product variety per value stream, as shown in **Figure 31.** The aim of the leagile production is to find trad-offs between the two paradigms (Nieuwenhuis, Katsifou 2015b, p. 234). The unpredicted demand, long lead time of components, and difficulty to match supply and demand - that characterized the purely lean approach, were all answered by the leagility . The automobile industry is an example of where this approach has been widely applied. The reason behind the spread of this approach is that current industry face several impediments which increase complexity, and prevent achieving profitability, most noticeable are the following (Ambe, Badenhorst-Weiss 2010, p. 2110):

- Globalization in design and manufacturing.
- Long order-to-delivery lead time.
- Unpredictability in production schedules.
- Abundant of inventories across the supply chain.
- Poor visibility of suppliers.

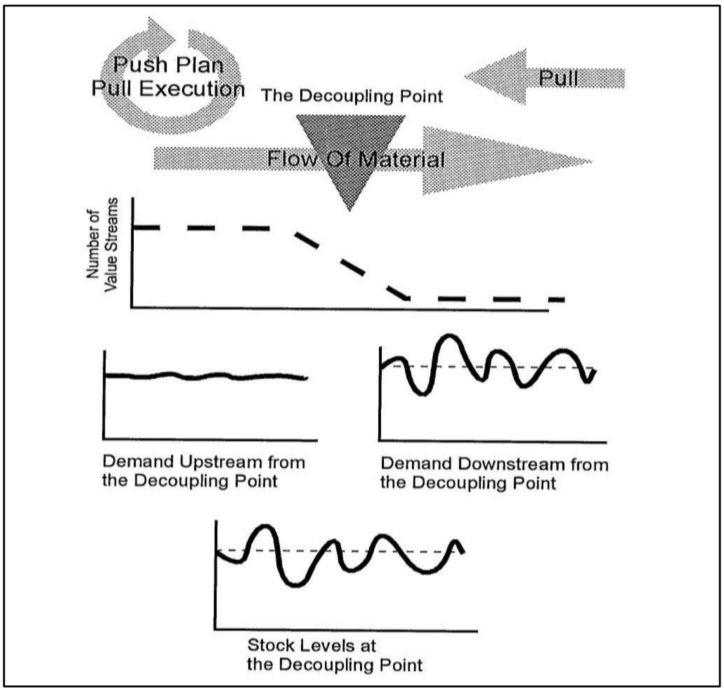


Figure 31 : Effect of decoupling point in Leagile supply chain (Ben Naylor et al. 1999, p. 114)

Leagility has become one of the main elements of success in manufacturing enterprises, which in turn has attracted both manufacturers and researchers to find its distinguishing impact and applicability in all industrial sectors (Mukhopadhyay 2015, pp. 361–362).

Supply chains have evolved since early eighties to be much more customized, and pay much more attention to lead time to cope with the current volatile demand. This drove companies to include the topic of agility in their Lean supply chains. In a study of PC supply chain operations, for example, leagile supply proves to be the up-to-date philosophy since the late nineties (Martin, Towill 2000a, pp. 212–213). Some researchers argue that the use of leagility is not viable in all production companies, and it depends on the time when customization occurs. For example, when product variety happens in early stages, the applicability of decoupling point in operations is not feasible, thus leagility cannot be the best fit. In this case, agile solely is more desirable (Stump, Badurdeen 2012, p. 120). Other researchers, however, prove the opposite through highlighting that it is difficult to separate leanness and agility in nowadays supply chains, since they both have many intertwined features, and thus, can rarely exist in isolation (Mukhopadhyay 2015, p. 367).

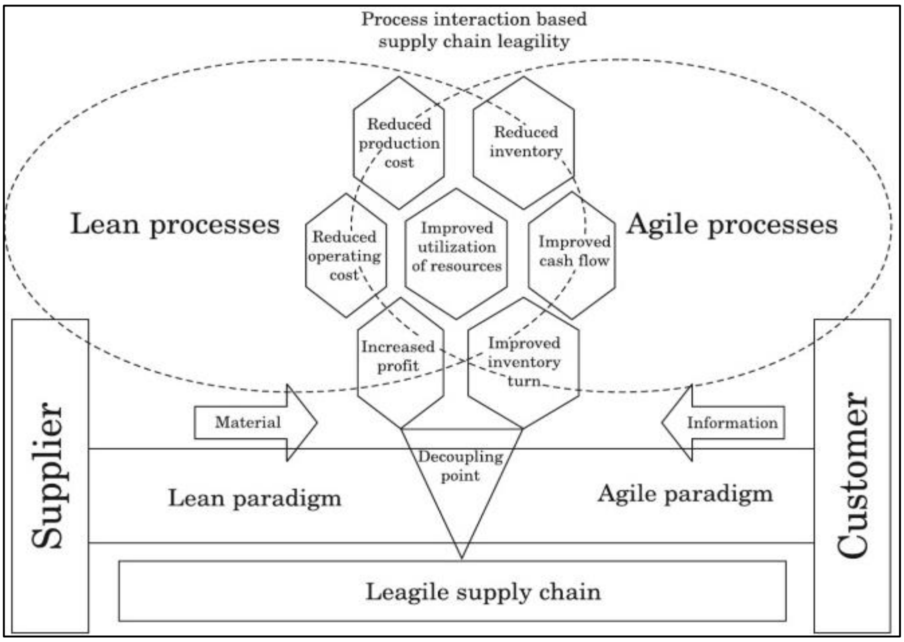


Figure 32: Integration of leagile processes (Mukhopadhyay 2015, p. 366)

The topic of leagility has been recently broadened to include vendor flexibility and sourcing flexibility where two types of legality were defined (Purvis et al. 2014, pp. 106–109):

- Leagility with vendor flexibility, where vendors are agile with high amount of volume and mix flexibility. In this case, sourcing flexibility is low
- Leagility with sourcing flexibility, where vendors are lean and sourcing flexibility is high. It's worth mentioning that agile vendor means operating in both high volumes and mixes

This chapter will expand more about leagility and present several aspects such as planning, decoupling point, mass customization, and the implementation.

2.5.2 Production planning and control of leagility

In automobile industry including Toyota “the epitome of leanness”, companies face the challenge to satisfy customers who do not want to wait until they get their cars. Thus, the traditional concept of Leanness which was labelled by Womack and Jones as a “pull” system, is changing.

Manufacturers nowadays, including Toyota, are adopting make-to-stock, and anticipate what will be sold to insure availability. The fact that Womack and Jones did not specify which customer the demand is driven by, made the assumption that leanness can be seen as a make-to-stock system, based on push strategy. This might resemble mass production at a first glance, what distinguishes “lean push” than “mass production push”, however, is the fact that the forecasting horizon in lean production is shrink and often does not exceed the two weeks period. This way of planning should not contradict with lean concepts like production scheduling “Heijunka”, or pulling orders using Kanban upstream. However, this would make it possible that demand does not match supply, which is forecast-oriented. Thus, an effort should be put in this area to accurately forecast demand. Other efforts should also be put on responding to customer in real time. In fact, responding to customer in real time is the essence of agility (Goldshy et al. 2006, pp. 59–60). To describe the production planning and control of legality, it is important to understand the existence of a decoupling point which lies between make-to-forecast and make-to-order activities. Stochastic methods are adopted to determine the amount of inventories of supplied parts and/or parts made in house. When the customer order is received, the customization occurs after the decoupling points. The leagile approach has an assemble-to-order strategy, where MRP is used to schedule final assemblies with high variations. The production of many of the low level components are used through Kanban. Such system is called push-pull (Bell 2006, p. 149). The next sub-chapter is to elaborate more on the push and pull environments.

Push vs Pull- Conflicting ideas and disagreements

We saw in the chapter’s overview, that the lean approach was called push plan, pull execution, and the agile part was called pull. Hence, this chapter is dedicated to clarifying the idea of push-pull in response to leagility. The topic of push and pull, however, is highly controversial in research, and several authors described push and pull differently. The terms push and pull although commonly used, they are not commonly understood, and lots of misconceptions exist to describe them (Hopp, Spearman 2004, p. 1). For example, (Powell, Arica 2015, p. 4) does not support using the term push-pull boundary to describe the decoupling point in leagility. Additionally, (Hopp, Spearman 2004, p. 1) disagree that push is linked to MTS, or using MRP, or central planning. They also disagree that pull means making to order. The authors argue that the only distinction is that pull systems limit the WIP. A literature review by (Powell, Arica 2015), presented more than 30 different definitions of pull since 1998. All in all, looking at literature in pull and push, one can quickly notice that there is scarcity of explaining the guises of combining push and pull (Diamantidis et al. 2015, p. 3), as in the case of leagility. Hence, this chapter attempts to further understand the push pull relation in leagile supplies. First, several definitions of push and pull will be presented, then they will be related to leaigle supply:

Push Systems:

Push systems have different descriptions from literature point of views. The following table provides an overview about the meaning of push in some selected literature.

Table 6: Different views on Push

Definition	**Source**
Push means anticipating the future, and aims at having the products ready by the scheduled due dates. In push producible units are decided based on (MRP) Material Requirement Planning, through which the lot sizes and starting dates are decided. Then, the "internal" production orders are pushed to the stages (see **Figure 33**).	Literature review (Klaas 1998, p. 5)
"Products are manufactured or assembled in batches in anticipation of demand and are positioned in the supply chain as 'buffers' between the various functions and entities".	(Christopher 2011, p. 104)
In Push systems, the manufacturer produces products which often would be unwanted, and would be scraped afterwards.	(Womack, Jones 2003, p. 24)
Push system is the system that does not put a limit on WIP.	(Hopp, Spearman 2004, p. 19)
"With push logistics, you push the order in the direction of the added value, without need of customer influence or a definite customer order".	(Schönsleben 2007, p. 164)

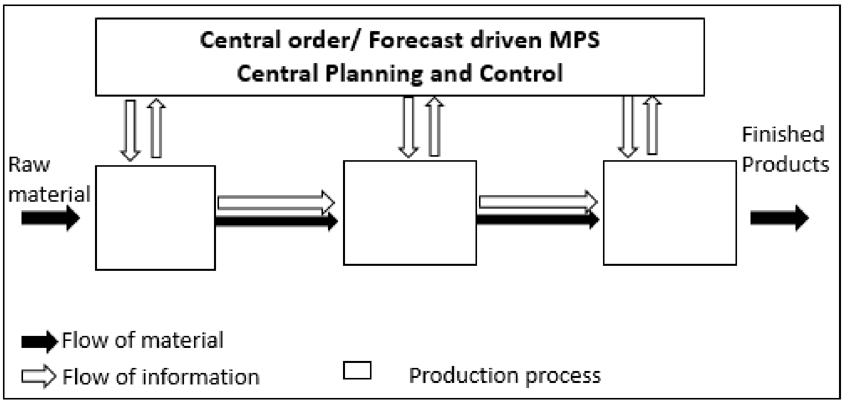


Figure 33: Typical literature view of push strategy (Klaas 1998, p. 2)

Pull systems:

Pull has different defections and point of views in literature, and the following table provides an overview about the meaning of pull in recent literature.

Table 7: Different views on pull

Definition	Source
In Pull mechanism, production of new parts is triggered based on actual demands, and is normally implemented using Kanban cards where the number of cards decide the WIP.	(Baynat et al. 2010, p. 4225).
Pull does not determine the start of production for parts like in MRP push based systems, in fact, it "authorizes" production. Thus, "the removal of parts from the end of the plant pulls component parts forward through the production system.	(Spearman et al. 1990, p. 880).
Pull in production: "*In Production-pull, value-adding activities take place in response of a specific withdrawal from an explicitly limited inventory buffer, or supermarket. The direction of information flow is the reverse direction of material flow, and production takes place in order to replenish an exact amount of consumed products and / or components"*.	(Powell, Arica 2015, p. 8)
Pull in Demand: *"value-adding activities only take place in response of real customer demand. However, production can still be either pull-based or push-based".*	(Powell, Arica 2015, p. 5)
The idea of pull, is that customer pulls the product from the manufacturer whenever needed.	(Womack, Jones 2003, p. 24)
The pull system is the one that can limits the WIP, and that is the only thing that distributes push and pull.	(Hopp, Spearman 2004, p. 19)

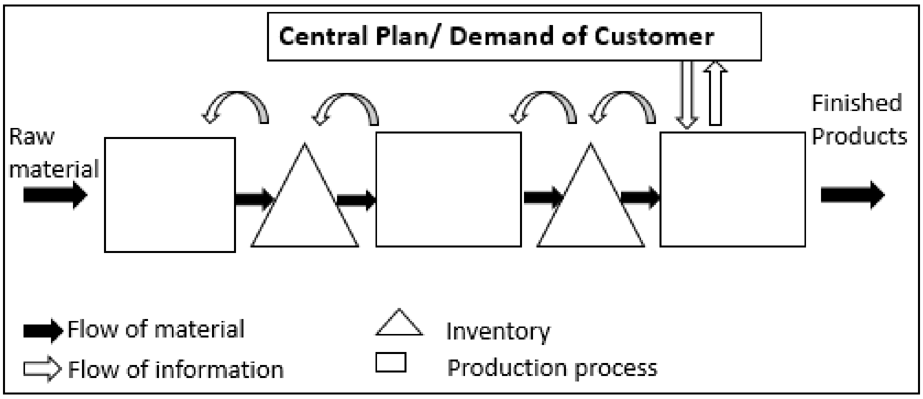


Figure 34: Typical literature view of pull (Klaas 1998, p. 2)

Now back to leagility, the above mentioned definitions can be aligned with the lean and agile parts as follows:

Push and Pull in leagility

Referring to the definitions of push and pull in **Table 6** and **Table 7**, the guises of the leagile push pull, are explained as follows:

Agile part as pull system

The agile part of the leagile supply chain, is characterized as a "pull demand" according to the definition provided by (Powell, Arica 2015, p. 5) of **Table 7**, since it is directly connected to "real" customer. The definition of pull demand supports the existence of a push production in the same supply chain "the lean part in leagile". Another thing that should be clarified here, is the use of MRP which is connected to agile as seen chapter 2.1. In fact, MRP in several articles was seen synonymous to push (Klaas 1998, p. 5), (Spearman et al. 1990, p. 880). The leagile literature saw the usage of MRP downstream as a pull because it is dealing with real customer order (Olhager 2010, p. 867). Nevertheless, from definition point of view, this subject has been controversial in literature, since some authors considered MRP as a pull system in material planning, and push system in operational scheduling level (Ho, Chang 2001, p. 178). Others saw MRP as a push system unless a WIP control used through the MRP software (Hopp, Spearman 2004, p. 19). In this thesis, however, the MRP in the agile part will be defined as a pull since it responses to real customer orders.

Lean part as push plan, pull execution:

The lean part in the leagile supply is labelled a "push plan, pull execution", although typical leanness is seen as a pull system according to Womack and Jones's definition. However, when applying leagility, there is a decoupling point, which is a generic inventory, for generalized parts. Usually leagility is connected to postponement strategy, which means not committing assembly activities until real order is made. This means, common platforms will be developed according to almost accurate trends, and these platforms are differentiated when customer order arrives. This will enable the company to conduct forecasting in a generic form for the common parts, which can be anticipated more accurately than final products (Christopher 2011, p. 178). The existence of forecasting aligns with the definition of "push" as mentioned by (Klaas 1998, p. 5) and (Christopher 2011, p. 104) in **Table 6**. (Swaminathan, Nitsch 2007, pp. 326–327) defines the decoupling point that separates the lean an agile systems as "push-pull" boundary, which is normally located in the point of differentiation "PoD". This gives an understanding of the reason why the Lean part was labelled as a push planned system. On the other hand, the pull execution stems from the controlled replenishment of inventories using Kanban, or using other means such as MRP with WIP control (Powell, Arica 2015, p. 8), (Hopp, Spearman 2004, p. 19).

A frame-work shown in **Figure 35** was presented based on a case study at BMW Rosslyn plants which integrated Lean and Agile paradigms in their production planning and control. (Ambe, Badenhorst-Weiss 2010, pp. 2118–2119). This comes in line with several other literature emphasizing that Legality means assemble-to-order, such that leanness is adopted upstream the customer order decoupling point, where planning is driven by forecasting for the common parts "push", and the execution is done through pull based-systems. The agile part, on the other hand, is used downstream the decoupling point and has customer order-driven operations (Hallgren, Olhager 2009b, p. 978), (Vonderembse et al. 2006, p. 228).

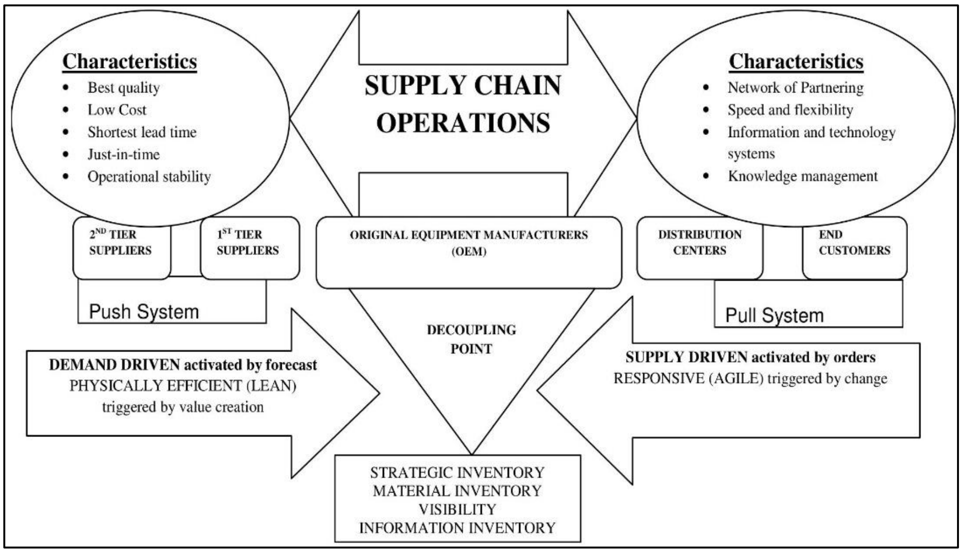


Figure 35 : Leagile in automobile (Ambe, Badenhorst-Weiss 2010, p. 2118)

Production planning and control matrix of leagility

To address production planning and control of leagility, we will first shed some light on how production is usually planned and controlled in normal supply chains. There are three main tasks associated with production planning; long term activities, mid-term and short-term activities **Figure 36** details the three main sets of activities as described by (Stadtler, Kilger 2005, pp. 88–91) and based on (Rohde et al. 2000).

- The long-term activities look at the big picture, such as product life cycle, and some economic and political factors. In this stage, products are split into groups of items sharing commonalties. In addition, the decision to locate the decoupling point is made. Much broader activities would include location of the plants and production systems, and supplier selection as well as material classification into ABC classes. The overall goal of these tasks is to minimize long term costs for all activities.
- The mid-term planning tasks encompass calculating forecasts on a weekly or monthly bases. Additionally, safety stocks of finished parts are agreed upon. This phase includes planning for the distribution (e.g. truck capacity). The mid-term planning also includes capacity planning, personnel planning, and MRP (material requirement planning).
- The third set of activities are called short-term planning, which deals with what should be replenished on daily bases for a single product, in addition to detailed transportation capacities. In this phase, lot sizing and sequencing of lots on machines is implemented. Moreover, this phase deals with staff at shop floor and their skills and schedules, in addition to shop floor control techniques (Stadtler, Kilger 2005, pp. 88–91).

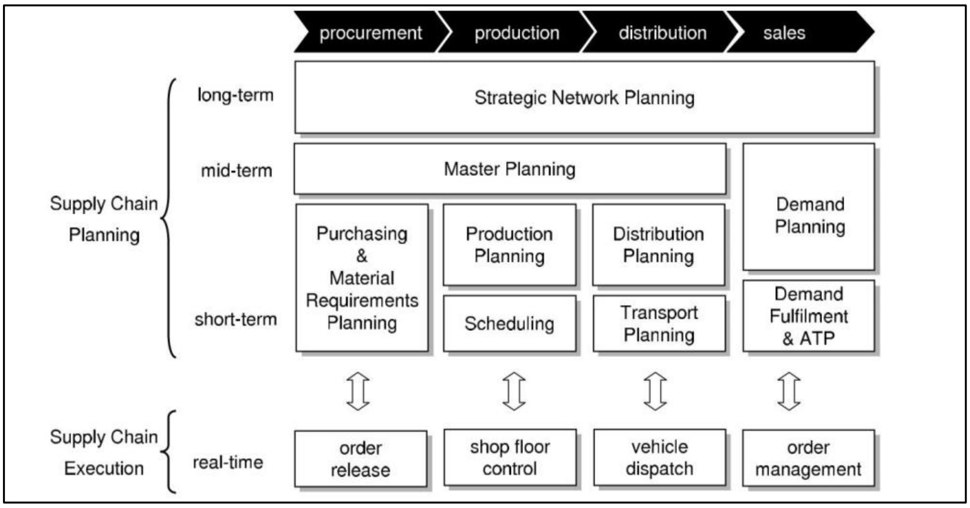


Figure 36: Supply chain planning and execution (Stadtler, Kilger 2005, p. 114)

To connect this with leagility, (Olhager 2010, p. 866) suggests the distinguishing of production planning activities before and after the decoupling point, making it clear that there should be two separate supply chain matrices for the make-to-stock parts, and the make to order parts. He based his study on the Supply Chain Planning matrix presented by (Rohde et al. 2000).
To elaborate on this, we explain the long-tem, mid-term and short term activities in Leagile supply as follows:

- Long term-planning in Leagility: The dual approach suggests that the strategic network planning, which represents the long term planning, should be different before and after the decoupling. In the upstream part, the physical efficiency is dominant, meaning focusing on minimum cost and maximum resource utilization during planning, while the downstream part is focused on market responsiveness (Olhager 2010, p. 867).
- Mid-term planning in Leagility: MTS items should have level planning strategy, while MTO items should have chase planning strategy. The downstream activities assume that the right quantities exist in the decoupling point, and thus the planning is based on capacity in downstream operations (Olhager 2010, p. 867). As an example of capacity planning before and after the decoupling point, lean operations tend to be 1.2 times of the average demand, whereas the value for agile operations would hit twice its average demand to cope with swings in demand, that would fluctuate between 20% to 100% of capacity (Mason-Jones et al. 2000, p. 59).
- Short-term planning in leagility: Withdrawing items from the decoupling point is time-phased in terms of the configurations downstream the decoupling point. This can be done through using MRP. Whereas the replenishment of the decoupling point is done in a rate based way due to the easiness of forecasting the amount of items that should exist in the decoupling point. (Olhager 2010, p. 866).

This model, implies the separation of the organization “virtually” into supplier “upstream” and consumer “downstream”. Consequently, the supplier depends on forecasting to decide the amount of items and modules that should be stocked, thus final assemblies will be quick enough. The time-phased approach grosses the material requirements against on hand inventory and schedule receipts and determines the receiving and releasing of items according to lead time (Blake 2001, pp. 2–3).

Table 8: Planning operations before and after the DP (Olhager 2010, p. 867)

Attributes	MTS and pre-CODP operations	MTO and post-CODP operations
Strategic network planning	Physical efficiency, based on lean principles	Market-responsiveness, based on agile principles
Master planning	Make-to-stock, replenishment of CODP inventory position	Make-to-order, delivery planning of customer orders with respect to capacity
Demand planning	Forecasting of items in the CODP inventory	Customer order management, product customization
Demand fulfilment	ATP, based on stock availability	ATP, based on lead time agreement, material and capacity availability
Distribution planning	The CODP is the most important inventory of the entire supply chain[a]	No inventory, all activities are driven by actual customer demand
Production scheduling	Rate-based approaches, e.g. Kanban	Time-phased approaches, e.g. MRP, with respect to capacity
Purchasing planning	Rate-based approaches, e.g. Kanban	Time-phased approaches, e.g. MRP

[a] There may be other stock points in the distribution system in a make-to-stock situation further downstream and closer to the customer, e.g. distribution centres, warehouses and retail stores.

