# Application of lean in high variety and low volume manufacturing

A qualitative case study in Norway

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# Preface

This master thesis was written in the spring of 2020 and marks the fulfilment of our Master's Programme in Industrial Economics and Technology Management at the University of Agder.

The decision to work together came late 2019, while we were doing our internships in China and India. Preparations started, but contact was limited, and progression was slow. Not before the middle of January, we got in touch with CSUB and decided to write our master's thesis about lean in their high variety and low volume manufacturing environment.

First of all, we would like to thank our supervisor Knut Erik Bonnier for the time and effort devoted to guiding this thesis. Further, we want to give a general thank to everyone that has contributed during the process.

Moreover, we want to thank CSUB for giving us access to their facility and for providing the resources needed to realise this thesis. We would like to thank our external supervisor at CSUB, Eli Bell, for providing us with information and for putting us in touch with all the people we needed. Lastly, we would like to express our gratitude toward each of the informants that have contributed to the research.

The master's programme has been an exciting journey with many unforgettable moments. Unfortunately, it all ended in the dusk of the SARS-CoV-2 pandemic. Nevertheless, we stay optimistic, looking forward to many more exciting journeys in the years to come.

**Grimstad, 22/5 2020**

Birgitte Austefjord Eivind Opsahl

# Abstract

The demand for customised products is increasing, and the importance of improving high variety manufacturing has become more prevalent. As manufacturers of customised products experience more competition, it has become vital to improve processes in order to increase competitiveness. Many high variety and low volume (HVLV) manufacturers have looked towards lean as a potential solution but may have found themselves to be “different” and not fitting within the traditional means of lean found in the high-volume manufacturing environment. However, the concept of lean thinking provides five principles moving beyond the traditional lean manufacturing environment, exploring the mindset behind the system. By exploring the five principles in relation to the HVLV environment, can the potential application of lean thinking in these environments be identified. The research takes a qualitative foundation in a single case study at CSUB Eydehavn, an HVLV manufacturer of glass fibre reinforced polyester solutions, exploring the implications of lean and the transformation process. The research has taken an abductive approach following the mindset of Straussian grounded theory.

The research concludes that lean principles can be applied to HVLV manufacturing with some adaptions. Lean is a process of aligning the organisation with its values and philosophy. Tools should be seen in the context of the values and principles of the organisation. It could be beneficial to emphasise flow efficiency to reduce lead times. The workflow can be increased by using visual management to create information transparency. HVLV manufacturers can with advantage focus on lean aspects such as continuous improvement and learning systems. To implement lean, the research recommends working to convince the organisation to change by informing and involving people to create a sense of ownership. Using external support to communicate the change message can be beneficial. In order to sustain lean, it should be opted to work on creating a lean culture that has strong support from the management.

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# Abbreviations

| | |
|---|---|
| **ATO** | Assemble-to-Order |
| **BTO** | Buy-to-Order |
| **CODP** | Customer order decoupling |
| **ConWIP** | Constant Work in Progress |
| **ETO** | Engineer-to-Order |
| **HVLV** | High variety and low volume |
| **LVHV** | Low variety and high volume |
| **MTO** | Make-to-Order |
| **MTS** | Make-to-Stok |
| **OPP** | Order Penetration Point |
| **PDCA** | Plan Do Check Akt |
| **POLCA** | Paired-cell Overlapping Loops of Cards with Authorisation |
| **TPS** | Toyota Production System |
| **VSM** | Value Stream Mapping |
| **WIP** | Work in Progress |

# 1 Introduction

The demand for customised products is constantly increasing. The high degree of customisation can lead to increased complexity and lead times (Strandhagen, Vallandingham, Alfnes & Strandhagen, 2018). To face these issues, manufacturers within high variety and low volume (HVLV) environments have increasingly started to explore lean as a suitable approach to improve competitiveness (Buetfering et al., 2016). However, difficulties with adapting to the new production paradigm have emerged. Evolving from the Toyota shop floor in the 1950s, lean has traditionally been found in the high-volume production environment. Trying to imitate Toyota, HVLV manufacturers might find themselves too "different" when trying to adapt the system to their own manufacturing environment (Lander & Liker, 2007). The experience of being "different" often stems from not being able to fit the principles and techniques due to a high product variety (Powell et al., 2014).

Recently the topic has attracted the attention of several researchers. It has been argued that some aspects of lean can still be applied, but the literature has been various and unclear regarding the adoption and deployment of lean in HVLV environments (Buetfering et al., 2016). How the base philosophies of lean thinking and continuous improvement can work in HVLV manufacturing needs to be further explored.

## 1.1 Problem statement

This thesis is based on a case study of CSUB, a Norwegian-based HVLV manufacturer of glass fibre reinforced polyester solutions which is evaluating the possibilities to implement lean in their organisation in order to get a competitive advantage. There is an uncertainty of what should be implemented, due to the unclarity of the application of lean in HVLV manufacturing and how CSUB should do a lean transformation. To clarify the uncertainty, the following research question has been set:

*How can lean be applied in CSUB, as an HVLV manufacturer?*

Both in the theoretical framework, and in the findings and discussion, there has been a focus on finding the "what?" and the "how?" regarding lean in HVLV manufacturing environments. The "what?" is presented with the foundation of lean thinking, tools and methods together with the differences found between lean in HVLV and LVHV environments (low variety and high volume). To find the "how", implementation barriers for lean and concepts of change management have been explored, both in the literature and the case study of CSUB. The research has taken an abductive approach following the concepts of Straussian grounded theory.