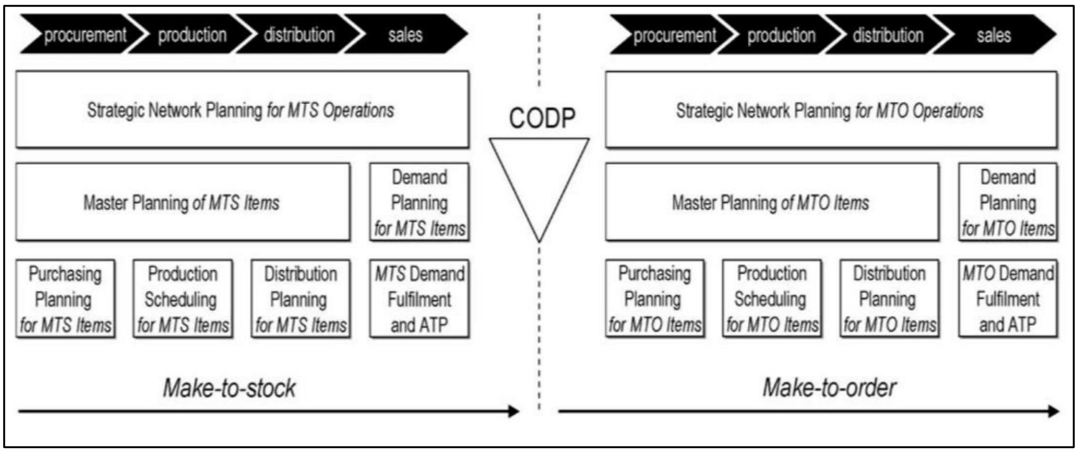


Figure 37: Supply chain matrix in leagility (Olhager 2010, pp. 866–867)

2.5.3 Integration of operations in leagility

We have seen in chapter 2.4 that several lean operations and agile operations can coexist alongside in an agile lean environment. We have also seen, how the planning and control activities are separated before and after the decoupling point during chapter 2.5.2. The question that could be raised here, whether the decoupling point should separate the lean tools and the agile tools applied in such supplies. Literature in leagility did not focus on how operations carried out before and after the decoupling point. An article published by (Olhager 2010, pp. 866–867) suggests a total separation between lean and agile operations since lean operations deal with repeatable products, and agile deal with highly customized ones. For example, the lean products can be processed through assembly lines, while the agile ones can be handled through job shop. Furthermore, the capacity of the agile part is significantly higher than the lean part, meaning that it can adapt to 20% to 100% demand fluctuations (Mason-Jones et al. 2000, p. 59). This means that the company might opt to some agile typical operations to cope with these fluctuations such as peak shaving, or using extra shifts (Baker 2008, p. 18–19, 35). Nevertheless, a total separation between the lean and agile operations is hard to find in real world practice, since the lean and agile operations are intertwined along the leagile supply. To give an example of this, let’s consider some of the traditional lean tools such as JIT, TQM, Continuous improvement and waste reduction, these tools would also exist in the agile part. On the other hand, some of the traditional agile tools such as ERP would also exist in the lean part (Mukhopadhyay 2015, p. 370). For example, both parts would implement, pull, smoothing, waste reduction, quality enhancement, and even inventory reduction techniques. The distinguishing here, is that the aim of these operations and the level of importance would differ. Let’s consider the change over time. Having rapid change over is an important process in both leanness and agility. However, when it is done in the agile part, it should be way more efficient due to the higher number of varied products the agile part contains. Another example is for the cellular manufacturing. The agility paradigm can take this methods to a new level “virtual production cells” if needed. Another distinction could be through the outsourcing. The agile part would depend on virtual partners due to the highly innovative and customized produces, while the lean part would maintain long term partnerships (Kovach et al. 2005, p. 6). **Figure 38** presents an illustration of the lean and agile operations that are integrated and inseparable in the leagile supply chain.

Process type	Process bundles (cells of leagility)	Individual process	Reference
Lean	HR practise	Employee engagement Employee multitasking	Shah and Ward, 2003; Losonci et al., 2011 {*employee engagement, multitasking, motivation, team work and communication*}
	JIT practise	Kanban JIT supplies	Sugimori et al., 1977 {*Kanban, JIT supplies, equipment layout, lot sizing*}
	TQM	Poke yoke Process control 5S Six sigma	Shah and Ward, 2003 {*Poke yoke, process control, Six Sigma, 5S*}
	Infrastructure practise	Product design Manufacturing strategy	Sakakibara et al., 1997 {*product design, manufacturing strategy, organisation characteristics, workforce management*}
	TPM	Preventive maintenance Equipment reliability	Shah and Ward, 2003 {*preventive maintenance, equipment reliability, efficient operation*}
	Waste reduction	Setup time reduction Value stream mapping Product standardisation Equipment efficiency	McCullen and Towill, 2001 {*value stream mapping, equipment efficiency, product standardisation, setup time reduction*}
	Continuous improvement	Kaizen	Pavnaskar et al., 2003 {*Kaizen*}
Agile	Flexible plan	Material plan Production plan	Gunasekaran and Yusuf, 2002 {*agile manufacturing, priority based planning*}
	Agile mfg	Distributed teams, global mfg and value based pricing Agile mfg techniques Concurrent engineering	Gunasekaran and Yusuf, 2002 {*agile manufacturing, distributed teams in global manufacturing, value based pricing, concurrent engineering*}
	Customer interaction/ market intelligence	Customer interaction frequency Market inputs	Sharifi et al., 2001 {*customer interactions/market intelligence and societal factors*}
	Effective technology/ information integration	IT processes/ EDI/ XML information interaction/ networked work space Adoption of ERP/ SCM/ SRM/ CRM software	Bajgoric, 2000; Vernadat, 1999 {*effective technology and information integration*}

Figure 38: Leagile processes (Mukhopadhyay 2015, p. 370)

2.5.4 leagility and mass customization (MC)

The fact that leagility enables companies to operate high mixes and high volumes as suggested by (Hallgren, Olhager 2009, p. 991), (Ben Naylor et al. 1999, p. 111), poses a question whether leagility is synonym to Mass Customization (MC), and the coexistence between the two paradigms. This sub-chapter will also relate mass customization to lean and agile paradigms for further understanding.

Leannes and MC

MC as defined by (Pine, 1993) is the ability to provide individualized products or services through adopting flexible and responsive production systems. Consequently, what distinguishes Mass Customization to lean is the fact that product variety is considerably higher in mass customization seeking for high amount of individualized products (Krishnamurthy, Yauch 2007, p. 602). Hence, when the degree of customization raises, that means customer involvement starts earlier in the design and assembly, which in turn, impedes lean principles of continuous flows and low inventories (Stump, Badurdeen 2012, p. 109).

Agility and MC

Mass customization resembles agile production in terms of individualized products. However, agility is broader in terms of its ability to respond to dynamic governmental and environmental changes, or new material advancements (Krishnamurthy, Yauch 2007, p. 602). The fact that Agility enables producing different products with different volumes, with immediate changeover and no or little incurred costs, means that a total agile system can achieve mass customization (Putnik et al. 2012, p. 225).

Leagility and MC

A study conducted by (Stump, Badurdeen 2012, p. 115) presents two types of Mass Customization depending on the time of customer involvement in the value stream; low level of MC means late involvement, and high level of MC means early involvement. Leagility fits well with the low level of mass customization as shown in **Figure 39** where customization happens during assembly based on modularization. A decoupling point is thus substantial in producing an effective and highly responsive system.

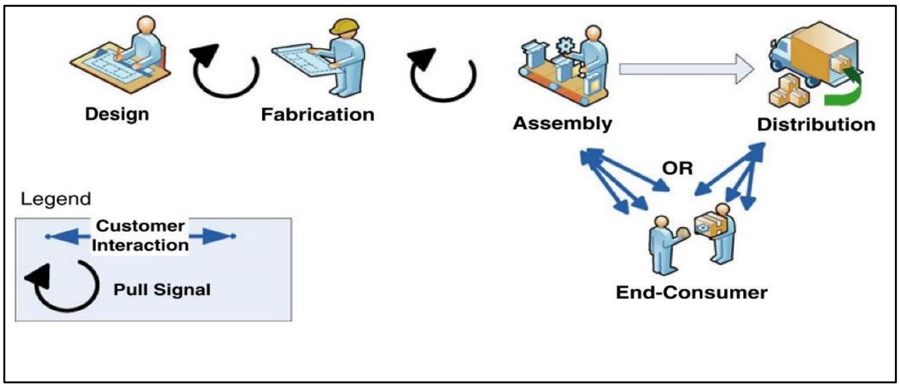


Figure 39: Low level mass customization- synonymous to leagility (Stump, Badurdeen 2012, p. 113)

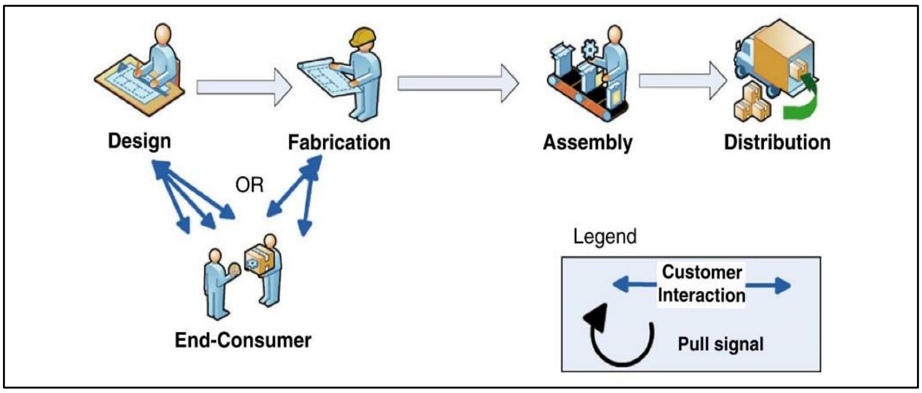


Figure 40: High level of mass customization (Stump, Badurdeen 2012, p. 114)

2.5.5 Decoupling point

In this sub-chapter we will expand on the issue of decoupling point, which is an integral part of leagility. First, it's worth to mention that decoupling point is not a new topic is literature, and several researchers tried to define the decoupling point (Berry and Hill 1992), (Vollmann et al. 1997) , (Hill 2000), (Sharman 1984) as shown in a literature review carried out by (Olhager 2003, p. 320). In any supply chain, there are two types of decoupling points; information decoupling point, which is the point where market data penetrates without any modifications or distortions, and material decoupling point where the production flow changes from make-to- stock to make-to-order. Hence, the two decoupling points should exist in every supply chain, and the best performance of the supply chain is when we shift the information decoupling point as far as possible upstream. This happens through information technology and effective sharing of data (Mason-Jones, Towill 1999, p. 16,24). However, in practice, the prevalent case is that both, the information and material decoupling points match in one point (Jodlbauer et al. 2012, p. 40). The following table illustrates the recent definitions of the decoupling point in literature:

Table 9: Definitions of the decoupling point in literature

Definition of decupling point	Source
"The point in the manufacturing value chain for a product, where the product is linked to a specific customer order". He refers to it as the Customer Order Penetration Point (COPP).	(Olhager 2003, p. 320)
"divides the manufacturing stages that are forecast-driven (upstream of the OPP) from those that are customer-order-driven (the OPP and downstream) "	(Olhager 2003, p. 320)
"is where we store T items as a deliberate but carefully … especially where T modularization is an integral part in achieving mass customization"	(Towill 2005, p. 36)
"boundary between push tasks – where we respond to forecast and pull tasks – where we respond directly to customer orders "	(Towill 2005, p. 37)
"the point at which strategic stock is often held as a buffer between fluctuating customer orders and/or product variety and smooth production output"	(Ben Naylor et al. 1999, p. 114)

The boundary that separates between "*Act; Make-to-stock; Push*" operations, than "*React; Make to order; Pull" operations.*	(Alicke 2005, p. 52)
Information decoupling point: *" the furthest point upstream to which information on 'real' demand flows i.e. information which has not been distorted by inventory policies such as re-order points and re-order quantities"*	(Mason-Jones, Towill 1999, p. 17) and (Christopher, Towill 2001, p. 7)
"the standardization-customization boundary (SCB) of the product"	(Kim, Kim 2014, p. 33)

The decoupling point is important because it separates forecast-based activities and order-based ones, which affects the controlling and planning for information and material flows. It also constitutes a major stock in which customer deliveries are made from, thus, it is crucial that the amount of the stored items be sufficient. Moreover, optimization has an important factor in upstream activities that are based on forecasting (Pieter 2001, p. 298). Usually these inventories encompass supplied and made-in-house component, and the amounts are made based on stochastic methods. When the order is received, customization starts in the pull system after the decoupling point, such that necessary parts are taken from stock, and attached through assembly lines to form customized products (Ambe, Badenhorst-Weiss 2010, p. 2118). This raises the question of locating the decoupling point, which has a paramount effect on the adopted production strategies i.e. MTO, MTS, ATO, ETO (Olhager 2003, p. 320)**.** In fact, the decoupling point or Order Pentation Point (OPP), can vary upstream and it depends on how long the customer is willing to wait until an order is delivered "customer lead time", in relation to how long does it take to produce the product "production lead time" (Karrer 2012b, pp. 37–38).

Another topic that is associated with decoupling is the profit margin. It should be noted here that the profit margin of items upstream the customer penetration point is normally low due to the high volumes to be produced in stock, while the items and end products downstream the CODP have higher profit margins due to the customization (Jodlbauer et al. 2012, p. 44).

All the above mentioned information makes it clear that the place of decoupling point is a strategic decision and should be carefully made. Hence, companies often face the dilemma whether to shift the decoupling point forward or backward. This decision is influenced with several factors as indicated by (Olhager 2003, pp. 325–326):

- Forward shifting: driven by the intention to reduce lead time, optimize processes and achieving reliability in delivery time. However, this might pose a threat to obsolesces. It might also reduce the customization level and increase WIP due to forecasted items.
- Backward shifting: driven by increasing of customization, reducing forecasting efforts, eliminating WIP and buffers, and in turn, reducing risk of obsolesces. On the other hand, this might pose problems in delivery lead time and manufacturing efficiency.

The representation shown in **Figure 41** shows that the decoupling point would be placed in different locations along the supply chain, and it decides the implemented production strategy. What should be asked here, is which place the decoupling point fits well with the leagility paradigm, and what production strategy are concerned?

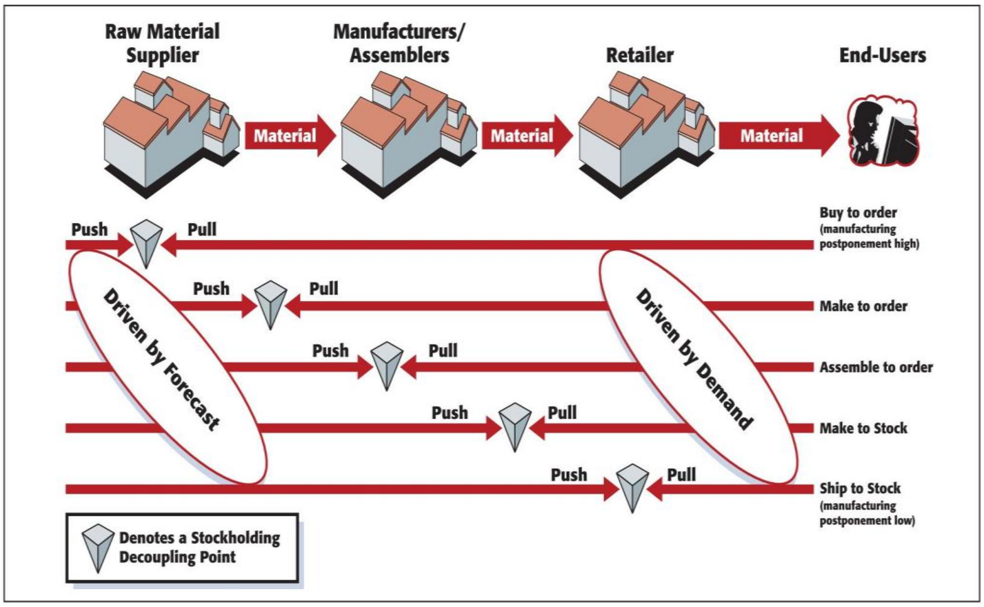


Figure 41: Material flow decoupling points (Towill 2005, p. 38)

Nature of decoupling point in Leagile supply chain

To relate this to leagility, literature shows that the definition of leagility fits very well with ‘‘Assemble to Order’’, where demand of products is accurately forecasted upstream the decoupling point (Vonderembse et al. 2006, p. 228). The leagility approach works such that big various volumes are in stock, and are being pulled off by the final assembly. Hence, upstream the decoupling, flow variations would be around ±5%, where downstream the decoupling it would reach ±75%. Dell company, for example, has managed to apply this approach through moving the decoupling point upstream and fully adopting the modularization approach to tailor the product to individualized customer needs (Towill 2005, p. 38). This concept was referred to as “postponement strategy”.

Postponement Strategy:

The postponement strategy is an integral part of literature in agility and decoupling point, and calls for using platforms, modules and not committing any final assembly or customization until customer requirements are known (Martin, Towill 2000b, p. 210). The postponement strategy, is also called “modular product design”, where customer chooses the modules to be assembled (Olhager 2003, p. 322). Naylor and Naim suggest that in the leagile supply, when adopting an assemble to order strategy, the differentiations are postponed as late as possible. Doing this allows the company to respond quickly to changes, but also reduces the value of products, since they are not fully assembled, and thus the risk of obsolesces decreases (Ben Naylor et al. 1999, p. 113).

2.6 Implementation of hybrid lean and agile production

Although the mindsets of "lean" and "agile might look simple from a theoretical perspective, complexity becomes apparent when implementing these mindsets (Goldshy et al. 2006, pp. 57–88). In this sub-chapter light will be shed on the implementation of the hybrid lean-agile attempting to present state-of-the-art methods from literature to put this hybrid into practice. This chapter will present some frame works from literature to implement the hybrid lean-agile. Four main methods were defined to implement such hybrids according to the literature review.

2.6.1 The Pareto distribution curve

The approach of pareto curve, suggests that 20% of products constitute 80% of the total demand. These products are made to forecast using Lean production tools. While, the rest of products, who are less predictable should be handled in a make-to-order strategy utilizing the agile approach. **Figure 42** details this philosophy according to (Christopher, Towill 2001, pp. 8–10).

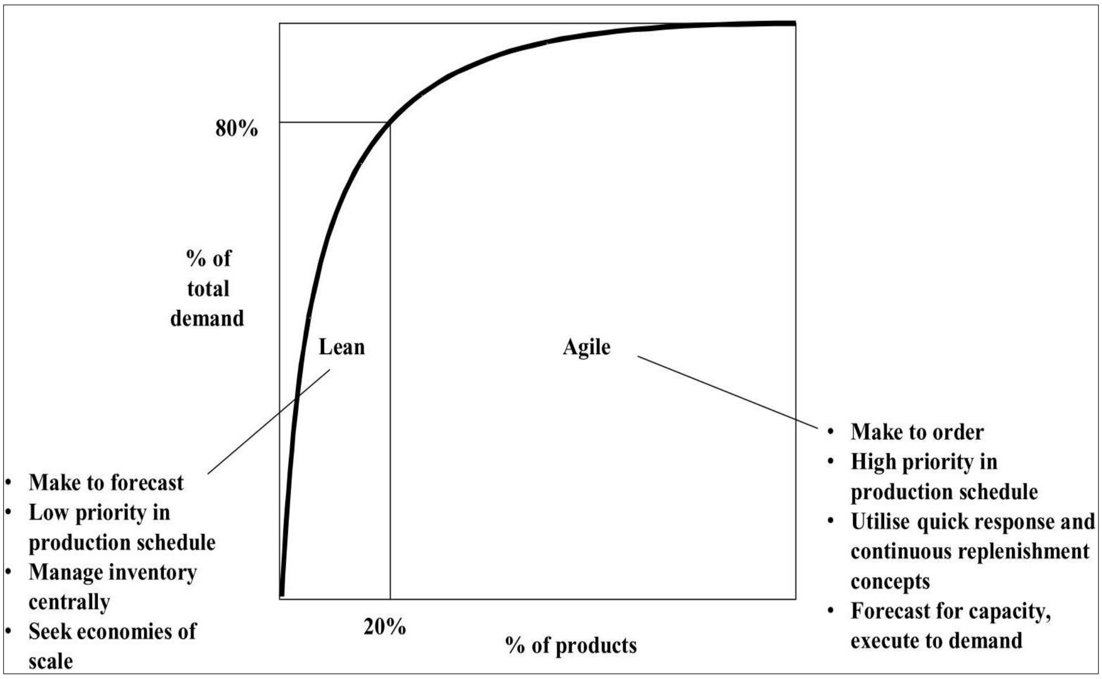


Figure 42: Pareto distribution in leagility (Christopher, Towill 2001, p. 8)

A method that looks similar to what explained by Chrisopher and Towill called ABC classification. The method is also based on Pareto distribution. The only distinction is that ABC classification takes into account the cost aspect when doing the classification. The items to be stored in inventory are sorted according to annual expenditure which is calculated thorough multiplying the cost and the usage for each of the products. Hence, 10% to 20% of products would form the A items that should be controlled carefully utilizing forecasting to improve accuracy. B items should have less amount of inventory that A items, and consequently C items may not be controlled rigorously (Greasley 2009, pp. 326–327). The bottom-line here, is that whether ABC or Pareto chart analysis are used, it is important to tailor our supply chain according to demand info of our products. This analysis can be done during the long term planning as we saw in chapter 2.5.2, and has a major impact on our supply chain performance, especially when applying hybrid lean and agile production.

2.6.2 Decoupling point

The definition and nature of decoupling point/order penetration point were discussed thoroughly in chapter 2.5.5. However, to implement such approach, there should be a clear mythology to decide the location of the decoupling point. The bases of locating the decoupling point, is twofold according to (Olhager 2003, p. 327):

The Relative Demand Volatility (RDV)

Which is the coefficient of variation that can be calculated through comparing the standard deviation of demand in relation to average demand. Consequently, a high value of RDV means the demand is volatile. Yet, Olhanger did not specify a threshold to which the assumption of high and low are decided.

P/D ratio

Which can be calculated through dividing the production lead time by the delivery lead time. A value of 1 means that they are equal, and a value of less than one means that the production can wait until the order is made by the customer, and thus MTO is viable. However, in such cases, one should look at REV value. If the value is very low, some items can be produced to stock to gain the economy of scale. This will lead to an ATO (Assemble to Order) case, where common parts with low RDV, and others with high RDV will be made to order (Olhager 2003, p. 327). In other words, ATO for one product, would encompass parts that are made to stock, and others that are made to order (Jodlbauer et al. 2012, p. 46).

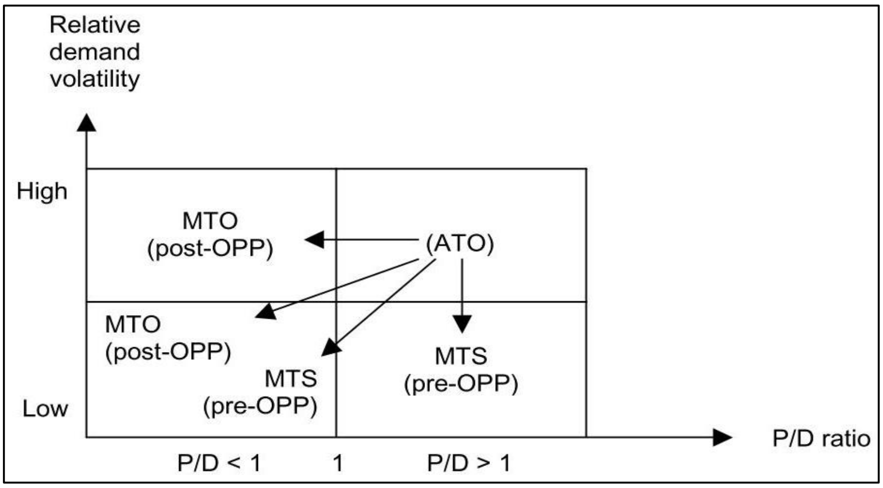


Figure 43: Factors affecting the position of decoupling point (Olhager 2003, p. 327)

Having said that, some researchers (Köber, Heinecke 2012, p. 455) showed that the model might hold some dynamic behaviours, since production is susceptible to capacity constraints, and seasonality in demand. Olhanger's model might guide us to the appropriate strategy. Yet, careful consideration should be given to seasonality and capacity constraints. **Figure 44** presents how the dynamic behaviour of demand of one product would look like.

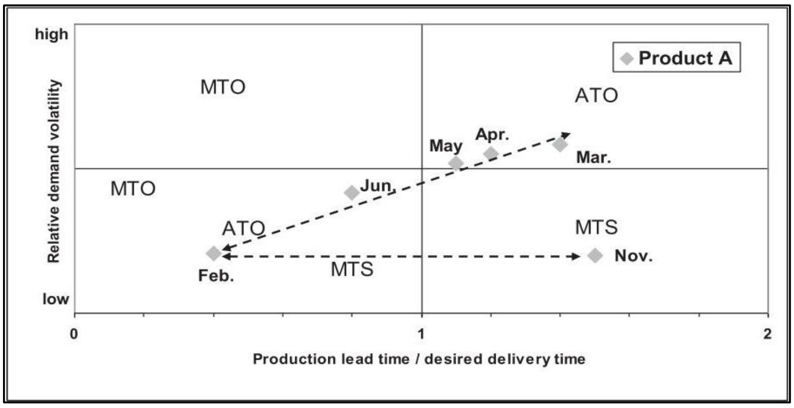


Figure 44: Dynamic position of decoupling (Köber, Heinecke 2012, p. 455)

2.6.3 Surge and base

The representation of **Figure 45** shows two types of demand; base demand that is forecastable, and surge demand which is unanticipated. The idea of surge and base calls for handling base demand in lean methods and achieving economy of scale, while, treating surge demand with agile methods to achieve higher flexibility. Consequently, more costs are incurred in the products produced in an agile way. This additional cost, however, is justified by the market advantage achieved. An example of this can be seen in apparel industry where low cost countries can produce the base demand, and the surge demand is produced locally with higher cost, in what is called as “spatial separation”. Another method of separation is “time separation”, where during slack times base demand is produced (Christopher, Towill 2001). It was observed that the serge and base classification matches the pareto chart one, since base products have high and stable demand, and are handled with MTS, and surge products have low and volatile demand are handled with MTO (Köber, Heinecke 2012, p. 456).

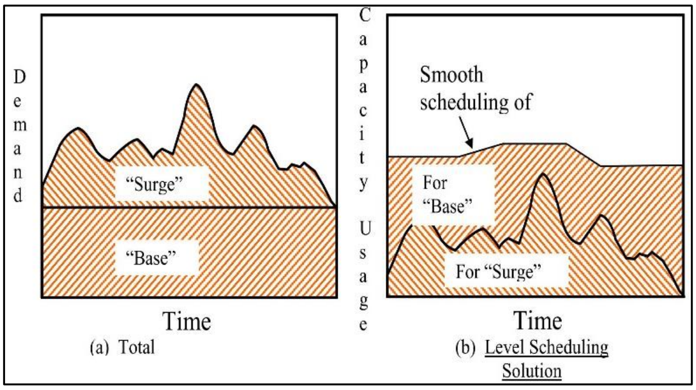


Figure 45: Surge and base demand (Christopher, Towill 2001, p. 10)

2.6.4 Simulation techniques

Simulation is considered an appropriate tool to understand and evaluate the behavior of manufacturing supply chains against different strategies. Even with well-defined methods to decide the decoupling point, the system might be subjected to dynamic behaviors, which necessitates using simulation studies to reach optimal solution as seen in the case of (Köber, Heinecke 2012, p. 458). Discrete simulation was used in different studies to decide the hybrid study, and specifically to locate the decoupling point (Onan, Sennaroglu 2007), (Köber, Heinecke 2012, p. 458), (Kim, Kim 2014, p. 32).

2.6.5 Frameworks and case studies

To implement hybrid lean-agile production effectively, the positioning of the decoupling point should be thought about and decided carefully. Thus, it is crucial to have a framework that addresses the products, processes, and business models for the supply chain that is characterized by uncertainty of its demand and lead time (Kim, Kim 2014, p. 32). Some methods and tools were presented earlier to apply hybrid lean-agile production e.g. (Olhager 2003, p. 327) and (Christopher, Towill 2001). However, looking at the literature of leanness and agility, one can observe that there is still gap about the applicability of these methods in real case situations, for example, when demand is volatile and seasonal (Köber, Heinecke 2012, p. 454). Two recent frameworks are suggested to implement the hybrid lean-agile production, and locate the decoupling point using simulation studies:

Köber and Heinecke's framework

As seen in (Köber and Heinecke 2012, p. 454), the researchers developed a framework that helps utilize the hybrid of MTS and MTO in the case of erratic demand, seasonality and capacity constraints. The model builds on the methods presented earlier by (Olhager 2003, p. 327) and (Christopher, Towill 2001). The method consists of three main phases as shown in **Figure 46**.

Phase I: Using Olhanger's method to categorize products in MTO and MTS quadrants based on P/D and RDV (CV). In the case study all products were located in the MTO quadrate.

Phase II: As a result of phase 1, all products where located in the MTO side, however, given that there is seasonality and demand volatility, the hybrid strategy is more economical. Thus, Pareto chart was used to sketch all products against demand. Every point on the curve is considered a simulation target.

Phase III: The last phase utilizes simulation, where every point on the pareto curve is considered a simulation scenario, for example, the first point of the curve would represent a case where all products are made to order, while another point would allocate one product as a made to stock, while the others are made to order. Different key performance indicators should be used, such as capacity utilization, price realization, service rate and delivery rate. In the case study, the hybrid situation achieved the best combination of capacity utilization and price realization, which justified the raised inventory cost comparing to other solo strategies.

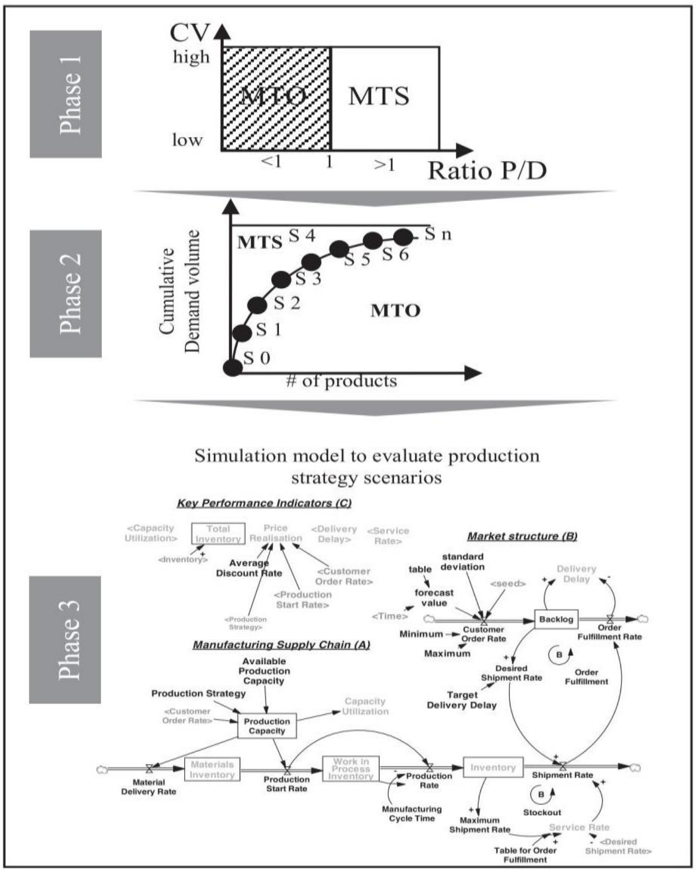


Figure 46: Framework for leagility implementation (Köber, Heinecke 2012, p. 457)

The model culminates in adopting a hybrid strategies MTS and MTO, and two decoupling points, one for the MTO products and another for the MTS products as shown in **Figure 47**. This hybrid outperforms the one solution supply chains that are only based on make to stock, or make to order.

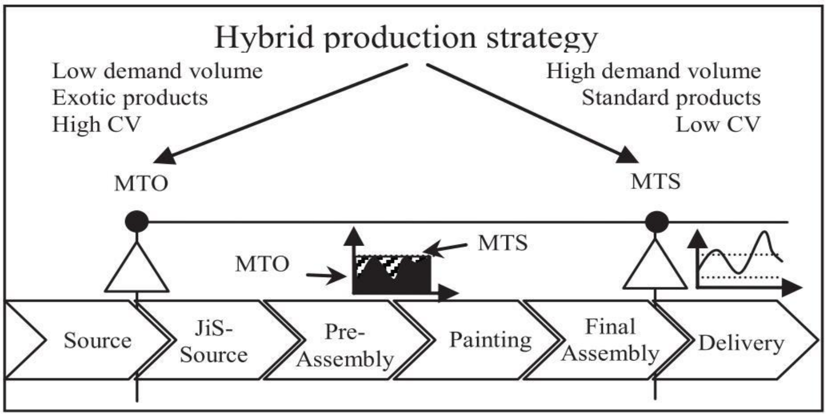


Figure 47: Hybrid production strategy (Köber, Heinecke 2012, p. 458)

Kim Framework, 2014

Another framework was recently suggested by (Kim, Kim 2014, p. 32), and was applied on a semiconductor industrial case. This framework resembles the above mentioned framework in terms of utilizing simulation, and considering the lead time and demand variations. The framework extends on a previous framework suggested by (Kim 2006). The framework consists of four phases:

Phase I: The first step should be to construct the product process matrix. The cornerstone of the matrix is to locate the point of customization for every product family. The decoupling is called here Standardization Customization Boundary (SCP).

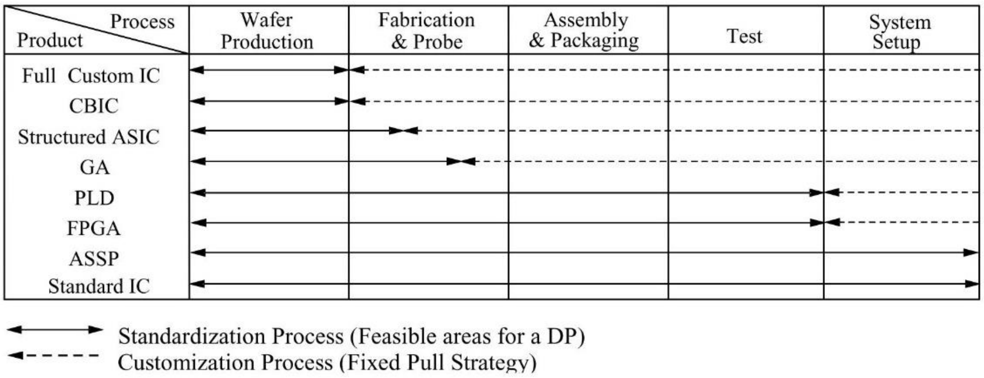


Figure 48: Product process matrix (Kim 2006).

Phase II: Decide feasible areas for every product: The feasibility scope is decided based on the customization processes for every product.

Phase III: Narrowing down the feasible area for the decoupling point, based on realistic considerations at the work place. The shaded areas in represent the feasible area before the decoupling point.

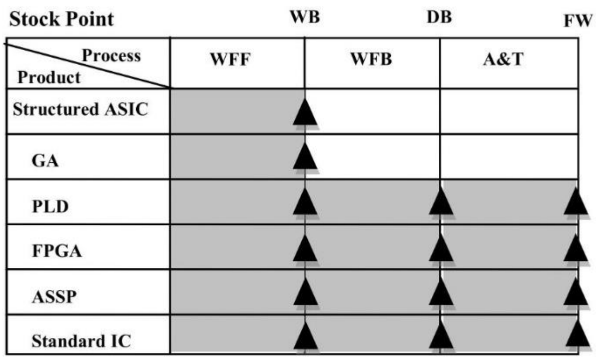


Figure 49: Feasible areas for decoupling point (Kim, Kim 2014, p. 36)

The matrix should be subjected to different scenarios to decide the optimal place of the decoupling point. (Kim 2006) provided a guideline that helps construct the matrix, and help during the decision making process in the steps that follows. The proposed guideline, however, the new paper presents some modifications on that guideline based on a simulation study. Thus, we will present the modified guideline in a flow chart, for clearer representation.

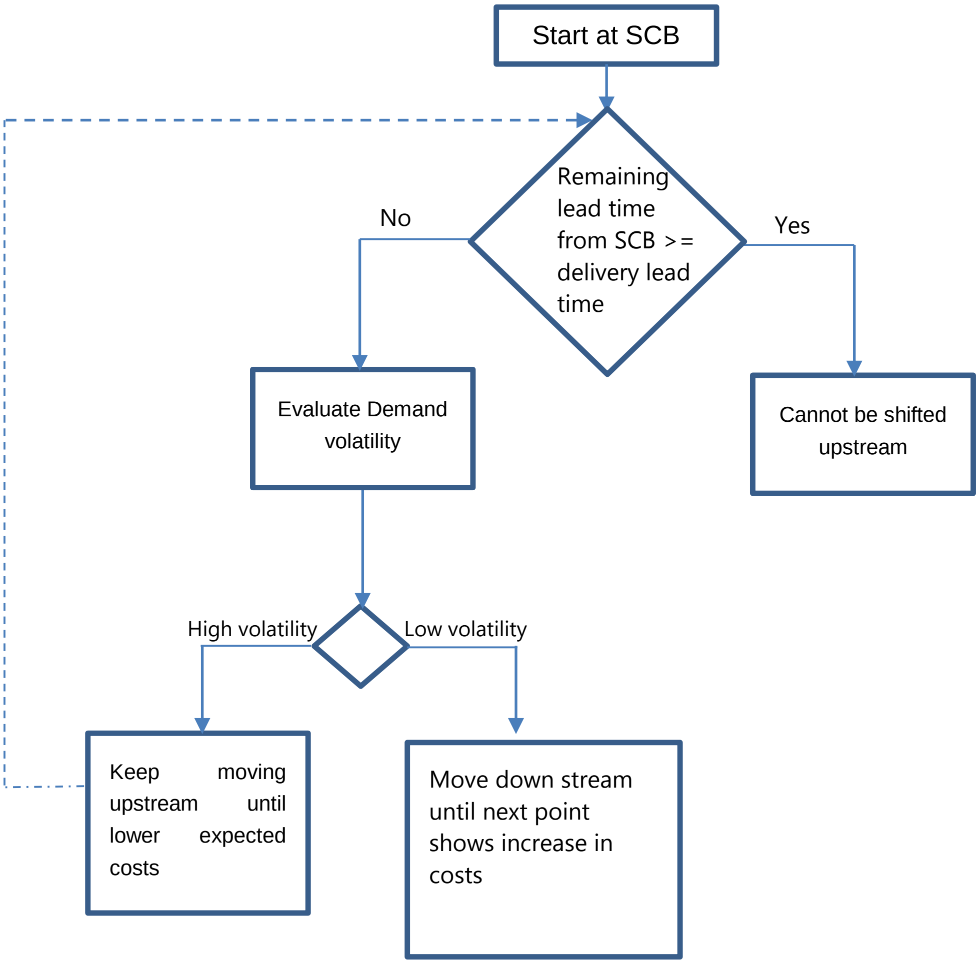


Figure 50: Modified Kim 2006 guideline for decoupling point position based on (Kim, Kim 2014, p. 43)

Phase IV: Simulation and Measurements: It is integral to translate the performance metrics into cost metrics. The variability of demand can be represented by different CV's of demand. With regarding to cost, if products have high carrying cost, and short life cycle then inventory cost is the most important metric. Eventually, total cost is calculated through summing up the inventory cost, incentive cost, and penalties for unfulfilllments (Kim, Kim 2014, p. 37). Thus, the decoupling point can be decided through the point with lowest total cost. The results of the simulation study are presented in Figure 51 and Figure 52 respectively.

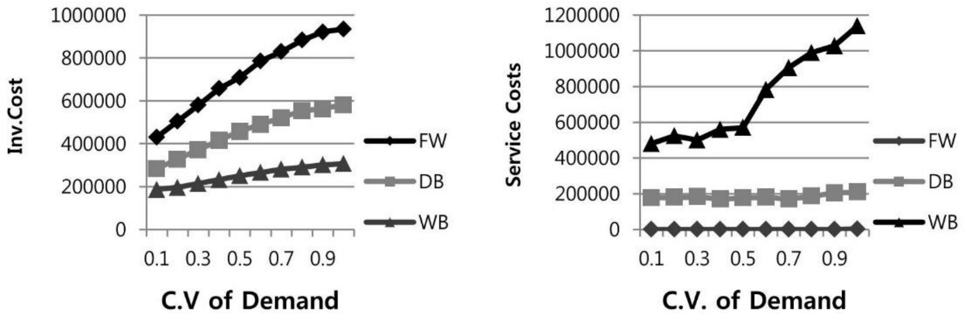


Figure 51: KPI's in the simulation study (Kim, Kim 2014, p. 41)

All in all, the framework helps in deciding where to place the decoupling point to have an optimal solution. Several alternative might be suggested and tested with such framework.

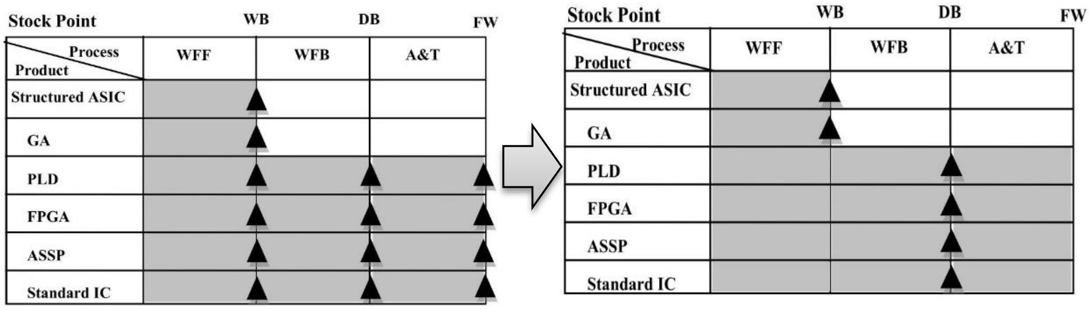


Figure 52: Product-process matrix before and after simulation

2.7 Summery and derived research gaps

This chapter stems from the literature review, and presents the basic research gaps in literature addressing the integration of lean and agile production. The following chapter presents the main research questions based on the literature review:

Research direction in lean, agile and leagile production

In literature, authors hold different positions regarding what is really needed in the current and future production environments. A clear direction cannot be seen when looking at the literature in this area. **Table 10** summarizes how the topic is seen by researchers during the last two decades. This was done through analyzing 37 different sources.

Table 10: Research directions in Leanness and Agility

Position of researchers and arguments	Sources
Agile Production is the future: agility is generally a superior system, and is the direction where companies should go.	(Narasimhan et al. 2006), (Hallgren, Olhager 2009), (Purvis et al. 2014), (Hormozi 2001), (Sharp et al. 1999),(Yusuf, Adeleye 2002), (Katayama, Bennett 1996)
Leanness is promoter to agility and underpins the application of Agility: Leanness is the basis, and it underpins achieving agility.	(Shahram et al. 2011), (Christopher, Towill 2001), (Wang, Koh 2010, p. 9).
There are different supply chains, lean, agile, resilient, leagile, and the choice depends on several criteria: This research focused on comparing the four supply chains, and based on different criteria and situations, companies choose what is needed e.g. type of products, volatility etc.	(Mason-Jones et al. 2000), (Agarwal et al. 2006), (Vonderembse et al. 2006), (Hallgren, Olhager 2009), (Purvis et al. 2014), (Lotfi et al. 2013),(Stump, Badurdeen 2012), (Goldshy et al. 2006).
Leanness has the potential to be highly flexible and achieves agility: Some backup tools should be added to Lean production. Yet, all the suggested ones indirectly are linked to agility i.e. ERP, IT systems, FMS, group technologies etc.	(Villa, Taurino 2013),(Drew et al. 2004), (Hayes, Pisano 1996), (Boyle, Scherrer-Rathje 2009), (Bell 2006), (Bohnen et al. 2011), (Prince, Kay 2003),(Onyeocha, Geraghty 2012), (Piazolo, Felderer 2013)
Leagility "combing leanness and agility" what is needed in today's environments. This research focused on the guises of the leagile supply, and the role of the decoupling point, postponement, MST-MTO hybrid etc.	(Ben Naylor et al. 1999), (Krishnamurthy, Yauch 2007), (Olhager 2010),(Nieuwenhuis, Katsifou 2015b, p. 234), (Martin, Towill 2000a, pp. 2012–2013), (Mukhopadhyay 2015), (Ambe, Badenhorst-Weiss 2010), (Olhager 2003, p. 327), (Jodlbauer et al. 2012), (Towill 2005), (Christopher, Towill 2001)

Hybrid lean-agile production from operational point of view

The aspect of flexibility and agility in lean production has been the subject of controversial discussion between researchers during the last decade. Whilst some researchers (Drew et al. 2004, p. 41), (Hayes, Pisano 1996, p. 36),(Boyle, Scherrer-Rathje 2009, p. 349) advocate that lean can support agility, others (Purvis et al. 2014, p. 102), (Ben Naylor et al. 1999, p. 112), (Chahal 2012, p. 407,408) show that lean does not, and should be enhanced with other strategies or systems. Most of the literature, however, deals only with the strategic view of the two approaches, such as drivers, objectives and effect on overall performance, while neglecting the operational level. In in other words, what should be clarified is how the lean tools, and the agile ones can coexist in such hybrids. To address the operational level, chapter 2.4 focused on the computability between the lean tools and agile tools, and proved that while some of the lean tools are compatible, others are not, and some should be accommodated to adapt to such hybrid environments. The results of this analysis, however, should be validated and investigated empirically.

The successful implementation of hybrid leanness and agility in practice

Although the integration between leanness and agility is currently attracting both manufacturers and researchers (Mukhopadhyay 2015, p. 362), literature in this area shows little about the implicational aspect as it focuses on the ‘what’ and ‘why‘, while neglecting the ‘how’. In addition, while some models have been recently developed, there is little evidence that these where successfully applied in real world practice (Naim, Gosling 2011, p. 352). Moreover, little information in literature was provided about the specific nature of the material decoupling point, and the elements that determine the exact location of the decoupling point (Nieuwenhuis, Katsifou 2015a, pp. 234–235), (Krishnamurthy, Yauch 2007, p. 601). Some frameworks have recently been proposed, see (Köber, Heinecke 2012, p. 458) to help companies locate the decoupling point and achieve an effective hybrid lean-agile production. Such methods, however, necessitates conducting case studies for verification (Köber, Heinecke 2012, p. 458). Same for the above mentioned framework of Kim, which was developed for semiconductor serial manufacturing. The authors of this approach are calling for applying this model on different environment, which might modify the framework (Kim, Kim 2014, p. 44). The pioneers of the term “leagilty” at Cardiff University logistics group, have recently published a paper that highlights where the research should go in the future based on previous literature in leagility during the last decade. The authors are calling for more empirical studies in the area of hybrid lean-agile production.

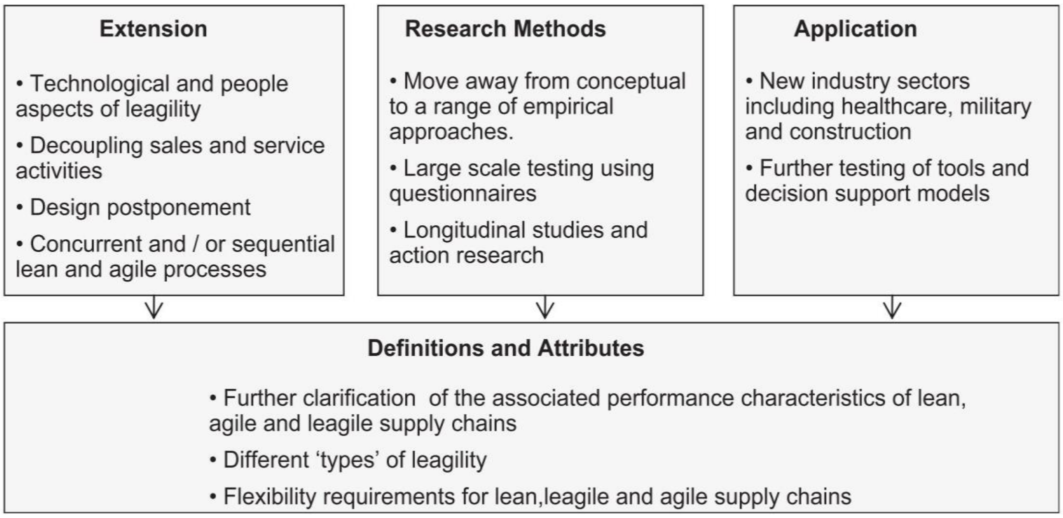


Figure 53: Future research possibilities (Naim, Gosling 2011, p. 352)

Planning and Control in hybrid lean-agile environment

Additionally, we have seen through section 2.5.2 how companies should tailor their planning and control activities differently before and after the decoupling point (Olhager 2010, p. 867), (Ho, Chang 2001, p. 177). However, it was also observed the lack of interpretation on how this separation of Production Planning and Control happens in practice. Furthermore, it was shown how when combining contradictory concepts like MRP and JIT (Benton, Shin 1998, pp. 424–429), or ERP and Leanness (Piazolo, Felderer 2013, pp. 13–18), more flexibility could be achieved. Yet, as stated by (Piazolo, Felderer 2013, pp. 13–18) the realization of such combination should be further investigated in future research. The aim here, is to further understand how planning and control is done in such hybrid situations, and whether there is clear separation of these activities before and after the decoupling point.