## 1.2 Research scope

The scope of the research has been limited to HVLV manufacturers of bespoke products characterised by high variation and low volume demand. The term of HVLV includes several manufacturing structures. However, the thesis has focused mainly on make-to-order (MTO) and engineer-to-order (ETO), which is the main structures typically related to HVLV. The scope has been limited to one case company, with observations from one manufacturing facility and interviews from the other departments. The research is conducted within five months, during the spring semester at the University of Agder.

Bertrand & Muntslag (1993) separates HVLV manufacturers into two main stages: non-physical stage and physical-stage. The first stage concerns engineering, design and planning activities, while the second stage concerns manufacturing and all physical activities. This thesis emphasises mainly the latter, with how elements in the organisation impact the potential application of lean in the physical space.

# 2 Contextual framework

In this chapter, the case company will be described. The case study is based on CSUB, which is a manufacturer of bespoke glass fibre products, with the main office in Arendal and production facility on Eydehavn and Bokn in Norway, and Klaipeda in Lithuania. The description is based on observations done at the office in Arendal and production site in Eydehavn, and information collected through interviews with informants at all three sites located in Norway. To provide anonymity, the informants are referred to as interview object 1-8. The first part will be a description of CSUB concerning their activities at Eydehavn and secondly their earlier experience with lean.

## 2.1 The case

This thesis has been performed with the help of CSUB. CSUB is a manufacturer of glass fibre reinforced polyester solutions (GRP - or to many known as fibreglass) delivering products to both land-based and offshore industries, such as aquaculture, oil and gas, and to the civil market. Each product is unique and designed for the customer by CSUB's engineering department. Some customers also do the design themselves. The volume of each product is low, usually ranging from one unique product to a group of a few products where the same mould is reused several times. An overview of their project progression is given in Figure 1.


**Figure 1 Project progression at CSUB obtained from CSUB's TQM system**

The company has three different production sites: Bokn and Eydehavn in Norway, and one in Klaipeda in Lithuania. The main office is located in Arendal. The production has a high degree of manual labour; therefore, the most labour-intensive products are located to Klaipeda for lower production costs. An organisational overview is given in Figure 2.

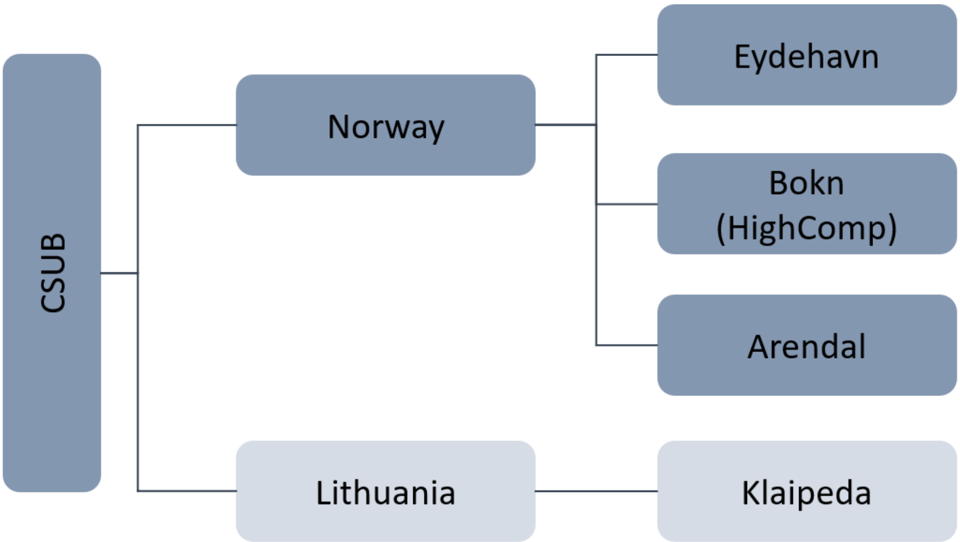


**Figure 2 Organisational overview of CSUB**

Due to the project-based nature of the production, the need for labour is fluctuating together with the seasonal demand of products. At the time of writing this thesis, it was approximately 250 individuals employed in the company. Since a large part of their customer base is within the oil industry, they have a seasonal based demand. The Offshore oil and gas industry have only a small scope of time where heavy equipment can be deployed out on the sites, giving little flexibility in delaying the delivery date when surpassing the deadline may have substantial consequences for the customer. The products are often “one-of-a-kind” and made with the requirements of a specific customer in mind.

CSUB operates within several sectors. The oil and gas sector are well developed, and the customers can often be large and rigid organisations with many requirements. On the contrary, they have the aquaculture industry, where many customers can be found in an entrepreneurial stage. It may be entirely new products to the market, where the customer does not entirely know what is required to bring the idea into reality. Regardless off the sector, CSUB delivers bespoke products customised for the specific needs of the customer. There are no competitors in Norway working with GRP on the same scale as CSUB, giving them a significant part of the market share. Nevertheless, they compete against manufacturers producing in other materials, such as steel and concrete.

## 2.2 The production

The production is based on glass fibre reinforced polyester (GRP) infused over a three mould under vacuum. The production process can be separated into four main stages: mould preparation, glass layup, vacuum infusion and cutting and coating, as illustrated in Figure 3. Every product is unique, but the processes are much the same every time. The variation comes in the form of design with different sizes, shapes, and complex details. The variation complicates the possibility of standardising the production when the product is continuously changing.


**Figure 3 Main processes in manufacturing obtained from CSUB's TQM system**

Producing with GRP is a labour-intensive manual process. The uniqueness of every product makes it essential to have manual labour to coupe with variations. Seasonal demand makes the need for labour to fluctuate, which causes the workforce to vary between periods. People have different backgrounds and nationality, causing both cultural and linguistic barriers. A changing workforce and cultural differences cause additional challenges when implementing new changes in the manufacturing environment.