3 METHODOLOGY

The research was conducted based on the derived research gaps. The onset was through the house of lean, which was investigated according to literature on how its contents support flexibility and agility. It was shown in chapter 2.4.1 how flexibility is an integral part of agility (Rabitsch, Ramsauer 2015, p. 4). The lean contents were then classified into three main categories; supporting agility, neutral and needs to be tailored to achieve more agility. Neither of the tools was contradicting to flexibility and agility. This was further investigated empirically through conducting interviews and case studies at four major manufacturers in Europe, namely: Magna Powertrain, Plansee, Austrian automotive manufacturer, and Miba Sinter Slovakia. The criteria for choosing the companies were based on functioning in a volatile market, and being involved in lean projects for long time, in addition to the willingness to support the research. In fact, eight companies were contacted seeking to enlarge the number of participants, and only the interested ones were involved in the study. The four companies not only have big market share in Europe, but also are considered first tier suppliers to major global automotive and technology companies in the world such as BMW, Mercedes, Toyota etc. Thus, we believe that the approaches these companies implement will resemble their customers, and thus, would represent to a large extent what is being implemented in top notch companies world-wide.

The interviews and case studies were conducted with production managers/quality managers/ supply chain managers. Each interview lasted for approximately two hours. During these interviews and cast studies, the companies mapped their systems to both the lean tools and the agile ones from literature, and were then asked to select which lean tools enhance flexibility and agility. Additionally, they were asked to select among a list of agile tools (see chapter 2.1), which important agile tools can coexist within their lean supplies. The selected agile tools, were also studied based on literature (see chapter 2.3) to elicit the ones that are in congruence with leanness, and this culminates in deciding what agile methods are needed to be incorporated within the lean system. In addition, the companies where asked to describe how production planning and control is done, and what tools and practices are being implemented in support of such hybrid supply chains.

Each interview culminated in a SWOT analysis, emphasizing the strength points of the supply chain, weaknesses, threats, and opportunities for improvement. For example, if a company was considering itself as a lean company, and was missing some of the integral methods of lean, then this was highlighted as an opportunity for improvement. Same, for a company that was suffering from high non fulfilment, and was missing a flexible pulling control. The SWOT analysis was based on literature in lean, agile and leagile production. This SWOT study primarily aimed at analysing the status quo and evaluating the level of agility and flexibility at the interviewed companies. Based on the production system applied at the four companies, they were classified as lean, agile, leagile and a mixture. The criteria for classifying the companies was based on the classification of (Agarwal et al. 2006, p. 212) and the literature review of leagility. The fourth item was added to denote the case of most of the interviewed companies, where no clear distinction could be obtained.

Table 11: Criteria for supply chain classification

Classification	Lean supply	Agile supply	Leagile supply	Mixture lean-agile
Criteria based on literature	Predictable demand, low product variety ,market winner is cost, and achieving the main lean tools	Volatile market, high product variants, high product flexibility, and achieving the main agile tools	Volatile market, decoupling point, postponement strategy, hybrid MTS/MTO, separated systems	Exhibiting characteristics and operations from both paradigms, no clear separation.

The final step was to investigate the applicability of the hybrid lean-agile through a case study at Miba. This was done through discrete simulation based on real data, and using a simulation software (Plant Simulation 12). The aim of this study is to solve a real world problem, where the need for hybrid lean-agile is exhibited. The case study will go through several implementation models, and concepts from the literature review. The aim is to prove that utilizing lean-agile hybrid will prove superior performance than the status-quo.

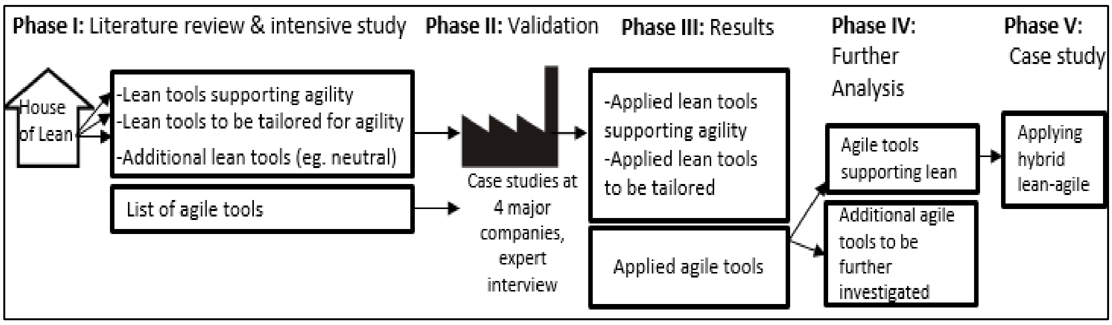


Figure 54: Research methodology

4 INTERVIEWS WITH INDUSTRY EXPERTS

The following chapter describes the main results of the four interviews, and then detailed every interview separately.

4.1 Overview about the interviewed companies

In an attempt to further understand the applicability of leanness and agility in real world practice, the empirical part was implemented at different big manufacturers in Europe. **Table 12** gives an overview about the interviewed companies. Three of the companies accepted to declare their name, and one company asked for anonymity, and will be referred to as Austrian Supplier.

Table 12: Overview of the interviewed companies

Items	Magna Power train	Plansee	Miba Sinter	Austrian Supplier
Business	Automotive	Powder metallurgy	Powder metallurgy	Automotive
Products variations	High (150 variations)	High (69 variants)	High (270 variations)	High
Production Strategy	ATO	Hybrid MTS MTO	MTO	MTO
Company size	Large	Large	Large	Large
Max delivery time	4 weeks	3-4 weeks or 1 week	3 – 4 weeks	1 week
Max throughput time	12 – 16 weeks	10- 11 weeks	4 weeks	3 days
Type of supply chain	Mixture lean agile supply	Leagile supply	Mixture lean agile supply	Mixture lean agile supply
Market winning strategy	Price and Quality	Service level and flexibility	Service level and flexibility	Price and Quality
Ability to handle surges and drops in demand	Moderate	High	Moderate	Moderate
Volatility of demand	Normal	High	High	Normal

4.2 Magna Powertrain

Company overview

Magna Powertrain is a global supplier in the automotive industry with full capabilities in powertrain design, development, testing and manufacturing, and providing complete system integration, which sets the company apart from other competitors. The company has two plants in Austria, one in Lannach and one in Weiz, and the interviewed plant is the Lannach's . The plant in Lannach employs 1600 people, and the one in Weiz employs 600. The plant in Lannach focuses mainly on gear shafts, and high value added parts, shipped to Weiz for storage, and from there along with other purchased parts, assembly is done and parts are shipped to customer. In Lannach, two main families are being produced which are driveline components and fluid pressure, with an emphasis on the former. The company has 31 assembly lines with some duplications, to produce 28 different types of products with different variants depending on the customer eg. BMW. On total, the company produces 150 different products to customers. Different lead times exist depending on the components short, medium, and large, but the highest production lead time goes for the forged parts which take around 12- 16 weeks. The market winning strategy for the company is mainly cost and quality. The company started applying lean production since 2000, and developed it over the years.

Interviewee

Name: Joachim Schuster
Position: Global Quality Manager
Company: MAGNA Powertrain GmbH, Plant Lannach
E-mail: joachim.schuster@magna.com

The mixture of leanness and agility at Magna power train

The interviewee sees that the nature of the industry Magna runs in, makes ultimate leanness hard to be implemented due to the long production lead times, and high levels of variations. *"Leanness is very much focused on levelling production, which the company tries hard to do"* said Mr. Schuster. To explain production levelling at the company, the interviewee mentioned: *"We typically run in batches and our goal is to run every part every day, e.g. AAABBBCC. The current level of changeover times, especially in component machining, is too high to run A, B, C and change over at each cycle".*

The company implements other typical lean methods such as value stream mapping and avoiding waste. Nevertheless, it was observed the limited usage of Kanban. *“In ultimate leanness, companies try to have efficient number of Kanban cards, to accept volatilities. However, the challenge is that the house of cards collapses if there are high changes in customer demand, which is where agility* interferes” said Mr. Schuster. Thus, the use of Kanban control is only confined to one stage in production which is the die casting. When levelling production causes too much inventory, this is where agility comes. Due to short term fluctuation, which causes bull-wip effect, the company tries to increase the amount of the final good inventory. In addition, the company attempts to adjust the number of shifts accordingly, with a base of 17 shifts per week. The company might also change the number of operators in the assembly lines, e.g. base 10 operators, but can also run with five operators. This will account for double takt-time from the customer. This also implies that there is scenario based planning, to be able to handle these changes. Additionally, the company has very good forecast and planning tools to prepare for the capacities ahead of time. Magna powertrain applies the postponement strategy, which is postponing the assemblies until real order is committed. This constitutes a material decoupling point between forecasting based production and real demand in assembly stage.

In addition, the company handles surges in demand through outsourcing, however, the company’s ability to handle big surges is not currently viable, while drops in demands are handled through swift actions, mainly thought about in advance as scenarios, to decrease the pace of production. The sound data exchange systems enables this process runs effectively. The reason why the supply is classified as a mixture of lean and agile production was due to the fact that a total separation of operations into a lean part and an agile part, was not the case. Section 4.7 presents all the identified lean and agile tools at the company.

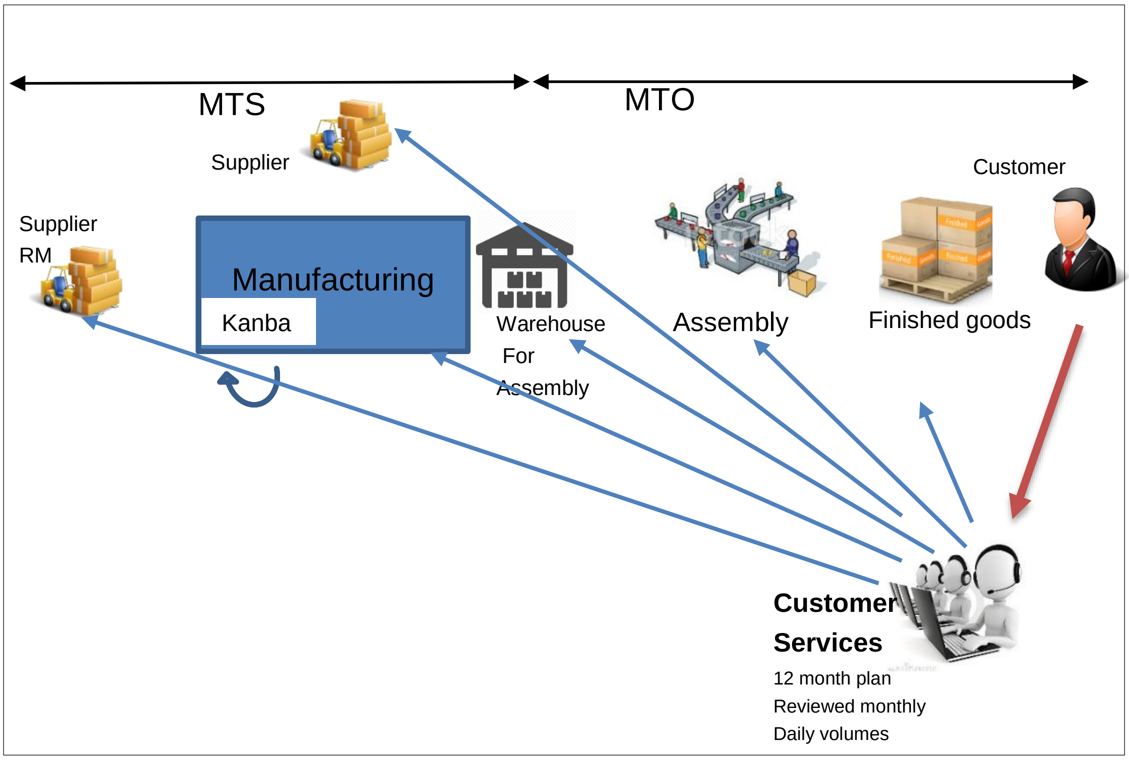


Figure 55: Decoupling point at Magna Power train supply chain

Production planning and control

The company plans for production as follows. Yearly planning is done based on internal and external data sources. Mid-term planning happens through a monthly meeting that looks at all information from sales, forecast, and customers. Based on all these, a plan per product per program is made, to specify how many parts will be produced on daily bases. The plan is for 12 months period and is reviewed and can be updated monthly. This is important to decide on the necessary capacities. However, assembly does not start until there is real customer demand for a period of 4 weeks. This necessitates the existence of make to stock items to be stored beforehand in the warehouse assembly. The company then, depends on an Assemble to Order ATO strategy for high lead time products. In other words, assembly is triggered through a period of around four weeks, and a make to stock strategy is applied for the components of these parts based on forecast and sales info during the midterm planning. The MRP is used to decide the starting of production according to BOM. Each stage has a minimum and maximum buffer level. For instance, if the assembly line reached the minimum level, the SAP is used for replenishment. The EDI connects all the stages together and enables sending information to all stages in the same time.

SWOT analysis

As a summary, SWOT analysis was used to evaluate the flexibility and agility of the current supply and present the weaknesses and strengths, and further opportunities to enhance the agility and ability to cope with market volatilities. The contents of this analysis are made based on observation and direct dialogs with the interviewees.

Figure 56: SWOT analysis of the lean-agile hybrid at Magna Power Train

4.3 Plansee supply

Company overview

Plansee company's main plant exists in Reutte, Tirol, Austria. The company's main business is to transfer powder material into finished products with exceptional qualities used in several industries, primarily in technology. The company's customers are functioning in the high-tech market. The company produces three families totally in house, which are thin film material, components, and semi-finished products with lots of variations per customer. The focus of the interview was on the thin film material family, such as sputtering targets, which has several variants, and was the focus of the interviewee at Plansee. The final products look as plates or tubes with different sizes and thicknesses. These products possess exceptional qualities thanks to the material and technologies used. The lead time ranges from 3 – 4 weeks for a portion of products sent to Asia for bonding, to less than 2 weeks for those manufactured completely in house. The company market winning strategy is flexibility and service level, and the market qualifiers are material qualities and cost.

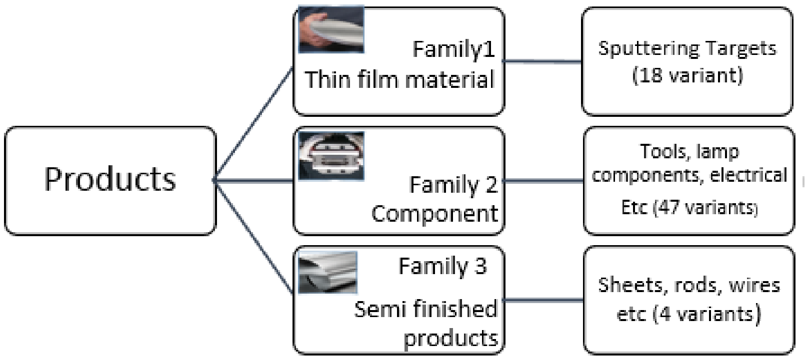


Figure 57: Main products of Plansee

Interviewee:

Name: Dr. Nikolaus Mitterer
Position: Head of Logistic Display & Solar
Division: Business Unit Coating
Company: Plansee group
Tel.: +43 5672 600-2176
Email: nikolaus.mitterer@plansee.com

The Leagile supply chain at Plansee

The company has a leagile supply chain for product family 1. The value creation activities is shown in **Figure 58**. The main decoupling point exists between the heating and the mechanical processing. The positioning of the decoupling point here was made because it is the point where differentiations happen. Additionally, both the material and information decoupling points coincide on the main decoupling point. Another generic inventory exists at the distribution centre "supermarket", and accounts for 35% of the products of family 1, that can be anticipated as they are considered as type A products. Thus, the company adopts hybrid MTS/MTO strategy in addition to a decoupling point. What characterizes the leagile supply in literature is the clear separation of activities between the lean part and the agile part. To explain this further, each part of the supply will be explained separately:

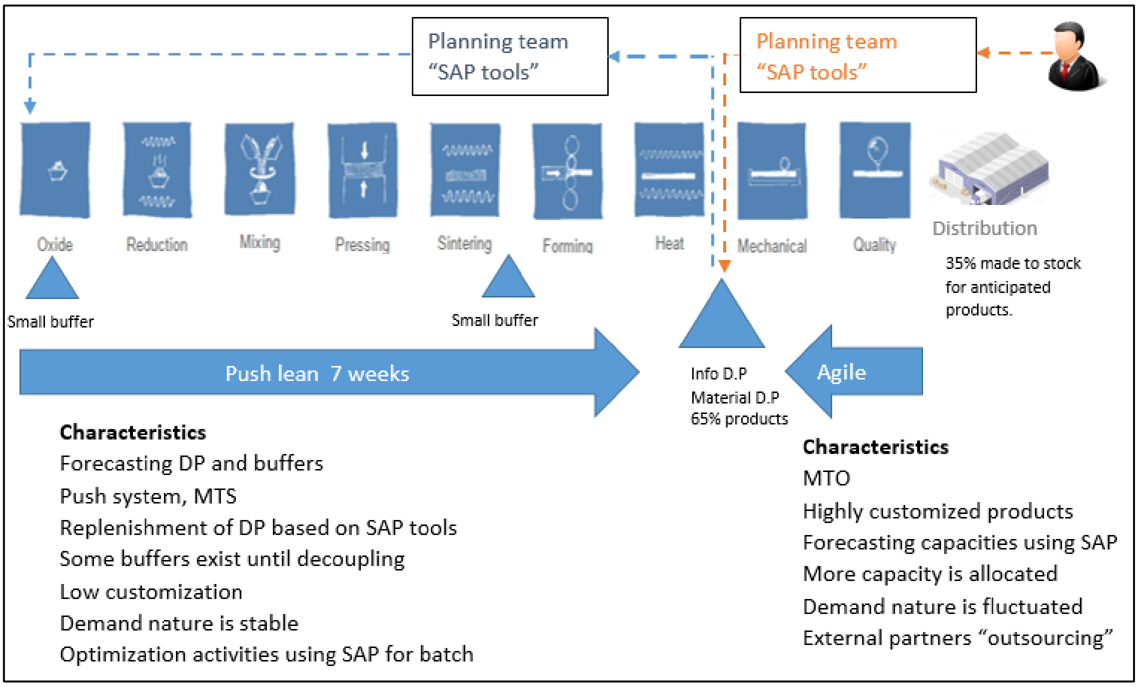


Figure 58 : Leagile supply chain of Plansee

Planning and control of the Lean part:

Before the decoupling point (upstream), products take the form of standardized products with MTS strategy based on forecasting in terms of size of decoupling point. Thus, forecasting activities for 65% of this family end at the decoupling point. Some buffers exist after the sintering and in the oxidation to react to variations during production, and that's applicable with lean as seen from the house of lean (chapter 2.2). Kanban is not used at the lean part. Nevertheless, the company uses SAP to replenish the decoupling point. It is also noted that there is a safety stock strategy applied in the decoupling point. The SAP decides the starting of production, quantities and optimized batch sizes to be produced in the line to replenish the inventory. The production planning activities are moderated by a dedicated planning team for the lean part, which implies that there are separation in planning activities before and after the decoupling point, as indicated by (Olhager 2010, pp. 866–867) in chapter 2.5.2. The complexity in the lean part is lower than the agile part. Moreover, controlling the production is also done through teams who check the inventories and make sure that production and quantities are done as planned. Quality control checks are constantly done after sintering, heating and extensively during every stage in the machining (cutting, grinding etc). However, the lean part does not utilize some of the traditional lean tools such as production levelling, Kanban, visual management and 5S on big scale. Yet, the interviewee believes that the nature of the upstream processes is based on line production with few stages, very few variants, short lead time, which don't support applying Kanban or CONWIP or any hybrid systems. Interestingly, was that when reviewing the bull-wip effect of the upstream part, the fluctuations were significant, which makes some concerns regarding the planning and control of the upstream part.

Planning and control of the agile part

The agile part starts from the mechanical processing, where complexity surges, and more differentiations are required. Another production planning team is responsible for the agile part, who looks at customer demand information for a period of 4 weeks. Based on these data, capacity planning is carried out. In case demand exceeds the company's capacity, the company deals with external partners who can absorb the surges. Another characteristic of the agile part is that the level of extra capacity allocated to this part is way bigger than the lean part, which incur additional costs, but guarantee a higher service level at the end. It is worth mentioning that, section 4.7 presents all the identified lean and agile tools at the company.

Figure 59: SWOT analysis of the leagile supply chain at Plansee

4.4 Austrian automobile manufacturer

Company Overview

The interviewed company, is a major automobile manufacturer in Austria. It is specialized in producing individual systems range from car door modules to full vehicles, and from extra-low volume through peak shaving to volume production. The interview focused on the production of complete cars. The company has been applying lean principles for a while, and they have reached a high level to satisfy some major customers with their lean systems like BMW. The company depends completely on a Make-to-Order policy. The lead time for producing one car is 3 days. It is worth mentioning that the customer places the order several weeks in advance, and can change it up to 6 days prior to receiving the order. Normally, the customer is willing to wait several week until receiving the order. The winning strategy of the company is primarily price, and the volatility of demand is relatively normal. The company has requested anonymity, and thus will be referred to as Austrian automobile manufacturer.

The mixture lean agile supply chain at the company

The interviewee thinks about leanness as "*a focused system to avoid waste that should not contradict to being agile"*. The company started focusing on being agile, especially after witnessing sudden demand drops in 2008 due to the financial crises, where more flexibility was needed. However, the demand nature in automotive industry is quit predicted, and is not like other industries such as retailor shops where one cannot predict the demand, as indicated by the interviewee. This makes the company dominantly lean, especially with the company's price market winning strategy. The company depends completely on a make to order strategy, and generally does not have make to stock items, due to the short supplier lead time. The customer is able to change the order within 6 days period to receiving the order. The production lead time for one car is 3 days, thus the company does not commit itself to orders unless these orders are confirmed. Raw material and some modules and accessories are ordered, and should be available 2.5 days prior to starting production, but within the 6 days of confirmed order. This reduces the risk of obsolescence. The modules and accessories are put at a supermarket, and according to the sequence they are sent to the production lines. Although the company applies lean production for a while, some of the integral lean concepts were missing such as defined value stream mapping for all the products, constant reduction of lead time, and cellular manufacturing. The following table summarizes the main lean and agile tools used by the company. Another interesting observation is that although the company is seen to be a lean company, it relies on some agile tools and practices to cope with variations, such as peak shaving and extra shifts, robotics, postponing some differentiation parts, modularization of assemblies. The company started using 3D printing, but on a narrow level of application. Thus, a conclusion was made to consider the supply as a mixture of leanness and agility.

Planning and control of production

The planning and control of production starts from yearly bases, which is broken down to daily bases. *"Main focus is to keep this as stable as possible"* said the interviewee. The E-Kanban works as follows: *"every stage has a min and max stock level, and when the level goes bellow the min level, then the system sends a signal to replenish"*. This is done through the SAP. The company levels the production in mixes, and based on the change over time. *"The fact that there is 6 days prior to production makes it easier for the company to find the optimal mix and to react to changes in demand"*. The company has a complete pull system, using an electrical Kanban to control all stages, and a centralized planning unit.

To conclude, the following SWOT analysis shows the strength areas, and weakness areas by the company, in response to lean and agile literature

Figure 60: SWOT analysis of the hybrid lean-agile supply at the company

4.5 Miba Sinter

Company overview

The company is cited in Slovakia, and was established in 1991, as part of the global network of Miba around the world. The company is a supplier to big companies like Mercedes and BMW. The company, supplies automotive industry customers with high-precision, high-quality solutions. The plant consists of 4 production units each has its own hierarchy. Miba siter produces 270 different products gathered in 10 main families which are Flags, Hubs, Pistons, Friction Rings, Synchronizer Rings, Stators, Setting Rings, Belt pulleys, Water pump pulleys, and Chain Sprockets.

The nature of demand is usually unstable, and the market winning strategy of the company is flexibility and service level. The company adopts a make to order strategy, and the lead time of production is 20 to 30 days. The company currently does not have a full implementation of leanness. The service level is very crucial to the company, and tremendous amount of costs are incurred if order is not fulfilled on time.   Thus, the company is considering shifting to a more flexible supply chain that enables it to cope with such risks more efficiently.

Interviewees:

Oleg Krajčovič
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Site Development – Miba Sinter Slovakia
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T +421 43 5802 262
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Email: michal.kubacka@miba.com

Mixture of leanness and agility at Miba

The company depends completely on a make-to-order strategy. The Lean system at the company is under development, and the current system is a combination of several tools from the lean and the agile paradigms that function together to satisfy customer orders. For instance, the company applies some of the traditional lean tools i.e. value stream mapping, TQM, 5S, cellular manufacturing, Kaizen and SMED. It also depends heavily on flexible manufacturing systems (CNC, CN), extra shifts, peak shaving and SAP, as agile methods. Nevertheless, the company is also developing the lean system, and considering applying production levelling and smoothing, supermarket and TPM. In addition, the company is currently studying a possibility of a using hybrid of MTS/MTO and decoupling point to increase the flexibility of its production. The fact that the order is made for 6 week time, encouraged the company to start producing by order. The current system, however, makes it difficult for the company to adapt to changes made in less than one month period due to the long lead time. In addition, varied products possess volatile demands, which impose risks at the company.

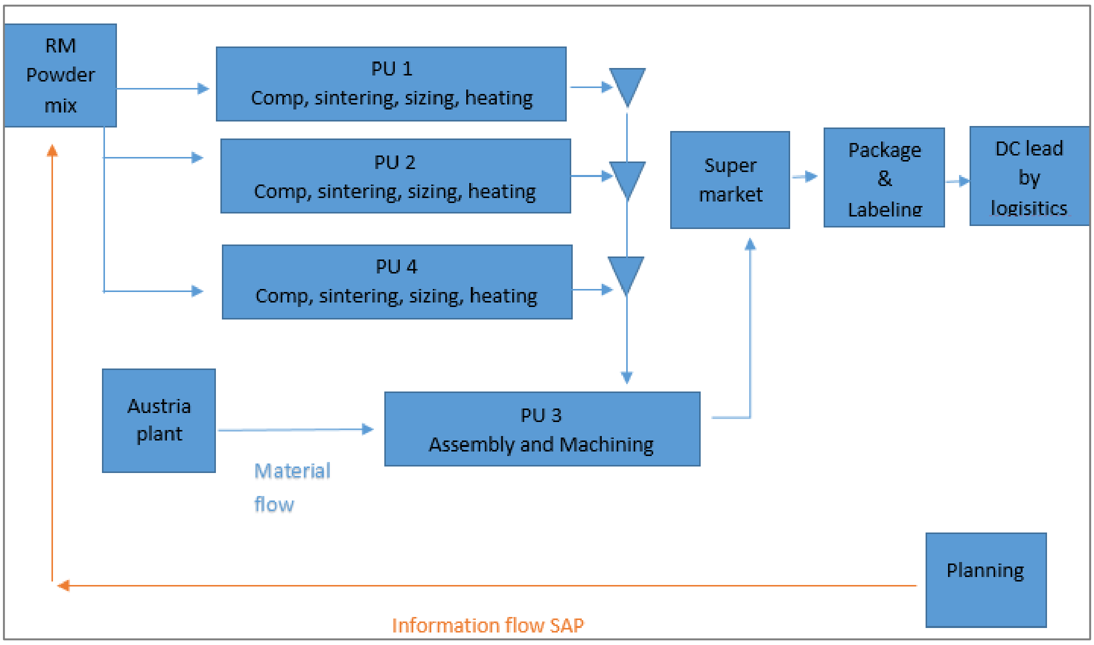

Figure 61: The supply chain at Miba

Production planning and control:

The current planning works as follows: Customers place the orders and the due dates for a period of 6 weeks. Orders are susceptible to change, and based on the capacity level, the company can inform the customer whether they can deliver or not. Usually, if the quantity of the order changed 30 days prior to the due date, some delivery problems would occur. The company relies on SAP to decide the optimal lot sizes, and to launch the production schedules. The company has batch production, and the inventories and buffer places are not controlled, making the system closer to a push type. MRP calculations are not often accurate due to the lack of continuous and electronic inventory tracking. The allowed flexibility level is +- 15% with the current system, making it not highly flexible. The current system provides feedback once every 24 hours done manually, makes the response a bit slow in some situations.

To conclude, the following SWOT analysis shows the strength areas, and weakness areas of the supply chian’s flexibility, in response to literature in leanness and agility.

Figure 62: SWOT analysis of the lean-agile supply chain at Miba

4.6 Expert Interview

In addition to the above mentioned company interviews, a Lean expert was approached. The aim of the interview was to discuss how agility and leanness should coexist, and to validate the classifications of the lean tools' agility.

Interviewee background

Mr. Hammer, is a senior knowledge expert in McKinsey. He has been actively involved in several lean projects at the industry. He is also an expert in company's operations, sustainability, Resource Productivity Practices. Mr. Hammer is also a global manager of McKinsey's Resource Productive (Green) Operations.

Interviewee contact information

Markus Hammer
McKinsey & Company, Inc. Austria ,Schottenring 19, 1010 Wien, Austria

Basic points from the interview

- Flexible Pulling Systems: The BK-CONWIP system (presented in chapter 2.4), seems to be an agile lean system, although there is high complexity in implementing such system. Yet, hybrid control system would be superior in multi-product situations.
- The agility aspect of lean production: The expert agrees that some of the lean production tools should be altered, and some agile tools should coexist within the lean system to achieve higher amount of service level.
- MRP vs Kanban: MRP is more applicable with long term planning and meeting long term demand, capacity, and it helps with levelling production as well. One the other hand, Kanban is used on day to day bases, self regularly units. It should be pointed that MRP is used in every company that expert dealt with. Additionally, the MRP helps in sourcing.
- Leagility Supply Chain: *"Lean and agile supplies should be compatible. The main difference between the two systems, is that in leanness, capacity is utilized to the most, while in agility, extra capacity 'more waste' is added, and thus the firm benefits from fluctuations"* said Mr. Hammer. Thus, from operational point of view they must be similar, while from planning and strategic point of view they could be divided into two separate parts; agile part for highly customized products and lean part for less customized ones. Another distinction is that leanness calls for stability, so you try to stabilize the

demand, so the principles such as quality can be applied. However, the mechanism would differ if variations were too high. For example, the lean hijunka box would not be applicable in case of high variations and low volume situation, especially when you cannot see these variations coming. In high variations you can apply the line balancing for planning. Consequently, agility is about the strategy planning, but leanness is for the execution. However, operations of the two approaches should be in congruence.

4.7 Results of the interviews

The empirical analysis was conducted at four major suppliers in Europe. The methodology was based on interviews. To investigate empirically the agility of the lean tools and validate them, the classifications resulted from the literature review (chapter 2.4) was shown to the companies, which they all agreed to unanimously. Then they were asked to select the ones they implement or will implement and find crucial in achieving agility (4.7.1). Then, companies looked at the agile tools compiled in chapter 2.1 , and chose the most important ones that underpin their lean supplies to cope with the current volatile market (4.7.2).

4.7.1 Validation of lean tools supporting agility

The following table summarizes the identified lean tools during the interviews:

Table 13: Mapping lean tools classification with the interviewed companies

Lean tools		Magna Powertrain	Austrian Supplier	Miba	Plansee
Lean tools supportive to agility	Supermarket, buffers	✔		•	✔
	Over capacity			•	✔
	Visual management, andon, and 5S	✔	✔	✔	•
	Standardization	✔	✔		✔
	Cellular manufacturing and Seru Seisan	•		✔	✔
	Lead time reduction	✔	✔	✔	✔
	Reduction of set up time using SMED (Single Minute Exchange of Dies)	✔	✔	✔	✔
	Multifunctional employees	✔	✔	•	✔
	Total Productive Maintenance (TPM)			•	
	One piece flow, Minimum lot size	✔		✔	✔
	Kaizen and communicate improvements			✔	
	Poka-Yoke			✔	

To be tailored	Scenario based takt time	✔			
	Tailored Kanban e.g. hybrid		✔	•	
	Careful elimination of waste	✔			✔
	Scenario based line balancing	✔			
	Adaptive level production	✔			
Neutral or pre-requisites tools	Cp, Cpk			✔	
	Availability			•	
	Sustaining the gains				
	5 Whys			•	
	MSA				
	OEE			✔	

Tools that are important for the company and are planned to be applied •
Tools that are important for the company and are already applied ✔
Blank cell means that the tool is not seen important for the company in achieving agility

4.7.2 Additional agile tools underpinning leanness

The chosen agile tools by companies are summarized as follows:

Table 14: Agile tools applied at the companies

Agile selected tools		Magna Powertrain	Austrian Supplier	Miba	Plansee
Agile tools that could support leanness	Flexible Manufacturing Systems (FSM)			✔	✔
	Hybrid MTS/MTO (Leagility)	✔		•	✔
	Decoupling point (leagily)	✔		•	✔
	Postponement Strategy (leagily)	✔			✔
	ERP software (eg. SAP)	✔		✔	✔
	EDI data exchange	✔	✔	✔	✔
	Scenario planning and market intelligence	✔	✔		✔

Additional Agile tools ,not related to leanness	Peak shaving	✔	✔		✔
	Extra shifts	✔	✔	✔	✔
	3D printing		✔		

Tools that are important for the company and are planned to be applied •
Tools that are important for the company and are already applied ✔
Blank cell means that the tool is not seen important for the company in achieving agility

4.8 Chapter summary

Several insights and observations can be obtained from the conducted interviews and case studies.

Agreement on the classification of lean tools

The interviewed companies agreed on the classification of the lean tools. This, was validated through asking the interviewees to select the tools they consider important and are applied, or to be applied at the companies, as shown in chapter 4.7.1.

Applicability of leanness

The interviewed companies adopt leanness for several reasons, such as reducing costs, or lead time. Nevertheless, it was felt that they were basically urged by their customers to be lean, and that's the main drive. Although all the interviewed companies exhibit several lean characteristics, a full and concrete implementation of lean production, with all the tools as in the house of lean, was not viable in any of the four companies. It was evident that companies would consider themselves as lean, even though the system does not include some of the main tools that characterize leanness such as Kanban, production leveling or defined value stream. The SWOT analysis shown after every interview, highlights that different flexible lean tools are yet to be applied, and there are several possibilities to achieve more flexibility in leanness just by applying some of the basic lean methods. On the other hand, it was validated and concluded that some of the lean tools should be tailored for agility in the current market environments.

Applicability of agility in lean supplies

The interviewed companies rely to achieving higher agility on some tools from the agile paradigms. Hence, integrating different tools from the agile paradigm to reinforce their lean supply is needed, especially in high volumes and mix situations.

Implementation of flexible Kanban systems

Although there is immense amount of literature about different Kanban systems to support flexibility, as shown in chapter 2.4.1, there was limited applicability of that in practice; among the interviewed companies, only Magna Powertrain had E-Kanban system based on safety stock levels.

Production planning and control in mixed lean and agile supplies

The use of ERP and MRP software is evident at the interviewed companies for production planning. The integration between ERP and lean is viable as seen in both the literature review and the interviews.

Applicability of leagile production

Literature in leagility, suggests a total separation between the lean operations and the agile ones. Whilst strategic separation between the two approaches is viable through a decoupling point, the operations of the two system are intertwined, and found hard to separate in majority of the interviewed companies. Only one company applied a leagile supply (4.3). The vast majority of the interviewed companies possess a mixture of lean and agile supply chains, with intertwined tools applied from both paradigms.

5 CASE STUDY

This chapter presents a case study based on simulating the material flow at Miba sinter Slovakia. The aim is to solve a real world problem using the concept of Leagile production.

5.1 Overview and problem description

The case study was implemented at Miba sinter Slovakia, and stemmed from the company interview presented in chapter 4.6. The SWOT analysis of the supply chain shows some weakness in the agile side of the supply chain. The high backlog and several non-fulfillments incur high costs, and affects customer's satisfaction. Moreover, the lack of data acquisition and data visualization result in inaccuracies in production control. To improve the flexibility and service levels, one of the initiatives the company is currently studying is the integration of lean and agile paradigms. Although the focus for the past few years has been on efficiency, leanness and low cost, the volatile market of the recent few years has led to a change in the way of thinking, and has given rise to a more emphasis on service level that ever. The customers are currently demanding high responsiveness to their changing demand, and the risk of non-delivered products is threatening. The fact that the market winning strategy of the company is currently service level puts an onus on the company's planners to achieve high level of flexibility and reconfigurability, while keeping production cost to the minimum and maintain lean processes. Although a compete MTO policy is applied for the 270 different products, the company in its quest for maximizing service level is considering a strategic inventory to be placed in the end of production, which accommodates several products within the 270 ones they produce. This methodology is called hybrid MTS/MTO as shown in chapter 2.6, and is considered an effective way in combining leanness and agility according to the literature. The method is also considered as a decoupling between lean and agile systems based on the products. The company however, would like to determine which products should be assigned to that strategic inventory, and based on which factors the decision should be made. Additionally, the company is interested in determining the optimal amount of products to be stored and the production control system that is suitable for this type of production. The main goal, is to achieve higher service level which overcomes the risk of obsolesces that may occur.

5.2 Goals of the case study

This work shows a use case of the implementation of lean and agile production in real work practice. The case study will include the topics of decoupling point, hybrid MTS/MTO, flexible production control, and simulation. The main goals are summarized as follows:

- Provide a practical use case of the implementation of hybrid lean-agile production, relying on several models from literature, and evaluating their applicability.
- Facilitating the company's decision making on the decoupling point topic.
- Designing a controlled strategic inventory, and assign products accordingly.
- Validating the results through simulation techniques, and compare the status-quo to the improved plan.
- Developing a framework for solving similar problems at companies.

5.3 Framework of the case study

The literature in the application of the hybrid lean-agile is rare. Although some frameworks and models were found in chapter 2.6.5. , the applicability of such models was not successfully validated in industry. Both frameworks address the positioning of decoupling based on discrete simulation. The two frameworks, however, reflect specific situations e.g. semiconductor, or seasonal demand. This necessitates developing a framework that reflects the current problem, and addresses the constraints inherent in the case study, such as time limitation, and non-easy access to data. The framework that was developed builds on (Köber, Heinecke 2012) and (Kim, Kim 2014) frameworks in terms of the work sequence or the models used for the decision making. The framework has five main stages (see **Figure 63**):

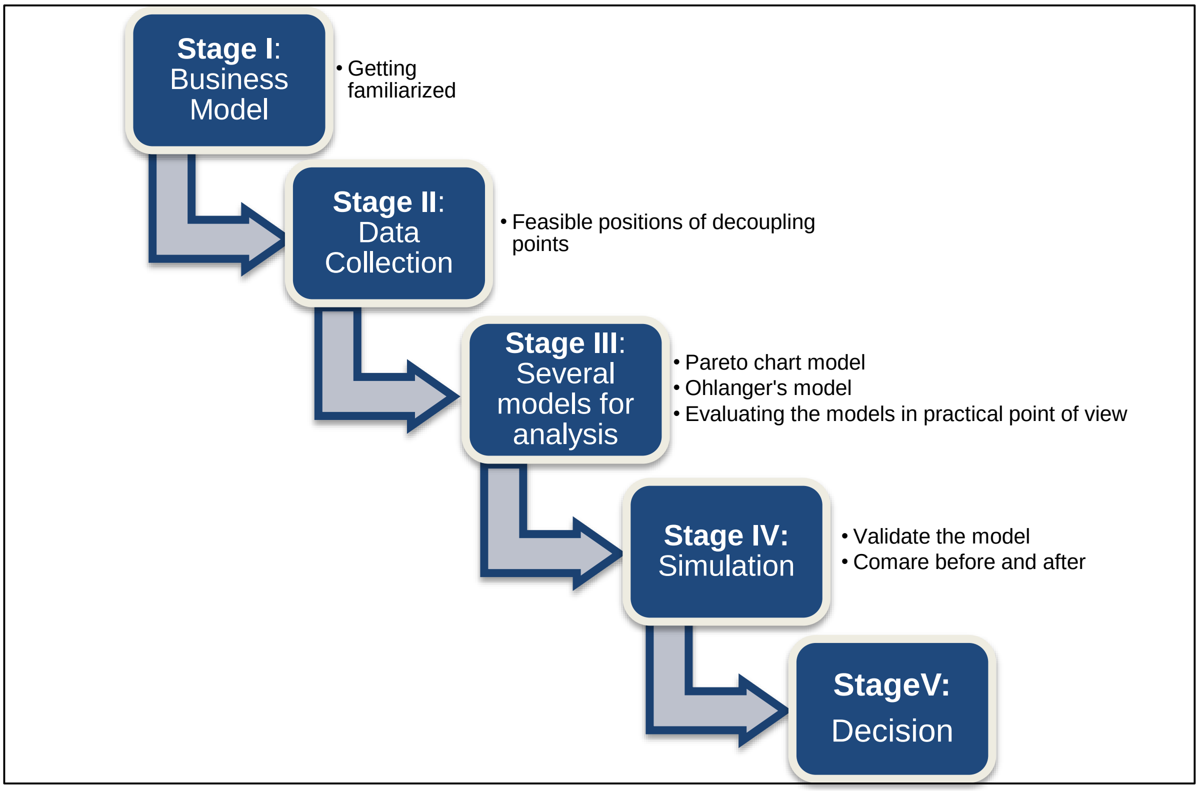

Figure 63: Framework of the case study

5.3.1 Stage I: Business model

As a first step it was crucial to understand the company's business model. This was done through the interview where the supply chain was explained, the leanness and agility was evaluated, the type of products were shown, in addition to the market situations and company's aspirations with regards to the topic of the use case. This was summarized in a SWOT analysis. Based on the results of the interview, several opportunities appeared and were discussed with the company to agree on what would be more interesting for the company. A time-line of one month and a half was agreed accordingly. The Business model was detailed through in interview part (chapter 4.6).

5.3.2 Stage II: Data collection

The next stage, was to agree on the products to be included in the study, and due to time constraints, it was agreed that the company will send data of the products that constitute 50% of their annual demand, and are considered as high runners. The number of products that were included in the case study was 17 products. An excelsheet was designed to gather the most essential information necessary for the study, such as processing times, set up times, transportation information, demand information, capacities of the machines, and delivery data for 2015. This was followed by several online meetings with managers and planners at Miba to clarify the data and understand the status-quo.

Table 15: Agreed products for the case study

Product Name	Number	Yearly demand (items)
Non provided 1	1.1.257	2,480,400
Washer	1.4.510	2,181,060
Non provided 2	1.2.311	2,064,600
Belt pulley	1.5.927	1,721,988
Chain sprocket	1.3.336	1,322,770
OTA	1.4.274	1,229,200
Assembly	1.5.477	1,185,840
VVT	1.4.483	1,148,560
VVT	1.5.704	1,134,182
Belt pulley	1.5.729	985,770
Belt pulley	1.4.446	919,720
Hub	1.4.391	908,000
Hub	1.4.355	768,000
OEA	1.4.480	760,120
Rotor	1.4.535	659,010
Chain sprocket	1.4.422	600,840

5.3.3 Stage III: Several models for analysis

There is consensus in the literature of hybrid lean-agile that the transfer to such supply chains requires a deep look into the products and relate the appropriate system to the suitable types of products, such that leanness is more appropriate in MTS situations, where demand in quite stable, and agility is more appropriate in MTO situation, where demand is highly volatile. Such decision requires comprehensive data analysis. Several models were addressed in chapter 2.6 that deals with the implementation aspect. Yet, literature is not ripe with use cases to validate these models. Hence, the reliability cannot be guaranteed. To overcome this issue, the data analysis phase went through each of these models one by one, and an attempt was made to evaluate these models from practical point of view.

Pareto analysis (MTS/MTO)

As described in chapter 2.6 by (Christopher, Towill 2001, p. 8), sketching the products in a pareto chart, based on sales information, mainly result in 20% of products being produced in a lean way based on forecasting, and 80% being produced in an agile manner based on real orders. To analyses the data of the 17 products, a pareto distribution was sketched based on annual demand of 2015.

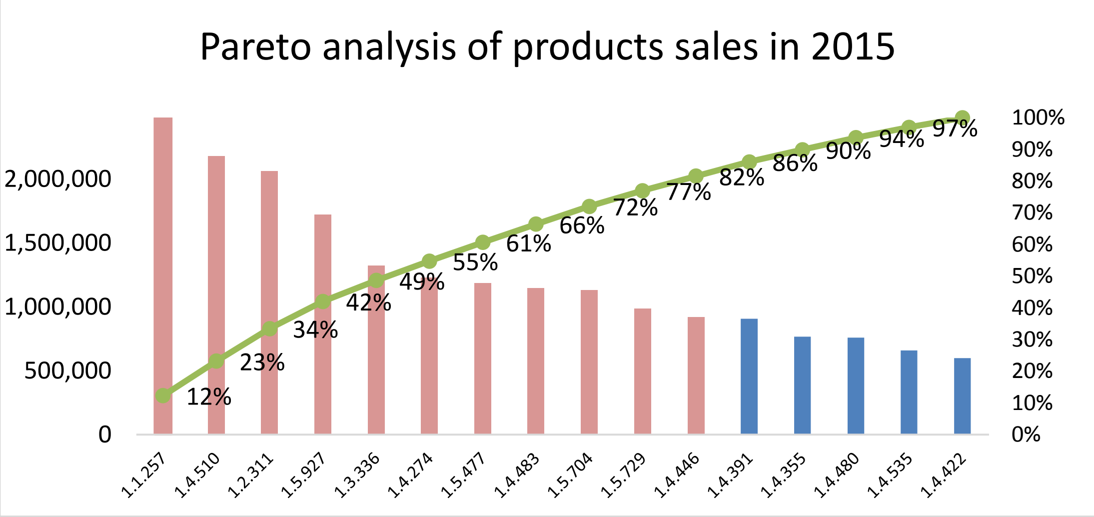

Figure 64: Pareto distribibition based on demand info 2015

Looking at the resulted distribution, one can easily conclude that an 80/20 division of products was not viable as more than 60% of the products constitute 80% of the demand, indicated in red. This might be due to the fact that these products constitute more than 50% of demand, thus, they are already high runners. This analysis, is a useful way to look at the big picture, and perhaps helps in showing which products should be the main focus. Yet, it neglects the volatility aspect, and assumes that the highly runners should not possess high volatilities and thus should be assigned as MTS. Whilst this could hold true for some of the highly demanded products, more invitation was needed to give more certainty. These reasons, led to relying on another model.

Decoupling point model by Olhanger 2003

The next model that was envisaged was developed by (Olhager 2003), and considers two main factors to strategically decide on the decoupling between lean and agile supplies i.e. relative demand volatility, and production/delivery time ratio. Relying on these two factors, companies are able to choose the right production strategy for their products i.e. MTS, MTO and ATO, and decide the right place of the decoupling point (See chapter 2.6). The model, however, would look simpler that what it is in practice, since it requires accurately calculating the indicators for every product. The steps needed to construct the model were carried out on all the 17 products as follows:

1. Relative Demand Volatility(RDV): The relative demand volatility is a measure to show how volatile the demand is, and is equivalent to the coefficient of variance, which can be calculated through dividing the mean by the standard deviation (Olhager 2003, p.327). This necessitates measuring the means and standard deviations for the seventeen products. The study was based on the delivery data in 2015, since it was available in the right form and structure needed for the study. Yet, delivery data reflects strongly the real demand data as indicated by the correspondent at Miba, especially when looking at one year period. Another interesting point, was that the deliveries were not made in fixed periods, and did not possess constant patterns in terms of quantities in each time period. This necessitates using weighted average considering the time periods between deliveries as weights of the delivered quantities. Formulas used are the following:

$$\mu = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}$$

Figure 65: Weighted mean average (Finch, p. 3)

$$\sigma^2 \quad = \quad \frac{1}{W_n} \sum_{i=1}^{n} w_i (x_i - \mu)^2$$

Figure 66: Weighted variance (Finch, p. 4)

Hence, measuring the weighted mean and weighted average for all the seventeen products makes it possible to calculate the relative demand volatility according to the following formula μ/σ as described by (Olhager 2003, p.327). For instance, taking product 14510, the average mean of demand was calculated as 15588 units every 2.5 days, with a demand volatility of 64% as shown in **Figure 67.** Demand representation for simulated products exist in Appendix D.

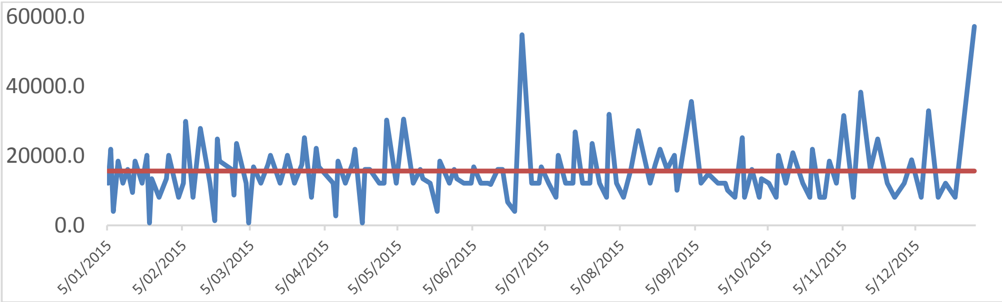

Figure 67: Demand situation for product number 14510 in 2015

2. P/D ratio: The second step of Olhager's model is to measure the ration of production lead time (throughput time) to delivery lead time. To do so, it was substantial to identify the bottlenecks of every product to know the maximum capacities that can be achieved. A value of 70% was fixed as the availability time, since the machines are subjected to failures, and uncertainties. They could also be used by other products which are out of the scope of the study. Let's take one product as an example. Product 11257 is manufactured through two main processes, compacting with 5.9 seconds/product, and sintering with 0.5 seconds per product. For every lot size of 209000 items a setup of 300 minutes is required in compacting. The transportation time is 25 minutes per lot. It is obvious that the compacting is the bottleneck as it has the highest cycle time. When deducting 30% of the operational time due to uncertainties, the maximum daily capacity is 9718 units per day, knowing that the company works 21.7 hours a day. This can be calculated through dividing the time available per day by the cycle time of the bottleneck. Then, the production lead time for one lot can be simply calculated by dividing the lot size by the daily possible amount i.e. 209000/9718. Hence, 21.5 working days are required to produce one lot. The calculated production lead times were reviewed by the company contact person, and were compared with real delivery times. If the value calculated exceeded what the company was able to deliver in reality, it meant that the availability should be slightly twisted. It can also mean that the company used special treatments and transportation to fasten up the production. Nevertheless, these variations were very rare in the calculated data. The next step was to know the delivery lead time. By asking the company contact person, and observing the demand data, it was indicated that customers are willing to wait 42 days since the order is made time until it is fulfilled.