The manufacturing is based on stages where activities are performed in different sections in the facility. Depending on the production layout and size of the product, it moves from one section to another, where various activities are performed. It has been observed that people flow on the product and not the product on the people. The lead times are relatively long, with much non-value-added time. Several projects can run in parallel, and production may become chaotic during the periods of high demand. It is expressed that the floor space is a bottleneck, which limits the work in progress.

## 2.3 Lean at CSUB, Arendal

Beside HighComp, there has not been any work with lean in CSUB. Some individuals have some experience from earlier work, but the general competence of lean is limited. Since CSUB was merged with HighComp in 2015, it has been expressed a desire to resume developing the lean system. Lately, the management at CSUB has looked into the possibility to apply lean in the production, but the decision is yet to be made.

### 2.3.1 Lean at HighComp, Bokn

HighComp is a supplier of aquaculture composite constructions, which merged with CSUB in 2015. HighComp won "Produktivitetsprisen" in 2014, a price given by *samarbeidsutvikling* for their work with implementation and use of lean philosophy, method, and tools. Applying lean was expressed to be a great success but sustaining, and further development of the lean system proved to be demanding. Today remains of the lean culture are still apparent, but much of the system has been lost with time. It has been expressed a wish to resume with the lean development and to expand it to the other production sites. The positive experience has led to optimism in that the company can gain significant benefits from establishing a lean culture.

# 3 Theoretical framework

The third chapter presents the theoretical backbone of the thesis. It is divided into four sections: High-variety and low volume (HVLV), the development of lean, lean in HVLV environments and implementing lean. The first section presents the definition of HVLV and gives an overview of what characterises the environment. The second section introduces the historical setting for the development of lean and how it has evolved. The third chapter will explore lean thinking in the setting of HVLV environments, and the last section considers the change process of a lean transformation.

## 3.1 High variety and Low volume (HVLV)

HVLV manufacturing can be related to both one-of-a-kind and small batch production environments (Buetfering et al., 2016). HVLV manufacturing can, in many cases, be of high complexity, and do generally experience demand in relatively low volumes (Strandhagen et al., 2018). Customers in this segment do often require a high degree of product customisation, which leads to customer engagement in an early phase of the project (Birkie & Trucco, 2016). Hicks, McGovern & Earl (2001) express that the HVLV segment is exposed to high uncertainties and can often be driven by a cyclical demand. Due to uncertainties in the market and uniqueness of the products, HVLV manufacturers can only produce when they have an order from a specific customer.

There is no clear definition or scope of what constitutes HVLV. Many choose to define HVLV based on supply chain structures and Customer Order Decoupling Point (CODP) (Buetfering et al., 2016), while others describe it as non-repetitive manufacturing (Portioli-Staudacher & Tantardini, 2012). Buetfering et al. (2016) have found HVLV to be commonly defined based on the supply chain structure and the CODP, and this definition is used further for this research.

Manufacturing value chains can be categorised by looking at the Customer Order Decoupling Point (CODP) or Order Penetration Point (OPP) which refers to where in the manufacturing value chain the customers get involved in the process, see Figure 4. It is common to divide HVLV into four different stages: Engineer-to-order (ETO), Make-to-order (MTO), Assemble-to-order (ATO) and Make-to-stock (MTS). In HVLV manufacturing, the CODP is typically ETO or MTO (Olhager, 2003).