3. Scale for volatility levels: looking at Olhangers model, it is noticeable that the model does not indicate what does a high RDV value or a low mean. The

current model lacks a scale that could be relied upon, and leaves it to the companies to decide the scale. Thus, an assumption was made to use shown in **Table 16**, which was discussed and approved by the company. The results of this analysis are shown in

Table 16: Scale of Relative Demand Volatility

Scale	Disruption	Degree	Colour
Low RDV	The level of fluctuation does not constitute a real risk to fulfilment	< 30%	
Medium RDV	The level of fluctuation would impose moderate risk in terms of fulfilment	30%-60%	
High RDV	The level of fluctuation could cause real problems in ability to fulfil the order	>60%	

Hence, all the requirements for the analysis are ready, the results of Olhanger's analysis can be depicted as follows:

Table 17: Volatility vs P/D metrics

Product	Relative Demand volatility CV	Production lead time (P)*	Delivery lead time (D)	P/D ratio
1.1.257	27.5%	21.5	42.00	0.512
1.4.510	64.2%	23.1	42.00	0.550
1.2.311	27.2%	11.3	42.00	0.270
1.5.927	49.1%	16.3	42.00	0.388
1.3.336	34.3%	16.7	42.00	0.397
1.4.274	29.5%	13.4	42.00	0.320
1.4.483	44.1%	14.3	42.00	0.340
1.5.477	51.0%	21.4	42.00	0.510
1.5.477	51.0%	17.7	42.00	0.422
1.5.704	74.3%	26.7	42.00	0.636
1.5.729	61.1%	13.1	42.00	0.313
1.4.446	45.6%	14.6	42.00	0.347
1.4.391	43.9%	10.0	42.00	0.237
1.4.480	35.7%	38.3	42.00	0.913
1.4.355	37.8%	9.5	42.00	0.227
1.4.535	30.4%	41.4	42.00	0.985
1.4.422	55.3%	28.7	42.00	0.682

(*): further info of calculating P exists in Appendix C

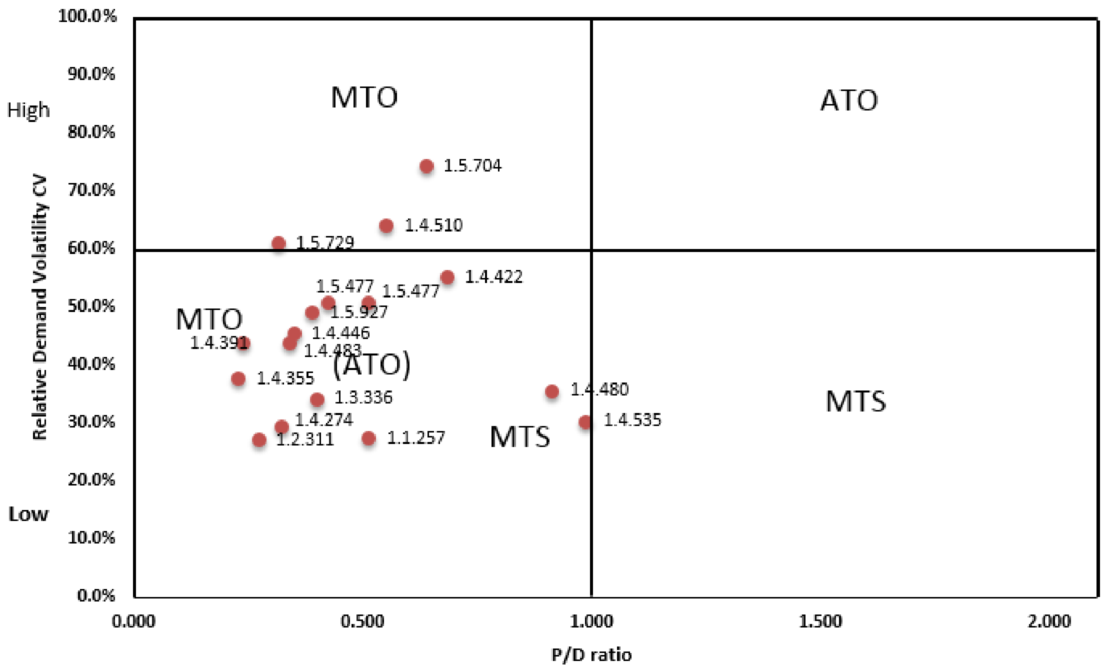

Figure 68: Products distributed according to Olhager's model

When comparing the results of Olhanger's model to those resulted from the Pareto analysis, it is evident that demand volatility is an important factor that should not be neglected. Relying only on pareto chart could be misleading for some products. For instance, product 14510 is the second most demanded product, and is recommended to be made to stock in a lean manner according to Pareto distribution, assuming that demand can be forecastable. However, the Olhanger's model shows that the high volatility of demand for this product, makes it advisable to shift the decoupling point to the early steps of products (MTO strategy), and be produced in a more agile way.

Additionally, the model shows that all products can be produced within the period customer is able to wait until receiving the product. A fast decision would be to apply a MTO strategy for all 17 products, since they can be manufactured within the allowed waiting period. However, demand volatility is the criterion that is to be considered before such decision. Although the company has been applying a MTO strategy for these products in the past, it suffers drastically from high backlogs, and delivery problems that urge the company to find a better solution to cope with these high fluctuations. The result of the model can be illustrated through the product-process matrix as shown by (Kim, Kim 2014, p. 36) in chapter 2.6.5. Taken into account the results from Olhanger's model, a representation of the decoupling point can be obtained, and the dominant operating system i.e. lean-agile can be chosen based on literature of decoupling point (see chapter 2.6.2).

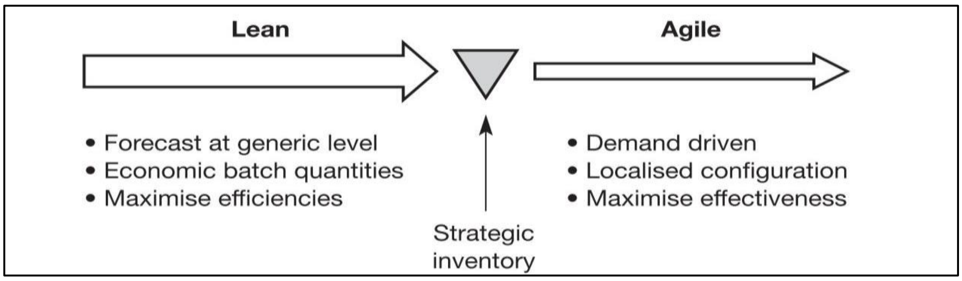

Figure 69: Decoupling point between leanness and agility (Christopher 2011, p. 102)

Product/ process matrix	Compacting	sintering	Sandblasting	Sizing	Welding	Turning	Brushing	Oil dipping	Thumbling/drying	Steam treatment	Rolling	Induction hardening	Boring, threadcutting...	Assembly	external	Supermarket	Dominant operations
11257																▲	lean
14510	▲															▲	agile
12311																	lean
15927	▲																agile
13336	▲															▲	agile
14274																	lean
14483	▲																agile
15477														▲			Leagile
15477														▲			Leagile
15704	▲																agile
15729	▲																agile
14446	▲																agile
14391	▲																agile
14480																▲	lean
14355																▲	lean
14535																▲	lean
14422	▲																agile

Figure 70: Product-process matrix for the studied products (Results)

What can be concluded from the analysis, is that the lean and agile operations should be tailored according to the product and demand nature. Meaning that, products which need agile operations should possess a make to order policy, while an investment on technologies, people and intelligent systems to handle demand variations. Assigning these products to stock, and decoupling them from real demand information, will not be the best decision, since it will increase the risk of obsolesces due to the complexity in forecasting the amounts of these inventories. The lean products, on the other hand, can be smoothed, levelled and controlled in an easier manner, which is what leanness strives for.

5.3.4 Stage IV: Simulation study

Using discrete simulation has recently become indispensable in similar studies tackling the choice between leanness and agility, and decoupling point, as seen in different studies by (Onan, Sennaroglu 2007), (Köber, Heinecke 2012, p. 458), (Kim, Kim 2014, p. 32). In this study, Plant Simulation Tecnomatix 12 was used to validate the results of Olhager's model, and to find practical solution on how the production system could be tailored according to lean paradigm or agile paradigm. Additionally, simulation was used to find the optimal amount of supermarket and choose the most appropriate triggering system that should be adopted to control production. Nevertheless, due to time limitations, this could not be done to all production, as this requires intense data gathering and experimentation. Thus, the decision with the company, was to choose two products among Olhager's model, i.e. one from the MTS quadrate, and another from the MTO quadrate (see **Table 18**).

Table 18: Product chosen for simulation

Product	Solution according to data analysis	Justification for choosing product for simulation
11257	• MTS, lean emphasis according to Olhager's model • MTS, lean emphasis according to Pareto	• The least volatile product • Constitute the biggest share of sales, and given special importance
15704	• MTO, agile emphasis according to Olhager's model • MTS, lean emphasis according to Pareto	• The highest volatile product • Indicated differently by the two models • Problematic product to the company in fulfilment

Simulation of product 11257: MTS, lean approach

Value stream description

The first step of the simulation was to understand the value stream, this was done through several online meetings with the company that were all recorded as well. The product is manufactured through three main processes. First, powder mixing, which is also shared with different products outside the scope of study. Once powder is ready, it is sent to a compacting machine. The machine has a processing time of 0.094 minutes/product and a set up time of 300 minutes per lot. The products are then moved on a conveyer to the sintering machine. The sintering machine has a processing time of 0.009 minutes/product, and negligible set up time. Then, products are piled in a space buffer to be taken through a forklift to the supermarket. Usually transposition is already optimized by the logistics unit in a way that it does not hinder the production. The production runs through three shifts that work 21.75 hours every day, including weekends. Several assumption has been made and approved with the company as well:

- Transportation is optimized, especially between sintering and supermarket.
- Powder is always ready as raw material before compacting.
- Availability of all machines was approved set as 70% for all the machines.
- Holidays are negligible from the simulation time.

Figure 72: Compacting machine

Figure 71: Sintering machine

Building the simulation Model

A model on plant simulation was created and the simulation was run and compared to the status quo for verification. The model was fixed once it provided similar behaviour to the real system in terms of total number of items produced. This was made certain through comparing the time for producing a lot, yearly demand, and yearly produced items.

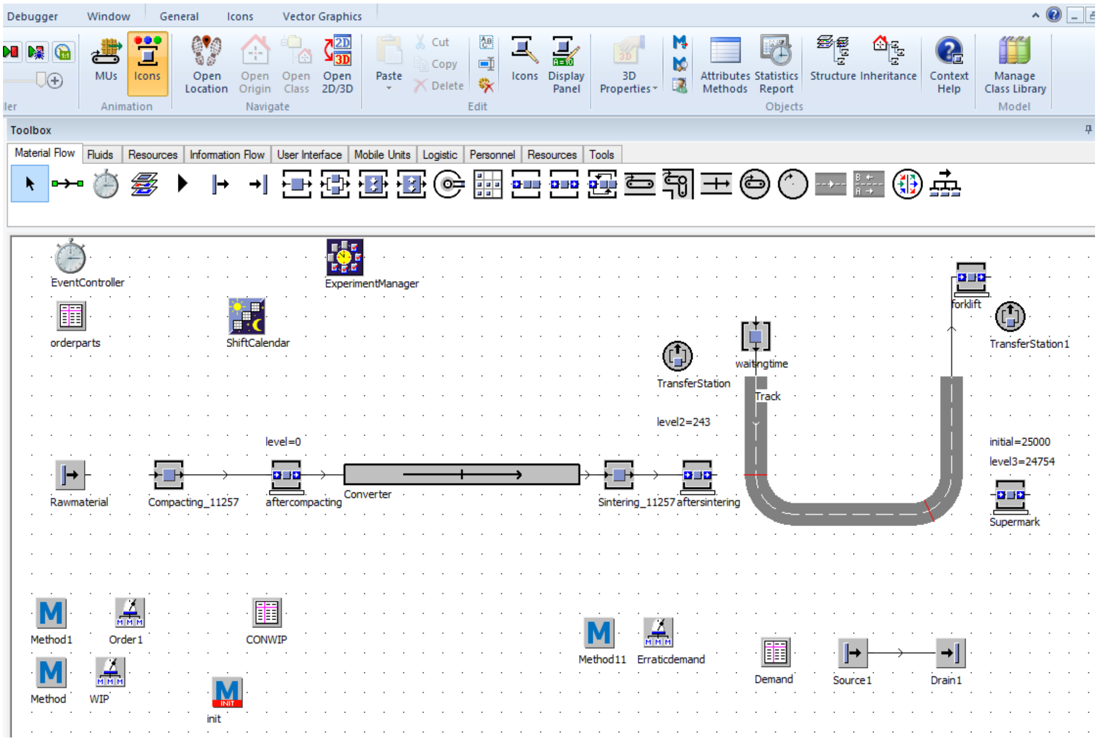

Figure 73: Plant simulation model for 11257

Identifying key performance indicators

To be able to compare between the status quo and the developed situation, it was imperative to define key performance indicators. Literature in systems' simulation show two main factors to be considered when carrying out similar studies (see chapter 2.6.5), which are service level, and inventory. Thus, the following two KPI's were used in this case study:

1) Service level: Calculated through comparing the produced items to the demanded items. This helps calculate the service level cost, which is an indication of the cost incurred from non-fulfilled and delayed orders, penalties and lost sales. For, the current product, non-fulfilment cost was estimated as € 0.094 per item by the company.

2) Inventory level: Measuring the inventory level in the system, including the WIP (Work in progress) helps calculate the inventory cost. For the current product, the yearly estimated cost for one product was estimated by the company as € 0.00012 over one year at the supermarket, and the WIP was estimated as €0.0002 per product.

Analysing system behaviour

The next step was to run the model simulation in different demand situations, seeking to understand the behaviour of the value stream. This was done through identifying several takt-times from the demand information of the product. The data analysis stage shows that the demand volatility for this product is 27.5%, and the average demand is 60,331 every 8.4 days. The current system would work properly according to this average. However, looking at the demand history for 2015, there were different cases where demand surged to 50% or even 60% volatile levels. The service level drops down drastically in such cases. That's due to the fact that, the compacting machine is the bottleneck of the value stream, and with 70% availability, it would not handle takt-times lower than 7.6 seconds. This, should be considered when designing the MTS model for the current product.

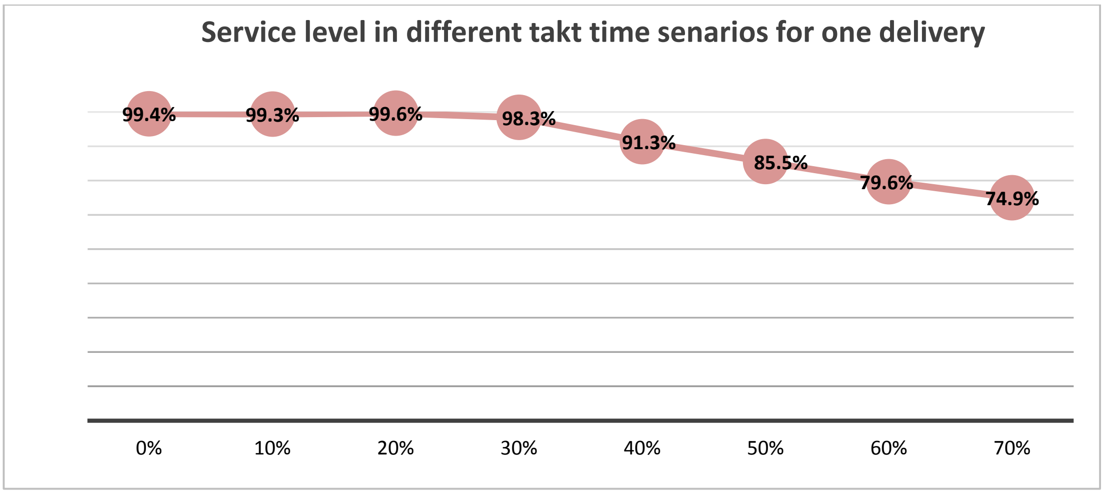

Figure 74: Service level for product 11257 in different volatility levels

Developed concept

The developed model consists of three major improvements: The first is the existence of a decoupling point in the supermarket, and the second is implementation of a CONWIP control strategy. The third is a stable production program with a fixed takt-time. Viewing the supermarket as a decoupling point means that prior to the decoupling point demand should be as stable as possible. The fact that the volatility level of this product is not relatively high, means that an optimal takt time can be forecasted in addition to the supermarket amount. This goes in line with the lean mentality to stabilize and smoothen demand. This distinction in planning operational before and after the decoupling point was supported by (Olhager 2010, pp. 866–867) as presented in chapter 2.5.2.

The use of supermarket is essential in such situation due to the existence of surges that exceed the capacity of the system. Moreover, chapter 2.4.1 shows that several pulling system were suggested in literature such as Kanban, CONWIP, hybrids etc. The decision to use CONWIP was due to the simplicity of the method, and that when observing behaviour of the system, no WIP controlled is needed between the stages. Moreover, this product does not possess high volatility degrees on average, to consider any hybrid situation.

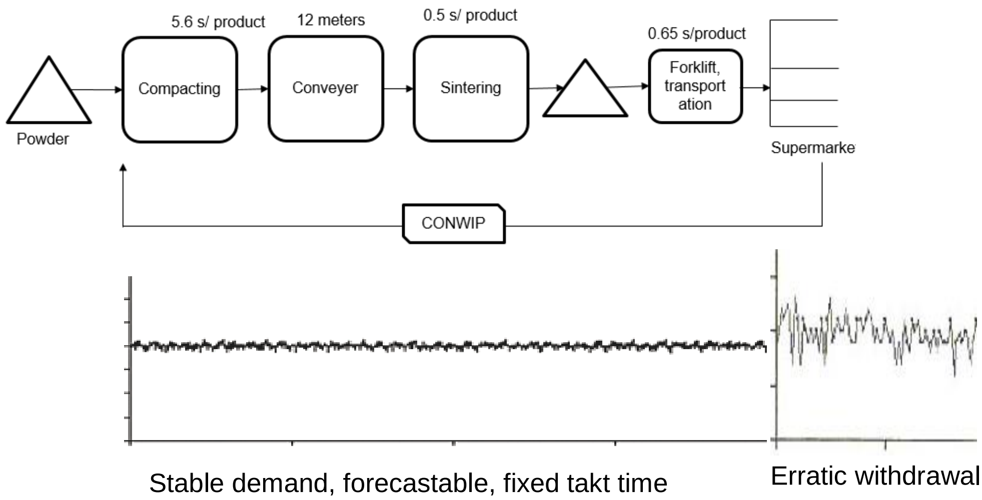

Figure 75: Developed concept for product 11257

Experimentation study- Optimizing supermarket

The first step was to calculate the optimal level of the supermarket. This was done through a tool in plant simulation called multilevel simulation experiential design. The experiment was done on six trials, each of which had different supermarket quantity, starting from 5000 until 55000. The takt-time was fixed to the worst case senior of 6.4 seconds, and the simulation period was set as 8.4 days (average ordering period for this product). When observing the overall demand for one year, there were very few cases where demand jumped to such high level. Nevertheless, the cost of unfulfilled orders imposes high risk, and justifies the extra cost of inventory, which is incomparable with the cost of non-fulfilment. Hence, the optimal level was decided as 40,000 pieces. This was then compared with the status-quo, and showed significant improvement in handling a surge in demand. Information about the experiments exist in Appendix B.

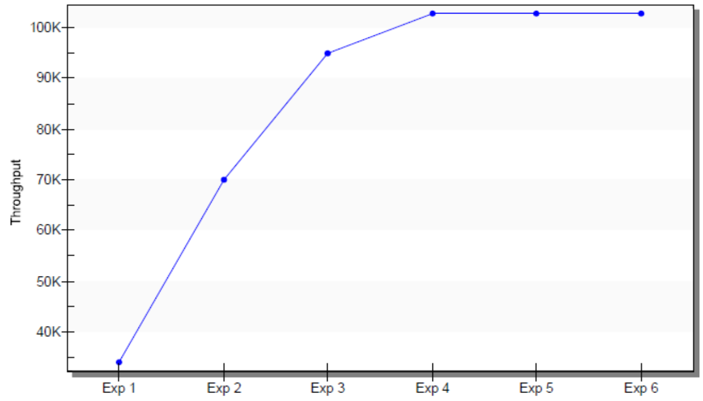

Figure 76: Result of multi-level optimization tool

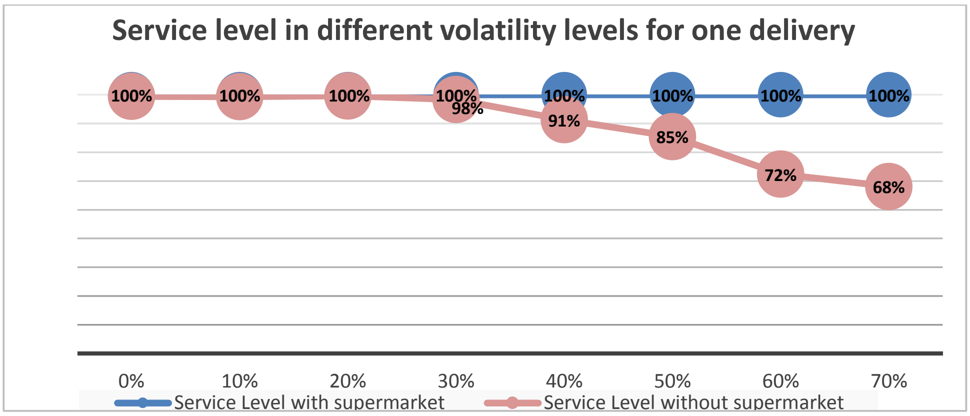

Figure 77: Comparing the service level of the new model to the status quo

Table 19: Experiment results- comparison between the developed model and status quo

Relative Demand Volatility RDV		0%	10%	20%	30%	40%	50%	60%	70%
Standard deviation		0	6034	12066	18099	24132	30166	36199	42232
delivery every (days)		8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
demand		60342	66437	72277	78300	84324	90099	96724	102769
Takt-time (s)		10.9	9.9	9.1	8.4	7.8	7.3	6.8	6.4
Developed concept	Throughput achieved	60342	66437	72277	78300	84323	90099	96724	102769
	Service Level	100%	100%	100%	100%	100%	100%	100%	100%
	Supermarket optimal amount	40000	40000	40000	40000	40000	40000	40000	40000
Status quo	Throughput achieved	60000	66000	72000	77000	77000	77000	70000	70000
	Service Level	99%	99%	100%	98%	91%	85%	72%	68%

Testing and evaluating the optimized model in real demand situation according to KPI's

To test the system in a real demand situation a simulation run was done for 316 days effective working time. Three trials were made with various amount of inventories i.e. 25000, 35000, 40000 to further investigate the results of optimization. The results of simulation showed that a supermarket of 40000 items gave the best performance in the current erratic demand situation, and could guarantee a service level of 100%. Implementing such system would not incur significant costs for this product since the inventory cost is significantly low. The developed model could achieve cost savings of 8142.7 Euros over the period of simulation. The fact that the company has 270 products provides a significant opportunity for achieving more cost savings when applying the same concept on bigger scale. This value, however, is a rough estimation according to the available data, and could vary in real situation. It is worth mentioning, that other sources of profit could be reached once such system is implemented. For instance, reaching a 100% service level means achieving higher customer satisfaction, which might increase sales or encourage the customer to intensify its cooperation with the company. Moreover, working on stable schedules decreases the efforts of planning, and gives the opportunity to benefit from the learning curve, and could decrease the lead time even more in the future. Results of testing are shown in **Table 20** , **Figure 78,** and **Figure 79.**

Table 20: Evaluation of developed model according to identified KPI's

		per piece per year	Current status	Developed model
	Takt time (seconds)		Erratic 8.4 - 15.02	fixed 10.9 sec
	Takt time changing period (days)		Erratic 4 2 - 12.5	stable
	Simulation time (effective days)		316	316
	Overall demand simulatoin		2531677	2531677
	mean life time in the system / item		2.6	5.8
Service Level	non fullfiled		86400	0
	service level		96.6%	100.0%
	service level costs per year	€ 0.094	€ 8,147.52	€ -
Supermarket	Supermarket optimal level		0	40000
	Supermarket cost per year	€ 0.00012	€ -	€ 4.80
WIP	WIP average per year		1000	1000
	WIP cost per year per piece	€ 0.0002	€ 0.24	€ 0.24
	Total cost		**€ 8,147.76**	**€ 5.04**
	Saving			**€ 8,142.7**

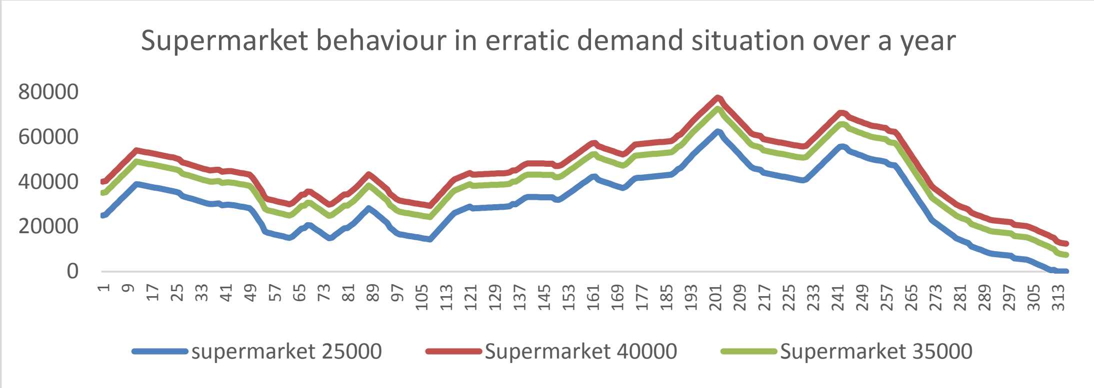

Figure 78: Triggering supermarket over 316 days

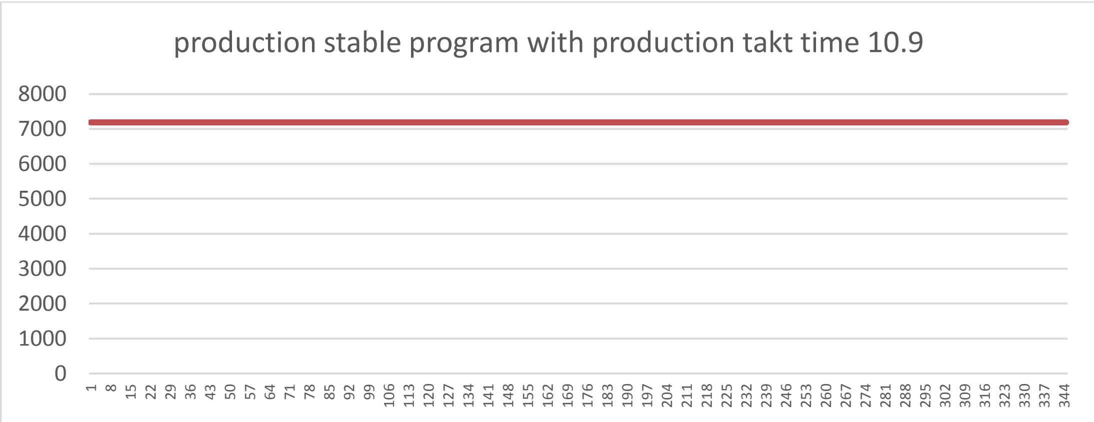

Figure 79: Production levelled program- optimal

Lean characteristics of the developed concept of product 11257

The reason why this product is dominantly lean in its nature, is that it possesses several lean traditional characteristics and practices, as follows:

1. Production levelling according to volumes (Stabilizing demand).
2. The existence of supermarket and buffers.
3. Production according to takt-time.
4. CONWIP replenishment system.
5. Standardization in terms of production quantities and takt-time.
6. Lead time reduction achieved when installing a supermarket.
7. Easiness to forecast the demand, and the low value of relative demand volatility.

Simulation of product 15704: MTO, agile approach

Value stream description

The second product that was chosen exhibits high volatility levels. The production goes through five main processes. The first step is powder mixing, and same as in the previous product, was excluded from the simulation study, as it is a shared process with several other products. The next process is compacting with a processing time of 0.181 seconds, and a set up time of 450 minutes for the complete lot. Then items move to sintering machine with a processing time of 0,181 seconds/product and 360 minutes of set up time per lot. Once items are sintered they are directly sent to sizing and turning with processing times of 0.16 seconds/item and 0.0321 seconds /item respectively. The turning machine has also a set up time of 120 minutes per lot. Several assumptions were made as follows:

- Transportation is optimized between stages
- Powder is always ready as raw material before compacting.
- Availability of all machines was approved set as 70% with a MTTR (Mean Time to Repair) of 1 minute.
- Yearly holidays are negligible from the simulation time.

Figure 80: Turning machine

Building the simulation Model

A model on plant simulation was created and the simulation was run and compared to the status quo for verification. The model was fixed once it provided similar behaviour to the real system. This was made certain through comparing the time for producing a lot, yearly demand, and yearly produced items.

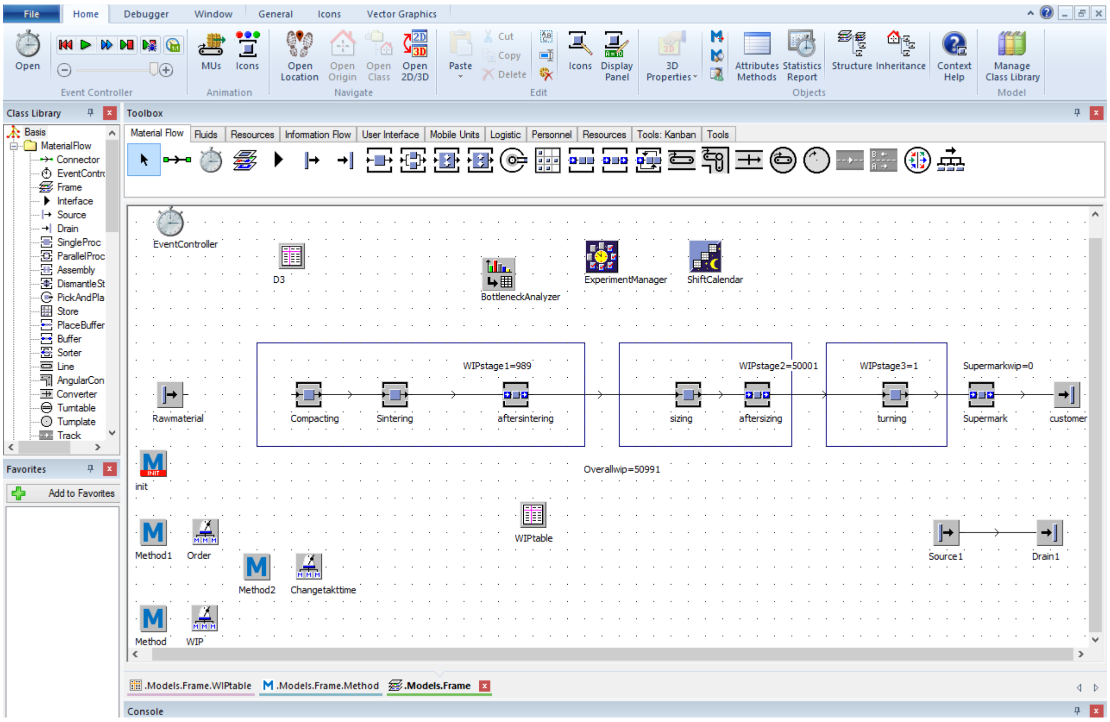

Figure 81: Plant simulation model for the product 15704

- **Identifying key performance indicators**

To be able to compare between the status quo and the developed situation, it was important to define key performance indicators. Literature in systems' simulation show two main factors to be conceded when carrying out similar studies (see chapter 2.6.5), which are service level, and inventory level. Thus, the following two KPI's were used in this case study:

1) Service level: Calculated through comparing the produced items to the demanded items. This helps calculate the service level cost, which is an indication of the cost incurred from non-fulfilled and delayed orders, penalties and lost sales. For, the current product, non-fulfilment cost was estimated by the company as € 0.739 per item for both special transportations, and penalties on non-fulfilled orders.

2) Inventory level: Measuring the inventory level in the system, including the WIP (Work in progress) helps calculate the inventory cost. For the current product, the yearly estimated cost was estimated by the company as € 0.05 per item over one year at the supermarket, and the WIP was estimated as € 0.1 per item.

Analysing system behaviour

The next step was to run the current model in erratic demand that is similar to the status quo, seeking to understand the behaviour of the value stream. This was done through programing a code (method) based on demand analysis of 2015, as follows:

Method for demand generation over erratic periods of (5:24:00, 4:09:21:36)

```
is
do
source1.interval:=z_uniform (99,7.84, 53.2);
end;
```

This generates random erratic demand bounded by upper and lower limits of takt-time 7.84 and 53.2 seconds, that guarantees a volatility level of 74.3% shown in stage III. Same goes for the intervals of changed demand, which hoovered between 5:24 hours to 4.38 days as obtained from the same source. Simulation was run for 316 effective days, and what could be noticed was that the current service level is too low 68.8%. This was due to the existence of a bottleneck in turning machine which has a processing time of 19.2 seconds and 70% availability rate. Even when running the system at average demand, service level falls below 50%.

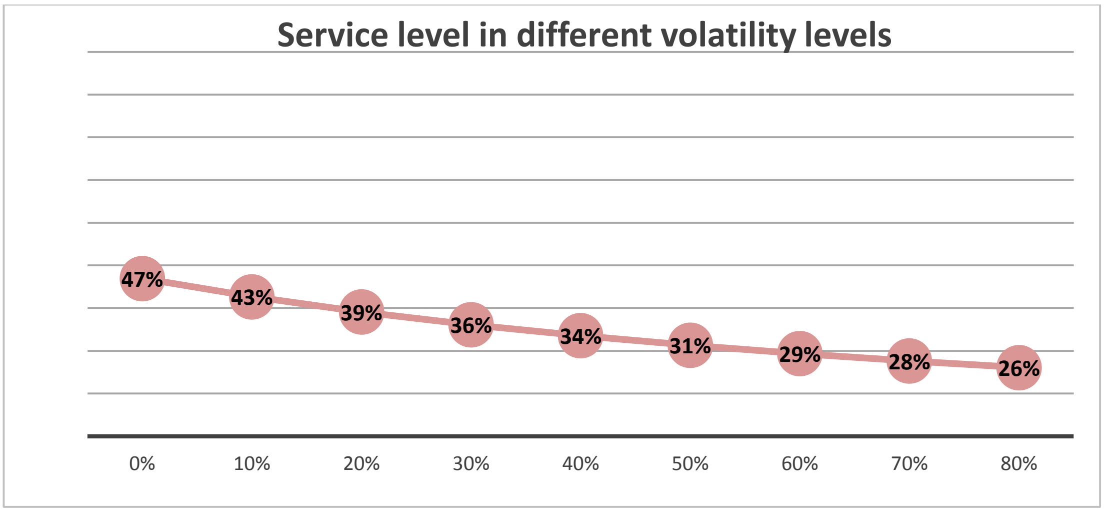

Figure 82: Service level for product 15704 in different volatility levels

Developed concept

Two developed concepts were constructed:

Concept 1: Employs several developments, first is solving the bottleneck problem through incorporating another machine with 30% availability. The existence of extra capacities in justified in this case due to the high level of volatility. The second development is using a tailored Kanban system called (BK CONWIP), as illustrated in **Figure 28** of section 2.4.1.4. The significance of this control strategy, is its aim to synchronize the movement of parts, the transmission of data in real time, the decoupling between demand info and Kanban control, and the existence of a CONWIP control for the overall number of WIP in the system. The third development was the addition of a supermarket to handle demand variations. A depiction of the developed concept is shown in **Figure 83**. The codes for BK-CONWIP strategy on plant simulation can be shown in Appendix A.

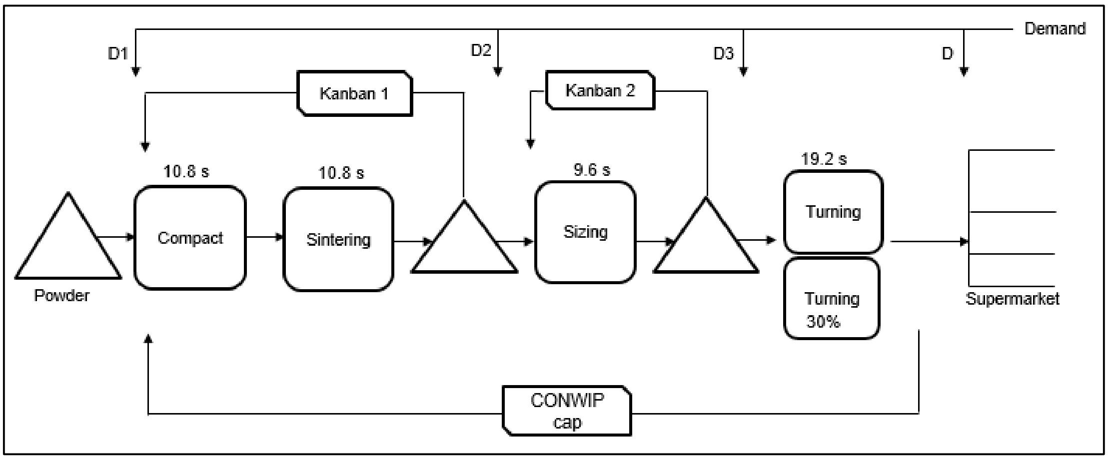

Figure 83: Developed concept 1 for product 15704

Concept 2: A second concept was also developed that only has an extra turning machine with 30 % availability. This aims to test whether a supermarket and a BK CONWIP are necessary and help making a good decision.

Experimentation study- Optimizing supermarket

Same as the previous product, the multilevel simulation experiential design was used to reach the optimal level of inventory and Kanban, CONWIP and base stock levels. 48 experiments with 144 simulation runs were carried out, for a period of day each. As a result the supermarket optimum level was set as 25000 items. It was also noticed that the number of Kanabn, CONWIP or base stock levels only affects the WIP in the system, and has no effect of throughput.

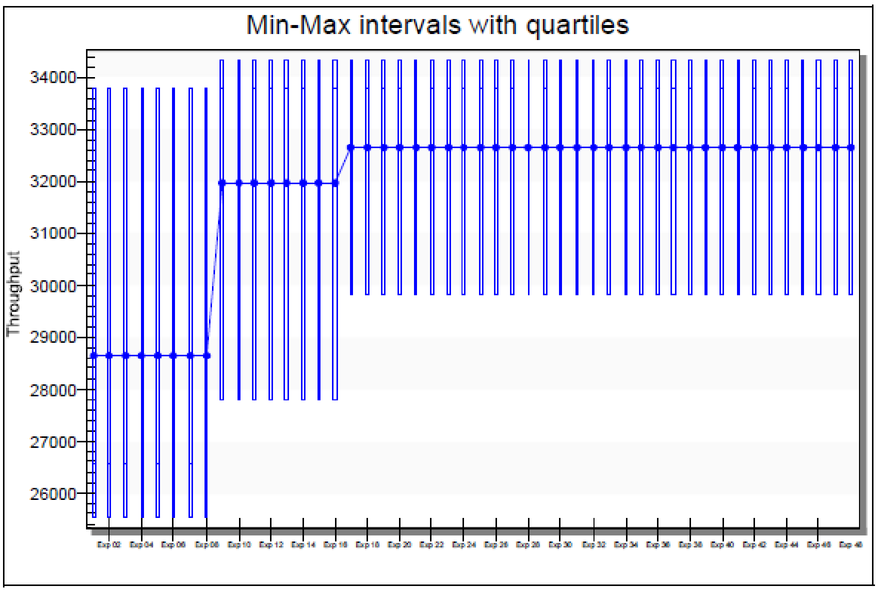

Figure 84: Result of multi-level optimization tool

The two developed concepts were run in different volatility levels, to test the system's capability to handle demand surges as shown in **Figure 85** and **Table 21.**

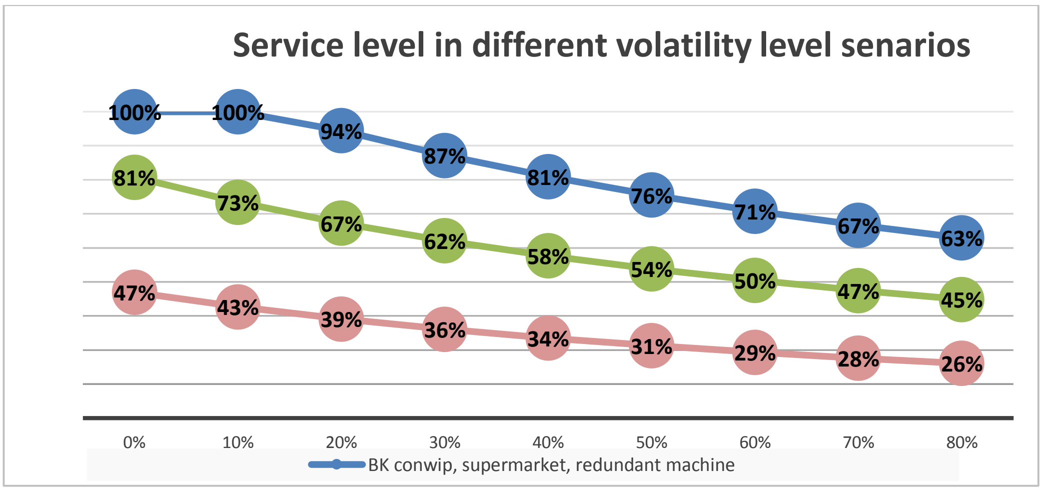

Figure 85 : Comparing the service level of the new model to the status quo

Table 21: Experiment results- coparison between the developed concepts and status quo

Relative Demand Volatility RDV		0%	10%	20%	30%	40%	50%	60%	70%	80%
Standard deviation		0	573	1145	1718	2291	2864	3436	4009	4582
delivery every (days)		1	1	1	1	1	1	1	1	1
demand		5728	6301	6874	7446	8019	8592	9165	9737	10311
Takt time (seconds)		13.7	12.4	11.4	10.5	9.8	9.1	8.5	8.0	7.6
Concept 1	Throughput achieved	5728	6300	6490	6490	6490	6490	6490	6490	6490
	Service Level	100%	100%	94%	87%	81%	76%	71%	67%	63%
	Optimal amount of supermarket	25000	25000	25000	25000	25000	25000	25000	25000	25000
Current status	Throughput achieved	2689	2689	2689	2689	2689	2689	2689	2689	2689
	Service Level	47%	43%	39%	36%	34%	31%	29%	28%	26%
Concept 2	Throughput achieved	4625	4625	4625	4625	4625	4625	4625	4625	4625
	Service Level	81%	73%	67%	62%	58%	54%	50%	47%	45%

Testing and evaluating the optimized model in real demand situation according to KPI's

To test the system in a real demand situation a simulation ran for 316 days effective working time. Both concepts were tested and compared to status quo in erratic similar demand situation, based on the defined KPI's. The results of the testing proved that concept 1, i.e. BK CONWIP, supermarket and redundant machine, achieved the highest service level and the lowest WIP as well. With regards to supermarket cost, the high cost of non-fulfilled items justifies the additional inventory costs resulted from the supermarket.

Concept 1 could achieve savings estimated by € 305,798.2 per year as compared to the current status, and a saving of € 6014.5 per year as compared to concept 2. Detailed results of testing are illustrated in **Table 22.**

This result, however, is a rough estimate based on the available data, and could vary in real situation due to the existence of hidden costs caused by the redundant machine, the need train workers, in addition to the IT construction and sensor technologies needed for BK-CONWIP. It is worth mentioning, that other sources of profit could be reached once such system is implemented. For instance, reaching a 100% service level means achieving higher customer satisfaction, which might increase sales or encourage the customer to intensify the cooperation with the company. Moreover, working on erratic situations necessitates special kind of workers, who can be adaptable to changes. This should also be assumed when implementing such system.

Table 22: Testing results

		per piece per year	Status quo	Cocept 2	Concept 1
	Takt time		Eratic 7.84 - 53.2	Eratic 7.84 - 53.2	Eratic 7.84 - 53.2
	Takt time changing periods (days)		Erratic 0.22 - 4.3	Erratic 0.22 - 4.3	Erratic 0.22 - 4.3
	Simulation time (effective days)		316	316	316
	Throughput achieved		902165	1302023	1312053
	Overall demand		1312053	1312053	1312053
	mean life time in the system per piece		11.46	0.7	3.958
Service Level	non fullfiled products		409888	10030	0
	service level		68.8%	99.2%	100%
	service level costs per year	€ 0.739	€ 302,747.38	€ 7,408.26	€ -
Supermarket	Supermarket optimal level		0	0	25000
	Supermarket cost per year	€ 0.0589	€ -	€ -	€ 1,472.75
WIP	WIP average per year		45516	1070	280
	WIP control limit in the system		50000	50000	400
	WIP cost per year per piece	€ 0.1000	€ 4,551.60	€ 107.01	€ 27.98
	Total cost		**€ 307,298.98**	**€ 7,515.27**	**€ 1,500.73**
	Profit as compared to status quo			**€ 299,783.7**	**€ 305,798.2**
	Profit as compared to concept 2				**€ 6,014.5**

Agile characteristics and tailored lean characteristics of the chosen concept of product 15704

1. Adaptive to a highly volatile demand.
2. Real time data transmission to stages.
3. Redundant machine.
4. Tailored Kanban control (BK-CONWIP).
5. Sensor technology employed for such production control.
6. Scenario based planning according to worst scenario.
7. Multi-skilled operators able to handle variations in work schedules.
8. Generation of profit out of volatile situations.

5.3.5 Stage V: Decision

The applied framework provides a good way to make decisions regarding the implementation of decoupling point and hybrid lean-agile production. The simulation study managed to validate the results of **Figure 68** and **Figure 70**. The results were reviewed by the company, and were seen reasonable. This gave confidence to the company, that applying hybrid MTS/MTO is a recommended, and will achieve better results if optimized efficiently. The use of BK-CONWIP was seen as complex by the company, especially from IT perspective. Additionally, , the use of simulation should also be expanded to include higher number of products as it provides an effective way to optimize the developed models, and test the system in almost zero cost. Hence, it is recommended that the company should tailor its products to the lean and the agile paradigms according to the above mentioned models. Moreover, while the results show that the model of Olhager can be based upon in choosing what to be produced as MTS lean way, it misses the cost factor. By considering cost of non-fulfilled items and inventory costs, more reliable decisions can be made. This, might be a trigger to develop the model, and include the cost factor. Still, the model can provide an initial direction or overview, and simulation is necessary in this case to reach influential decisions.

5.4 Summary of the case study

The case study tackles a real problem at Miba sinter Slovakia, characterized by problems with costly non-fulfillments, due to the current highly volatile market. The company is considering a supermarket and a replenishment system as a solution. The case aims at employing the hybrid lean-agile production and the decoupling point approaches based on simulation to improve the service level, and cope better with the volatile demand. Due to time limitations a handful of products (17 products) were chosen by the company among the 270 products they produce. These products constitute 50% of the company's revenues, and are the most vital. A suggested frameworks was developed based on (Köber, Heinecke 2012) and (Kim, Kim 2014) to solve the problem and provide a basis and a way for thinking for similar problems. The first step was to understand the supply chain and analyze it for the 17 products. Then, several models from literature were tested e.g. Pareto chart and Olhanger's models to analyze the demand and production data, and make a decision on the feasibility of the decoupling point. This gave an initial decision regarding the suitable places of the decoupling point, and the type of operations i.e. leanness or agility needed to support the production of each product **Figure 70**. This, was followed by a simulation study using Plant Simulation Tecnomatix 12 software. The target was to test the supermarket and optimize the quantity of material stored, and to validate the results of analysis. Two products were tested; one labeled as lean with low volatility, and another labeled as an agile product with extremely high volatility. The simulation for the first product managed to make it as lean as possible, through leveling production by volume, stabilizing demand, and optimizing a supermarket with a CONWIP control strategy. The second product was a highly volatile product and required different treatment. Consequently, a supermarket with a responsive BK-CONWIP control strategy, and a redundant machine were developed and optimized to achieve a service level of 100%. The additional costs needed to operate such product are justified by the high cost of non-fulfilled or delayed items.