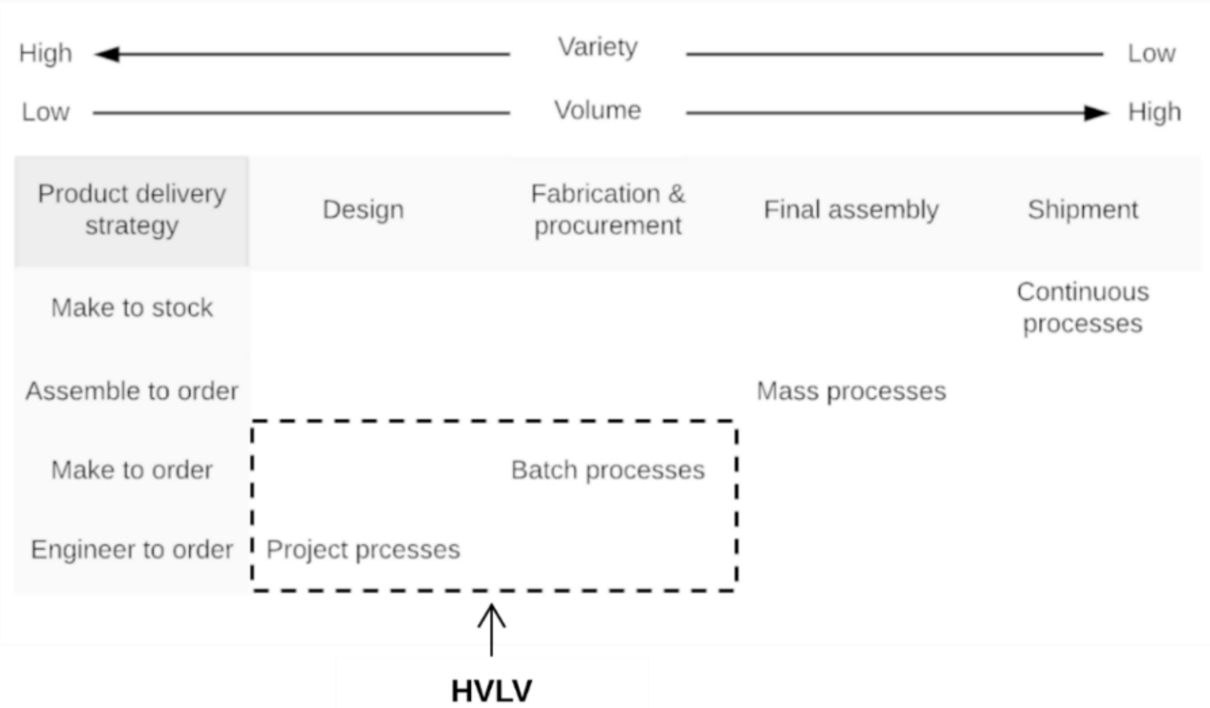


**Figure 4 Types of production depending on the CODP inspired by Olhager (2003) and Hayes & Wheelwright (1979)**

ETO and MTO are distinguished by either if the customer or the manufacturer is doing the engineering and design process (Amaro, Hendry & Kingsman, (1999)). MTO is typically when the customer delivers complete drawings for the manufactory to produce, while in ETO the engineering is performed by the manufacturer. Jina, Bhattacharya & Walton (1997) suggest that HVLV manufacturers typically produce 20 000 units or less per year, whereas low variety and high volume (LVHV) producers usually have a volume above 100 000 units. Table 1 gives an overview of some characteristics separating HVLV from LVHV.

**Table 1 Characteristics of HVLV and LVHV based on Buetfering et al. (2016) and Jina et al. (1997)**

| Characteristics | HVLV | LVHV |
|---|---|---|
| Volume | Very low - Low | High - Very high |
| Customisation | Moderate - Very high | Very low- Low |
| Complexity | Moderate - Very high | Very low- Low |
| Lead time | Variable | Fixed |
| Job of operators | Different for each product | Repetitive |
| Work knowledge | Tacit | Structured |
| Specialision of people and equipment | Low | High |
| Demand | Unsatable | Stable |
| Turbulence | Moderate - High | Low |

Jina et al. (1997) state that HVLV manufacturers is more prone to turbulence than high volume production. The word *"turbulence"* is used to describe the variation and uncertainty regarding inputs within manufacturing (Bhattacharya, Jina & Walton, 1996). Four types of turbulence commonly found in HVLV is listed (Alfnes, Thomassen & Gran, 2016; Jina et al., 1997):

1. ***Schedule:*** Changes in the schedule because of variation in demand.
2. ***Product mix:*** Changes in product mix between periods due to differences in the market.
3. ***Volume:*** Like product mix, changes in the market caused by aggregate volumes.
4. ***Design:*** The degree and frequency of design change within the expected lead time. Changes in design cause uncertainty and rework in manufacturing.

There can be different degrees of turbulence in a manufacturing system. Turbulence should be sought to be eliminated by reducing the turbulent inputs, or the production needs to be flexible enough to handle the variation and uncertainty (Bhattacharya et al., 1996). Jina et al. (1997) express that the four types of turbulence have a more considerable effect on HVLV environments because changes in lower volumes do naturally cause greater impacts.

## 3.2 The development of lean

After the devastating loss in the second world war, the Japanese industry experienced scarcity in resources. During the 1950s, Eiji Toyoda, Shigeo Shingo, and Taiichi Ohno at Toyota Motor Company developed the Toyota Production System (TPS) as a response to the scarcity of materials in the market. The aim of the system was "Cost reduction through the elimination of waste" and "Full utilisation of worker's capabilities" (Sugimori, Kusunoki, Cho & Uchikawa, 1977). Sugimori et al. (1977) further explain *cost reductions from elimination of waste* as a system that will assume that anything besides the minimum required amount of equipment, material, parts, and workers which are necessary for the production, are excesses that only will raise the costs. Cost reduction is by just-in-time production and jidoka (automation). *Full utilisation of worker's capabilities* involves treating workers with consideration and dignity. Modig & Åhlström (2017) express that TPS can often be misunderstood to be a set of tools when it rather is a philosophy which starts with value and ends with tools, as depicted in Figure 5.