This shows that using simulation is vital in such studies to help optimize the production and find the best hybrid of leanness and agility. It also validates the results of Olhanger's analysis, and guides the company towards choosing the right strategy for their products. On total, the development made on the two products achieved an estimated profit saving of € 313,940.9 a year, as compared to the status quo, in terms of service level, supermarket and WIP costs. The contribution of case study, is that it provides a successful use case of the implementation of hybrid lean-agile production, which is still rare in literature.

6 CONCLUSIONS AND OUTLOOK

This master's thesis makes several contributions in the areas of lean, agile and hybrid leagile production. It tackles their applicability in volatile markets throughout interviews and case studies at four major suppliers in Europe i.e. Magna Powertrain, Miba Sinter Slovakia, Plansee Group, and Austrian Supplier. The contributions stemming from this work can be divided into three main points:

The agility of the lean production system

Although there was several literature addressing the comparison between the leanness and agility from strategic level, this work adds to this research by addressing the operational level. It shows that while the two systems share several similarities and differences, a combination between the two systems is possible. Thus, the agility of the lean system was investigated in both literature and industry, and it was concluded that the lean tools are divided into three categories: supporting agility, to be tailored for agility, and natural or prerequisites. The tools that should be tailored are particularly in the areas of production planning and control, pulling control systems, Just-in-time tools, waste elimination, and virtual production. Same goes for agility, where several agile tools were found needed to be incorporated i.e. decoupling point, hybrid MTS/MTO, Flexible Manufacturing Systems (FMS), and ERP planning. Some other tools were also applied in the industry e.g. Peak shaving, extra shifts, 3D printing, but still require further investigation in terms of suitability with leanness. Nevertheless, due to the lack of a unanimously approved agile model in literature, it was not possible to compare all the agile tools to leanness. In this thesis, however, an effort was made to compile 67 agile tools and elicit some of them that would be applicable with leanness from literature and case studies. Further research should continue this work to find a comprehensive model of agility, and go through the compatibility of each of the agile tools to lean production.

Applicability of lean and agile paradigms in industry:

It was observed through the interviews that the one single approach is not viable in the current market environment. Thus, most of the companies apply a mixture of lean and agile tools to achieve the level of robustness needed. Another observation made during the interviews was that at companies that are considered as lean companies, there was some missing basic practices in lean such as Kanban, pull, levelling, 5S, TPM, value stream mapping etc. This could be attributed to a shift towards the agile paradigm. But also, this could be due to a lack of awareness in the contents of the lean system. It was evident from the interviews and case studies that more flexibility could have been achieved at the companies if those missing tools had been adopted. This could be further investigated through a survey that includes larger number of companies, and investigate the applicability of the each of the lean tools and the agile tools as well.

Applicability of hybrid lean-agile paradigm (decoupling point, MTS/MTO hybrid, postponement):

The hybrid lean-agile approach was investigated through literature and case studies. Although there is large number of research in this area, its applicability in the industry is still a niche market; only one company out of the four interviewed ones, had successfully implemented a highly flexible leagile supply chain. Although the other companies were applying a mixture of tools from both paradigms to increase the level of flexibility, this was not done in a systematic way, and the level of flexibility achieved at those companies was non comparable with what literature in leagility strives for. Consequently, a successful case study was applied at one of the four companies (Miba sinter Slovakia), which managed to implement several approaches from the hybrid lean-agile paradigm, such as hybrid MTS/MTP and decoupling point. It also managed to apply some tailored lean tools such as BK-CONWIP. Significant improvements in service level and cost savings were generated out of this study. The essence of this approach is to have scenario-based planning for the decoupling point and a clear framework. Thus, the thesis suggests a framework of implementation that proved effective during the case study. Furthermore simulation is a very beneficial tool that should be used in such situations. On total the case study at Miba sinter Slovakia managed to achieve cost savings of € 313,940.9 a year only for two products out of 270 the company produces. Having said that, it would be interesting to expand this study, to a wider range of products, especially in production lines that share multi-products. This provides a fertile soil for implementing the decoupling point with postponement strategy. Further research should address this situation.

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Abbreviations

MTO: Make to Order
ATO: Assemble to Order
MTS: Make to stock
KPI’s: Key performance indicators
JIT: Just in time
MRP: Material Requirement Planning
ERP: Enterprise Resource Planning
DP: Decoupling Point
CODD: Customer Order Decoupling point
FMS: Flexible Manufacturing Systems
EDI: Electronic data interchange (EDI)
Cp: Processes capability
BK-CONWIP: Base stock, Kanban, Constant Work In Progress.
MRS: Master Production Schedule
CRP: Capacity Requirement Plan
AGVSs: Automated guided vehicle systems
AS/RS: Automated storage and retrieval systems
CNC: Computer numerically controlled machines
CAD: Computer-aided design
CAM: Computer-aided manufacturing
CAPP: Computer-aided process planning
POS: Point-of-sales data collection
KBS: Knowledge based systems
RDV: Relative Demand Volatility
PD ratio: Production lead time/ Delivery lead time
SD: Standard Deviation
SWOT: Strengths, Weaknesses, Opportunities, and Threats.
MSA: Measurement System Analysis
SCF: Shop Floor Control
MPS: Master Production Schedule

Appendix A

BK-CONWIP codes on plant simulation

Method to generate demand

```
is
do
if D1.yDim> 0  and Kanban_Buffer1.occupied=true and
conwip_Buffer.occupied=true and compacting.occupied=false and
compacting.operational=true then  -- check

rawmaterial.cont.move(Compacting); --send material to machine

Kanban_Buffer1.cont.move(compacting.MU.pe(1,1));  --stick  kanban card
CONWIP_buffer.cont.move(compacting.MU.pe(2,1));  --stick conwip card
D1.cutRow(1);    --delete demand request

END;

if D2.yDim> 0 and aftersintering.occupied=true and
Kanban_buffer2.occupied=true and sizing.occupied=false and
sizing.operational=true  then – check
aftersintering.cont.move(sizing);  --move part to sizing
Kanban_Buffer2.cont.move(Sizing.MU.pe(1,1));  --stick Kanban stage 2
D2.cutRow(1);  --delete demand request

end;

if D3.yDim> 0 and aftersizing.occupied=true   then   --demand arrives stage 3
if  turning.occupied=false and turning.operational=true then  -- send part to
the machine availble and delete demand request
aftersizing.cont.move(turning);
D3.cutRow(1);
    else
         if turning1.occupied=false and turning1.operational=true then
        aftersizing.cont.move(turning1);
        D3.cutRow(1);
        end;
end;
        end;

if D.yDim> 0 and supermark.occupied=true  then   -- if demand arrives check
supermarket
supermark.cont.move(customer); -- fulfil demand
D.cutRow(1);  --delete demand
end;
```

```
end;
```

Methods to remove Kanban cards from after sintering as exist strategy

```
is
do
@.pe(1,1).cont.move(Kanban_Buffer2);
end;
```

Method to remove Kanban from after sizing as exit strategy

```
is
do
@.pe(1,1).cont.move(Kanban_buffer1);
end;
```

Method to remove CONWIP after turning machine as exit strategy

```
is
do
@.pe(2,1).cont.move(CONWIP_Buffer);
end;
```

Method for initial state

```
is
	i:integer;

	Part:object;
do
	D.delete;
	D1.delete;
	D2.delete;
	D3.delete;
	WIPtable.delete;
for i:=1 to level_supermark loop
	part:=.Mus.PartA.create(supermark);
	next;
for i:=1 to level_aftersizing loop
	part:=.Mus.PartA.create(aftersizing);
	.MUs.Kanban2.create(part);
	.MUs.CONWIP.create(part);
```

```
        next;
for i:=1 to level_aftersintering loop
        part:=.Mus.PartA.create(aftersintering);
        .MUs.Kanban2.create(part);
        .MUs.CONWIP.create(part);
        next;
for i:=1 to initialKanban_buffer2 loop
        .MUs.Kanban2.create(Kanban_Buffer2);
        next;
for i:=1 to initialKanban_buffer1 loop
        .MUs.Kanban2.create(Kanban_Buffer1);
        next;
for i:=1 to initialCONWIP_buffer loop
        .MUs.CONWIP.create(CONWIP_Buffer);
        next;
end;
```

Appendix B

Optimizing the supermarket, experimentations for product 11257

Exp	supermarket	Throughput
1	5000	34000
2	15000	70000
3	25000	95000
4	35000	102769
5	45000	102769
6	55000	102769

Optimizing the supermarket, experimentations for product 15704

Exp	supermarket	after sizing	Kanban	CONWIP	Throughput
1	10000	50	50	50	28641
2	10000	50	50	550	28641
3	10000	50	550	50	28641
4	10000	50	550	550	28641
5	10000	550	50	50	28641
6	10000	550	50	550	28641
7	10000	550	550	50	28641
8	10000	550	550	550	28641
9	20000	50	50	50	31974
10	20000	50	50	550	31974
11	20000	50	550	50	31974
12	20000	50	550	550	31974
13	20000	550	50	50	31974
14	20000	550	50	550	31974
15	20000	550	550	50	31974
16	20000	550	550	550	31974
17	30000	50	50	50	32660
18	30000	50	50	550	32660
19	30000	50	550	50	32660
20	30000	50	550	550	32660
21	30000	550	50	50	32660
22	30000	550	50	550	32660
23	30000	550	550	50	32660
24	30000	550	550	550	32660
25	40000	50	50	50	32660
26	40000	50	50	550	32660
27	40000	50	550	50	32660

28	40000	50	550	550	32660
29	40000	550	50	50	32660
30	40000	550	50	550	32660
31	40000	550	550	50	32660
32	40000	550	550	550	32660
33	50000	50	50	50	32660
34	50000	50	50	550	32660
35	50000	50	550	50	32660
36	50000	50	550	550	32660
37	50000	550	50	50	32660
38	50000	550	50	550	32660
39	50000	550	550	50	32660
40	50000	550	550	550	32660
41	60000	50	50	50	32660
42	60000	50	50	550	32660
43	60000	50	550	50	32660
44	60000	50	550	550	32660
45	60000	550	50	50	32660
46	60000	550	50	550	32660
47	60000	550	550	50	32660
48	60000	550	550	550	32660

Appendix C

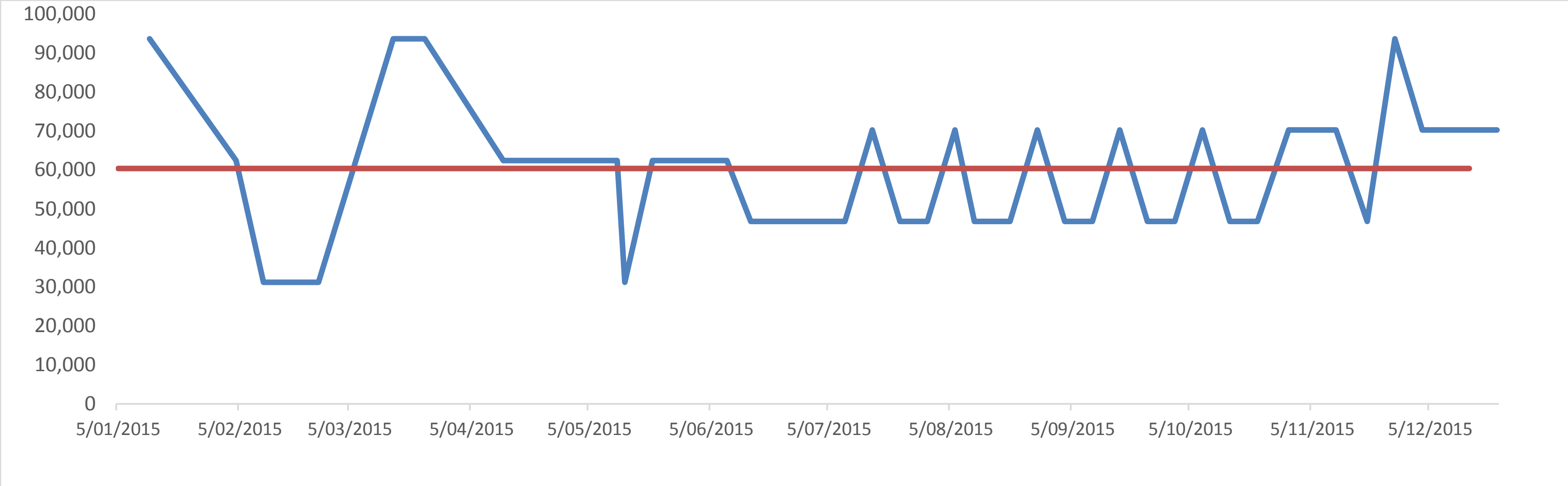
Production lead time calculations

Product	lot size avg	Processing times															Set up times							bottleneck	daily possible amount	Availability	capacity issues due to availbility	**Production lead time**
		Compac-ting	Sin-tering	Sandblasting	Sizing	Welding	Turning	Brushing	Oil dipping	Thumbling/drying	Steam treatment	Rolling	Induction hardening	Boring, thread cutting ...	Assembly	Ext. Op.	Compac-ting	Sizing	Welding	Turning	Rolling	Induction hardening	Boring, threadcutting...					
1.1.257	209,000	0.094	0.009														0.001							0.0940	13882.98	0.70	9718.09	21.5
1.4.510	132,000	0.1	0.033				0.16		0.08								0.003			0.003				0.1600	8156.25	0.70	5709.38	23.1
1.2.311	115,000	0.09	0.026							0.03							0.003							0.0900	14500.00	0.70	10150.00	11.3
1.5.927	104,000	0.143	0.084		0.11	0.1					0.124						0.003	0.004						0.1430	9125.87	0.70	6388.11	16.3
1.3.336	112,000	0.104	0.037		0.14							0.108	0.056				0.005	0.002			0.002	0.001		0.1360	9595.59	0.70	6716.91	16.7
1.4.274	89,000	0.138	0.108	0.018	0.08					0.13				0.122			0.005	0.005					0.003	0.1380	9456.52	0.70	6619.57	13.4
1.4.483	78,000	0.167	0.09		0.09												0.005	0.006						0.1670	7814.37	0.70	5470.06	14.3
1.5.477	87,000	0.188	0.12		0.15										0.23		0.005	0.003						0.23	5800.00	0.70	4060.00	21.4
1.5.477	72,000	0.1	0.1		0.14										0.23		0.006	0.007						0.23	5800.00	0.70	4060.00	17.7
1.5.704	76,000	0.181	0.181		0.16		0.32										0.006	0.005		0.002				0.321	4065.42	0.70	2845.79	26.7
1.5.729	66,000	0.182	0.09		0.143												0.008	0.008						0.1820	7170.33	0.70	5019.23	13.1
1.4.446	68,000	0.184	0.08		0.09	0.2					0.043						0.015	0.007	0.001					0.1960	6658.16	0.70	4660.71	14.6
1.4.391	65,000	0.133	0.052	0.008	0.14												0.005	0.007						0.1400	9321.43	0.70	6525.00	10.0
1.4.480	72,000	0.2	0.066		0.66		0.27				0.06					0.28	0.006	0.003		0.006				0.6600	1977.27	0.95	1878.41	38.3
1.4.355	66,000	0.117	0.041	0.041	0.13												0.004	0.012						0.1320	9886.36	0.70	6920.45	9.5
1.4.535	63,000	0.169	0.06				0.6	0.25			0.066						0.006			0.007				0.6000	2175.00	0.70	1522.50	41.4
1.4.422	64,000	0.16	0.16		0.13		0.41	0.409				0.375	0.15				0.007	0.006		0.007	0.004	0.003		0.4090	3190.71	0.70	2233.50	28.7

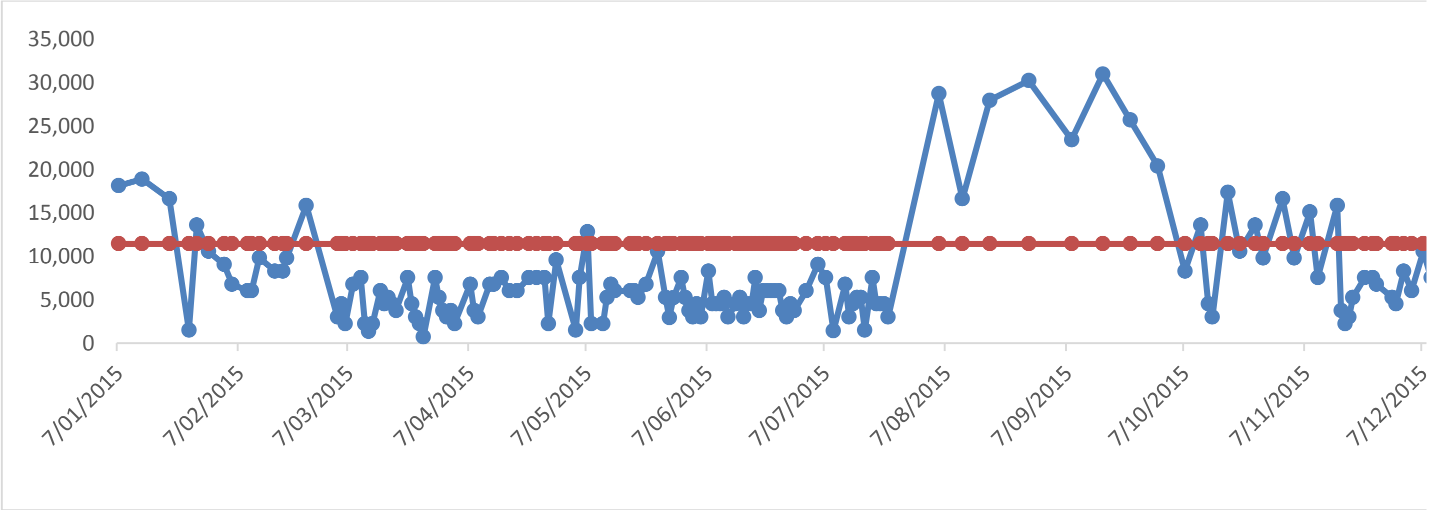
Appendix D

Demand representation for the chosen products for the simulation

Product number: 11257, mean demand: 60331, mean periods: 8.4 days, SD: 16562, Volatility level: 27.5%



Product number: 15704,   mean demand: 11456   mean periods: 2 days, SD: 85172, volatility level: 74%



Appendix E

Agile compiled tools based on literature review

Tools	area	Source
Top management support and employee involvement and empowerment	Human	(Vázquez-Bustelo et al. 2007, p. 1309), (Wang, Koh 2010, p. 159)
Team working, self-directed teams, cross-functional teams	Human	(Vázquez-Bustelo et al. 2007, p. 1309), (Wang, Koh 2010, p. 159)
Job rotation, multifunctional workforce, job enrichment (responsibility on multiple tasks)	Human	(Vázquez-Bustelo et al. 2007, p. 1309)
Training and education, higher average skill levels, workforce skill upgrade, continuous training and development, cross-functional training	Human	(Vázquez-Bustelo et al. 2007, p. 1309)
Knowledge workers, IT-skilled workers	Human	(Vázquez-Bustelo et al. 2007, p. 1309)
Decentralised decision making	Human	(Vázquez-Bustelo et al. 2007, p. 1309)
Additional shifts	Human	(Baker 2008, p. 18)
Entrepreneurial firm culture Reward schemes to encourage innovation and based on both financial and non-financial measures	Human	(Vázquez-Bustelo et al. 2007, p. 1309)
Rapid Hardware	Technologies	(Wang, Koh 2010, p. 159)
3D Printing technologies	Technologies	(Nyman, Sarlin, p. 4195)
Enterprise resource planning (ERP)	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309), (Gunasekaran, Yusuf 2002, p. 1376)
Material requirement planning (MRP)	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309), (Gunasekaran, Yusuf 2002, p. 1376)
Robotics	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309), (Gunasekaran, Yusuf 2002, p. 1376)
Automated guided vehicle systems (AGVSs); automated storage and retrieval systems (AS/RS)	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309)

Computer numerically controlled (CNC) machines	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309)
Rapid Hardware	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309)
Modular assembly softwares	Technologies	(Wang, Koh 2010, p. 159)
Kanban, JIT	Technologies	(Wang, Koh 2010, p. 159), (Gunasekaran, Yusuf 2002, p. 1376)
Computer-aided design (CAD)/computer-aided manufacturing (CAM)	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309), (Gunasekaran, Yusuf 2002, p. 1376)
Rapid prototyping tools	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309), (Gunasekaran, Yusuf 2002, p. 1376)
Intranet, internet and world wide web	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309), (Gunasekaran, Yusuf 2002, p. 1376)
Electronic data interchange (EDI)	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309)
Electronic commerce	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309), (Gunasekaran, Yusuf 2002, p. 1376)
Visual inspection	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309)
Manufacturing cells	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309)
Virtual reality software	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309)
Flexible manufacturing systems (FMS)	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309)
Group technology	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309)
Computer-aided process planning (CAPP)	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309), (Gunasekaran, Yusuf 2002, p. 1376)
Point-of-sales data collection (POS)	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309)
Bar codes, automatic data collection	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309)
Real-time	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309)

communication/execution systems	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309)
Design for manufacture/assembly (DFM/A)	Technologies	(Vázquez-Bustelo et al. 2007, p. 1309)
Strategic alliances based on core/complementary competencies	organizational internal external	(Vázquez-Bustelo et al. 2007, p. 1309)
Annual cross functional planning	organizational internal external	(Baker 2008, p. 18)
Virtual firm/organization	organizational internal external	(Vázquez-Bustelo et al. 2007, p. 1309)
Integration of functions from purchasing to sales; firm-wide integration of functions	organizational internal external	(Vázquez-Bustelo et al. 2007, p. 1309)
Scenario planning, and market intelligence	organizational internal external	(Rabitsch, Ramsauer 2015, p. 4)
Global supply chain management	organizational internal external	(Vázquez-Bustelo et al. 2007, p. 1309)
Integrated supply chain; integrated and interactive partner relations	organizational internal external	(Vázquez-Bustelo et al. 2007, p. 1309)
Outsource off-site	organizational internal external	(Baker 2008, p. 18)
Hybrid MTS and MTO	organizational internal external	(Jodlbauer et al. 2012, p. 46), (Ben Naylor et al. 1999, p. 114)
Postponement of differentiation	organizational internal external	(Ben Naylor et al. 1999, p. 114)
Decoupling point	organizational internal external	(Ben Naylor et al. 1999, p. 114)
Customer integrated processes for designing, manufacturing, marketing, and support	organizational internal external	(Vázquez-Bustelo et al. 2007, p. 1309)
Strategic relationship with customers, close relationship with suppliers; thrust-based relationship with customers/suppliers Internal and external cooperation	organizational internal external	(Vázquez-Bustelo et al. 2007, p. 1309)
Business process reengineering	organizational internal external	(Vázquez-Bustelo et al. 2007, p. 1309)
Rapid-partnership formation	organizational internal external	(Vázquez-Bustelo et al. 2007, p. 1309)
Formation of cross-functional product development teams	concurrent engineering	(Vázquez-Bustelo et al. 2007, p. 1309)

Multidisciplinary team working environment	concurrent engineering	(Vázquez-Bustelo et al. 2007, p. 1309)
Customer and supplier integrated multidisciplinary teams	concurrent engineering	(Vázquez-Bustelo et al. 2007, p. 1309)
Early involvement of different agents in the product development process and concurrent execution of functions/activities	concurrent engineering	(Vázquez-Bustelo et al. 2007, p. 1309)
Intelligent engineering design support system; groupware Collaborative work	concurrent engineering	(Vázquez-Bustelo et al. 2007, p. 1309)
Concurrent design of products and processes	concurrent engineering	(Vázquez-Bustelo et al. 2007, p. 1309)
Global access to databases and information	Knowledge management	(Vázquez-Bustelo et al. 2007, p. 1309)
easy access to integrated data; open information/communication policy	Knowledge management	(Vázquez-Bustelo et al. 2007, p. 1309)
Knowledge based systems (KBS) , knowledge management systems	Knowledge management	(Vázquez-Bustelo et al. 2007, p. 1309)
Sensitive information protection	Knowledge management	(Vázquez-Bustelo et al. 2007, p. 1309)
Organizational structure that promotes innovation and training and education;	Knowledge management	(Vázquez-Bustelo et al. 2007, p. 1309)
learning organization	Knowledge management	(Vázquez-Bustelo et al. 2007, p. 1309)
Team-to-team learning	Knowledge management	(Vázquez-Bustelo et al. 2007, p. 1309)
Firm-wide integration of learning,	Knowledge management	(Vázquez-Bustelo et al. 2007, p. 1309)
continuous learning	Knowledge management	(Vázquez-Bustelo et al. 2007, p. 1309)
Knowledge acquisition from internal and external sources	Knowledge management	(Vázquez-Bustelo et al. 2007, p. 1309)
Core-competence management	Knowledge management	(Vázquez-Bustelo et al. 2007, p. 1309)