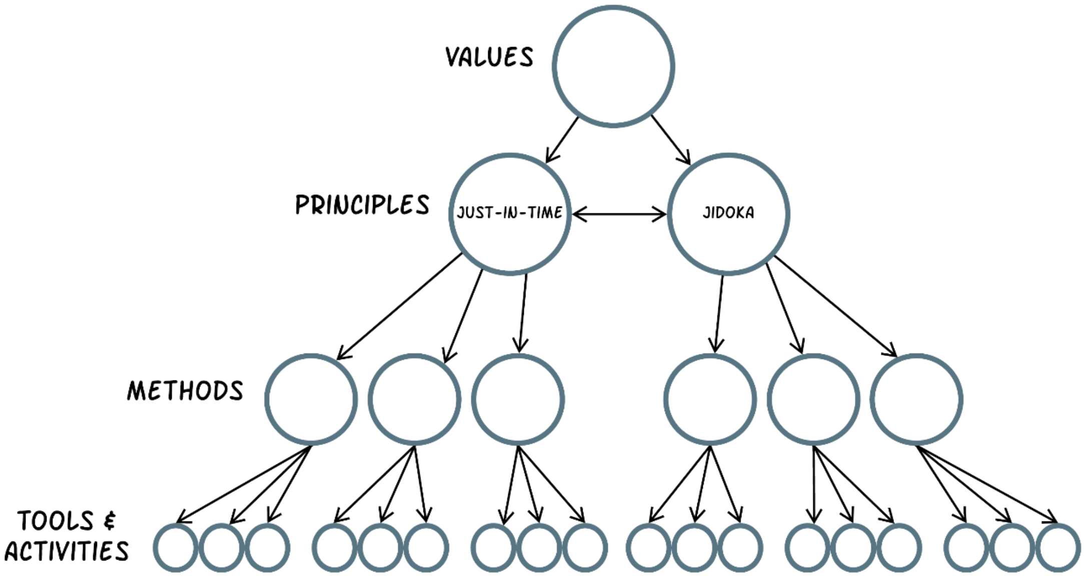


**Figure 5 The hierarchy of the Toyota production system, described by Modig & Åhlström (2017)**

The term "lean" was introduced by John Krafcik in 1988 and was later popularised in the world of management when the authors Womack, Jones and Roos published the best-selling book *The Machine that Changed the World* in 1991. The book basis in Toyota Production System and have since the time of release had a significant influence on organisations all over the world. The concept of lean has evolved beyond its original application in vehicle manufacturers' shop floor to have wide application in other types of manufacturing and non-manufacturing organisations.

Many companies deciding to become lean has experienced struggles in understanding what it means for their type of business (Womack & Jones, 2003). Many companies have tried to implement what they have observed while visiting Toyota's facilities, but the highly standardised and repetitive production environment makes their system hard to replicate, forgetting the soft elements which are the backbone of TPS. Particularly industries operating within a high variability and low volume production environment can meet difficulties with some aspects of lean (Bicheno & Holweg, 2016).

What many fails to recognise is that TPS is not a toolbox, but rather a philosophy. The idea of TPS did not emerge overnight but over a period of 30 years (Ohno, 1988). Liker (2004) and Modig & Ålström (2017) describes it as a long-term vision or philosophy, where following the right processes towards this philosophy will yield the right results. Establishing a lean philosophy in an organisation may be difficult when every company is different and do, therefore have different needs. Thus, the idea of lean may vary between every organisation, and which elements are right in building their culture must be recognised. Pepper & Spedding (2009) express concerns about the implementation of lean philosophy, as a lack of understanding of the concept may lead to myopic ways of approaching the situation. Lander & Liker (2007) suggest viewing lean as a long term journey, creating a culture for continuous improvement while embracing cultural change and people empowerment.

The concept of lean has been interpreted differently by various people, and a common definition of the concept cannot be said to exist. Modig & Åhlström (2017, p. 85) takes it as far as saying; ”There *are as many definitions of lean as there are authors to define it”*.

## 3.3 Lean in HVLV manufacturing

The demand for customised products is continually increasing (Strandhagen et al., 2018), and the importance of improving high variety manufacturing has become more prevalent. As manufacturers of customised products experience more competition, it has become vital to improve processes to increase competitiveness (Buetfering et al., 2016). Lean has earlier been perceived as not suitable for HVLV manufacturers, but research has found that introducing lean in these environments has had a positive effect on productivity ((Birkie & Trucco, 2016; Jina et al., 1997; Powell & Van der Stoel, 2016)). The misconception is not without reason; the variation and uncertainty found in HVLV manufacturing have proven to cause challenges for lean implementation (Alfnes et al., 2016; Jina et al., 1997). Further, Buetfering et al. (2016) express the research concerning lean in HVLV environments to still be inadequate.

Manufacturers within the HVLV environment do often consider the implementation of lean to be less effective due to the belief of their working environment to be “different” (Lander & Liker, 2007). They fail to understand that all companies are different and that the use of lean practices has different practicality concerning the exposed environment. Jina et al. (1997) recognised the HVLV environment to be more prone to variability and uncertainty, which Browning & Heath (2009) argue can cause a negative correlation with the implementation of lean practices.

Jina et al. (1997) recognised three main obstacles in the implementation of lean in HVLV environments. First, there is no clear definition and scope of what constitutes HVLV. Since manufacturers of different volumes and complexity, from various industrial structures, fall within the term of HVLV, it may be difficult to formulate a lean manufacturing strategy that embraces a consensus for all the manufacturing structures. Secondly, HVLV manufacturers are typically more prone to turbulence when often working with a high rate of bespoke products, causing higher variability and uncertainty of inputs and outputs. Lastly, the manufacturing system is exposed to turbulence, causing uncertainties in both the internal and outbound supply chain.

Introducing lean in HVLV manufacturing differs from LVHV due to the profoundly different characteristics found in the two manufacturing environments (Buetfering et al., 2016). HVLV manufacturing covers a range of different manufacturing environments, which contains various types of issues and varieties. Operating in an HVLV environment can prove difficult when means of traditional high-volume production does not conform to the variating low volume environments.

Hines, Holweg, and Rich (2004) refer to lean as strategic and operational. Lean on a strategic level is about lean thinking, while the operation level involves the use of lean production tools and methods. They emphasise the importance of understanding both systems in order to become lean. The five principles of Womack & Jones (2003) originates from lean thinking, based on observations in repetitive manufacturing environments, but the concept has since been applied to various settings. Operational lean builds on the tools and methods established in TPS, but as lean was taken into use in other environments, new tools and methods have emerged.

### 3.3.1 Lean Thinking

"Lean thinking" aspires to create greater value for the customer while simultaneously eliminating waste (Womack & Jones, 2003). *Muda* is the Japanese word for "waste" and is used for any human activity demanding any resources without creating any value (Womack & Jones, 2003, p. 15). Ohno (1988) identified seven types of waste for their Toyota Production System: defects, overproduction, inventories, processing, movement, transportation and waiting, but other types of wastes have also been added in other contexts. The founders of TPS wrote several books describing different techniques and important philosophic reflections. However, the mindset needed to form a successful Toyota system has proved to be hard to imitate (Womack & Jones, 2003). Womack and Jones have tried to capture the essence of the TPS philosophy in their book *Lean thinking* by presenting the five principles illustrated in Figure 6.

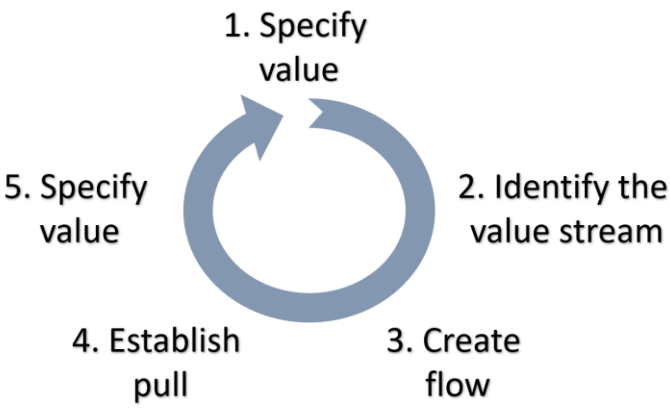


**Figure 6 The five principles of lean thinking, based on Womack & Jones (2003)**

*Lean thinking* bases in Womack and Jones' (2003) five principles; (1) specify value, (2) identify the value stream, (3) flow, (4) pull and (5) perfection. The principles provide a guideline to create customer value by eliminating waste while improving the flow in work processes. The five principles have been widely explored in the traditional LVHV setting, but the interest has also emerged in the HVLV environment (Buetfering et al., 2016). Since turbulence and long lead times are prominent characteristics of HVLV manufacturing, is the principles of lean thinking an appealing concept in building a lean culture and increasing competitiveness.

The five principles of lean thinking has been critiqued for being centred around repetitive production, and less suitable for environments with more variation and low volumes (Hines, 2012; Powell et al., 2014). The limitations found in the five principles are supported by Koskela (2004), claiming one-of-a-kind and construction to be mostly out of the scope. Koskela claims that *Lean Thinking* does not take variation into regard. However, Powell & van der Stoel (2016, p. 287) do still suggests the five principles of lean thinking to be the ideal starting point for evaluating lean principles in HVLV manufacturing.

**Specify value**

Womack & Jones (2003, pp. 29–36) emphasises that lean thinking starts with value and can only be defined by the ultimate customer. On the contrary of Womack & Jones's definition of value, Powell et al. (2014) expresses a need to expand this principle of value in HVLV to include all major stakeholders, and not only the values of the ultimate customer. They expressed that because the end product tends to be more complex in HVLV manufacturing, it is necessary to engage with the customer throughout the value stream to ensure that all specifications are met.

Traditionally, LVHV manufacturers use standardisation to eliminate most forms of variability, but in the case of HVLV manufacturers are variability an essential feature for generating customer value (Jina et al., 1997). Powell & van der Stoel (2016, p. 288) suggests that customisation should be seen as a strategic source of generating value. Rigid standardisation cause inflexibility, which may harm the competitiveness of the company. Many view the removal of waste as value creation, but the definition of waste depends on the customer's understanding of value (Hines et al., 2004).

**Value stream**

The value stream is all the actions required to bring a specific product from a concept to a finished product in the hands of the customer (Womack & Jones, 2003, pp. 19–21). Rother & Shook (1999) describes a value stream as all the value-added and non-value-added activities currently required for producing a specific product. Womack & Jones (2003) suggest that waste should be identified in the value stream, then the existence of the waste should be challenged and improved on to develop a system of perfection. Traditional LVHV manufacturers do often find their value stream to be highly linear and repeatable. In contrast, in HVLV manufacturing the value stream is prone to product variation and iterations between different process stages (Powell & Van der Stoel, 2016, p. 288).

A common method used to identify the value stream is value stream mapping (VSM), which is a pen and paper tool used to help understand material and information flow (Rother & Shook, 1999). Operating in turbulent environments creates challenges for HVLV manufacturers in using VSM, as the flow is disrupted by variation (Alfnes et al., 2016). Jina et al. (1997) specify that applying VSM in HVLV manufacturing becomes more difficult as turbulence in the system increases and Alfnes et al. (2016) highlights that for even modified versions of VSM, the turbulence has to be reduced to a moderate level for the method to be applicable.

Takt time is a fundamental concept in the mapping of repeatable production and flow (Bicheno & Holweg, 2016). The concept of takt time is based on creating a fixed pace by regulating the production relative to the available work time divided by demand (Slomp et al., 2009). In traditional LVHV can takt time be the available daily work, divided on daily demand. However, the concept becomes problematic in environments with high turbulence. Alfnes et al. (2016) express that it makes little sense to control daily pace when demand is unstable. Instead, it is suggested a possibility to establish a pace based on longer periods.

**Flow**

Flow is how the product and work progress from the beginning to the end. Establishing flow requires rearrangement of activities in such a way that the product can flow through the system with as little non-value creating time as possible (Womack & Jones, 2003, pp. 21–24). LVHV manufacturers can establish flow through rigid standardisation of products and value streams. In contrast, products and value streams in HVLV are less capable of standardisation (Powell & Van der Stoel, 2016, pp. 287–288). Several projects can be running in parallel, and schedule and design changes cause turbulence in the flow (Alfnes et al., 2016). To support flow, there should be a focus on building flexible and multifunctional work teams that can switch quickly between different tasks to avoid hold up problems due to lack of the right skills when needed (Jina et al., 1997; Koskela, 2000).

In the discussion of flow, there are two forms of efficiency often compared to each other: resource efficiency and flow efficiency. Resource efficiency is the traditional focus on high utilisation of resources. On the other hand, flow efficiency challenge the thought on efficiency by shifting the discussion over to how much time is spent on processing the unit (Modig & Åhlström, 2017, p. 13). A perfect situation would be a resource efficiency of 100%, while at the same time having absolute flow, which is the state illustrated with a star in Figure 7. However, Modig & Åhlström (2017, p. 100) express the state of full resource and flow efficiency to only be theoretical. When variation increases, does the correlation between resource and flow efficiency become relative to each other. Moving toward high flow efficiency will be at the expense of resource efficiency, and the contrary for moving towards high resource efficiency. Companies facing high variety will find it more challenging to combine resource and flow efficiency, than companies with low variety (Modig & Åhlström, 2017, pp. 100–106).

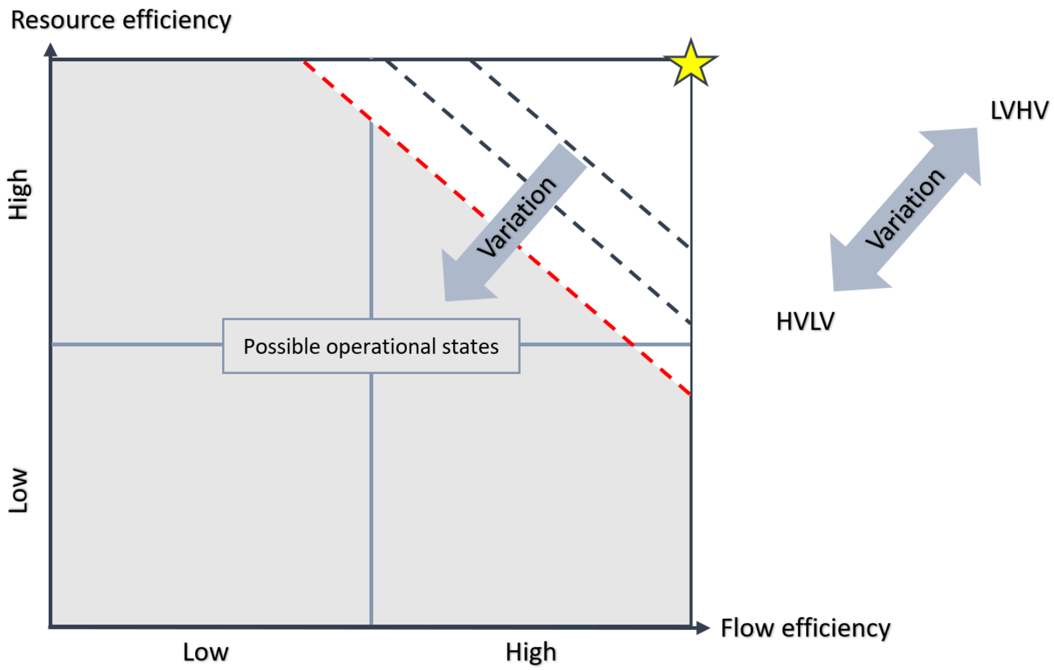


**Figure 7 The efficiency matrix based on Modig & Åhlström (2017). The relation between resource and flow efficiency become relative to each other with increasing variation.**

Powell & van der Stoel (2016, pp. 289–290) emphasise the importance of considering buffers when creating flow in HVLV manufacturing. According to Bicheno & Holweg (2016, p. 45), there are three types of buffers; *inventory, time and capacity*. Powell & van der Stoel (2016, p. 290) and Gran & Alfnes (2019) express that due to the customisable nature of HVLV manufacturing there are few benefits to add buffers against inventory variations, and time buffers will make little sense when the lead time is already long and uncertain. It is only found sensible to add buffers against the capacity since the emphasis should instead be on increasing the flow efficiency than the traditional goal of maximising the utilisation of capacity.

The reasoning behind buffering the capacity utilisation in improving flow derives from the Kingsman's equation, depicted in Figure 8. The capacity utilisation is the capability of workers and machines to produce over time. Bicheno & Holweg (2016, pp. 38–42) explains the phenomena as when the capacity utilisation increases, the lead time will increase exponentially depending on the degree of variation. Variation is caused by unevenness in customer demand and the capacity to get work done. Figure 8 illustrates the effect variation has on the lead time when capacity utilisation increases. The effect can be seen to have a more significant impact on environments with high turbulence.

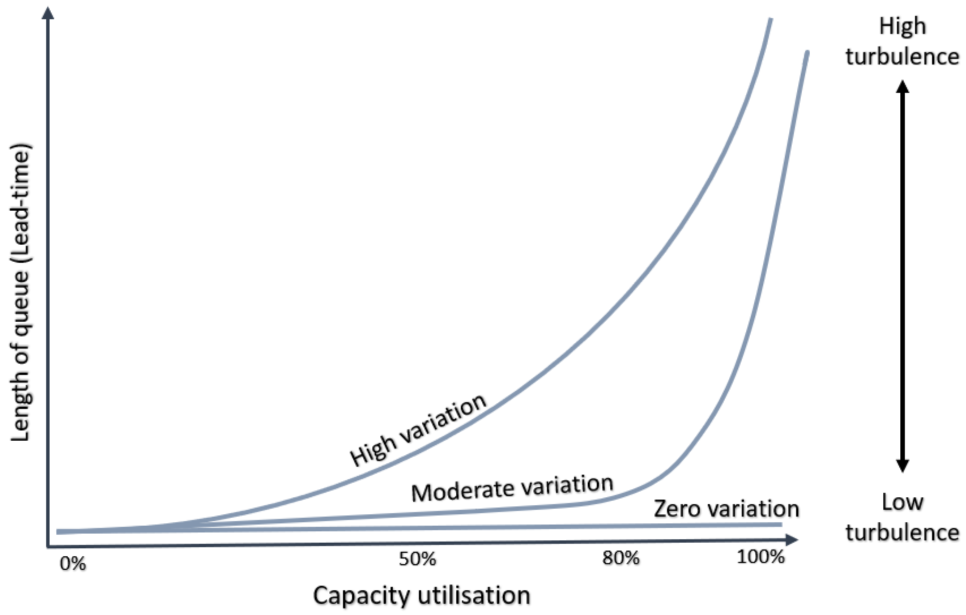


**Figure 8 Visualisation of the Kingsman equation, based on Bicheno & Holweg (2016)**

### Pull

A pull production means that the amount of work-in-progress (WIP) is limited within the production. That means that no new product can be manufactured before another product has been finished (Hopp & Spearman, 2004). Controlling the amount of WIP can lead to shorter lead times in the production, more visibility of problems and higher quality (Hopp & Spearman, 2004). The concept of pull is that work is released based on the status of the system. In push production, the work is released without considering the system (Bicheno & Holweg, 2016, pp. 15–16).

Powell & van der Stoel (2016, pp. 292–296) suggests three systems which can potentially be used in HVLV environments to create pull: Kanban, ConWIP and POLCA. Kanban will be explained more thoroughly in section 3.3.2. In respect to HVLV manufacturing, the traditional use of Kanban as a pull system is limiting, but it is suggested that some aspects of Kanban can still be taken into use. As an alternative system, there are Constant Work-In-Progress (ConWIP) and Paired-cell Overlapping Loops of Cards with Authorisation (POLCA), which are hybrid push-pull systems made for environments prone to variation. Nevertheless, these systems are more complicated and resource-demanding and can still be limiting in turbulent environments (Powell & Van der Stoel, 2016, pp. 296–299).

### Perfection

When organisations start improving the flow in their value stream, it becomes clear that it is always the potential to become even better. The concept of "continuous improvement" originates from the Japanese word "Kaizen". Liker & Convis (2011, p. 36) explain the concept of Kaizen as; *"At the root of kaizen is the idea that nothing is perfect and everything can be improved"*. The Kaizen mindset seeks to continually look for improvements in all levels of an organisation to achieve an everlasting effort to become better (Bicheno & Holweg, 2016, pp. 62–64).

Powell & van der Stoel (2016, p. 291) emphasise the importance of daily continuous improvement activities to create a continuous process flow. An essential term related to the concept of Kaizen is "Gemba". Gemba is a Japanese word described by Bicheno and Holweg (2016, p. 15) to be "*the place of action*". Concerning Kaizen, it can be interpreted as that the one operating the process, is the one with the best knowledge of how to improve it. There is also a concept of breakthrough improvement, which is events or activities including significant improvements in processes (Harrington, 1995). Large recurring problems are solved by the direct allocation of resources. The difference between continuous and breakthrough improvements are illustrated in Figure 9.

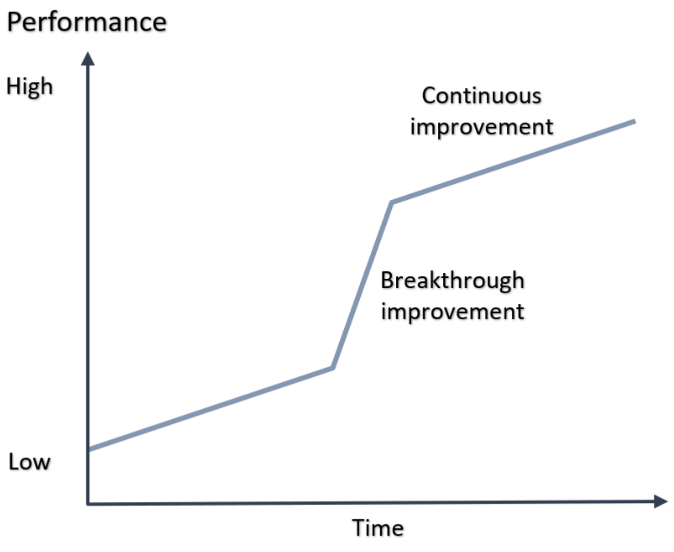


**Figure 9 Difference between continuous and breakthrough improvements, based on Harrington (1995)**

Continuously striving to learn as an organisation is deeply connected within continuous improvement. By having a learning culture, the organisation stands equipped to quickly adapt to new changing situations (Nonaka & Takeuchi, 1995; Wang & Ahmed, 2003). To optimise the organisational learning, there should be a focus on creating a strong team culture, where every member of the team need to work to learn and generate knowledge for the organisation to stay competitive (Wang & Ahmed, 2003). A strong team culture is a key factor for sharing tacit knowledge. Tacit knowledge is the knowledge that cannot be written down or shared verbally, it is the "know-how". To stimulate creativity in the team, it is essential with transparency in the organisation, that all the information is open and available for everyone in the organisation (Nonaka & Takeuchi, 1995).

Implementing new beliefs and practises can be challenging. Members of the organisation tend to keep beliefs and practises if they perceive some value in them, even though there might be other ways that are more value-creating and efficient than the current (Wang & Ahmed, 2003). Drucker (1993) emphasises that in order to implement new practises, the old beliefs and practises need to be abandoned first. Facing a perceived crisis or a change, people are found often to have more willingness to abandon their old beliefs and to come up with new creative solutions (Nonaka & Takeuchi, 1995).

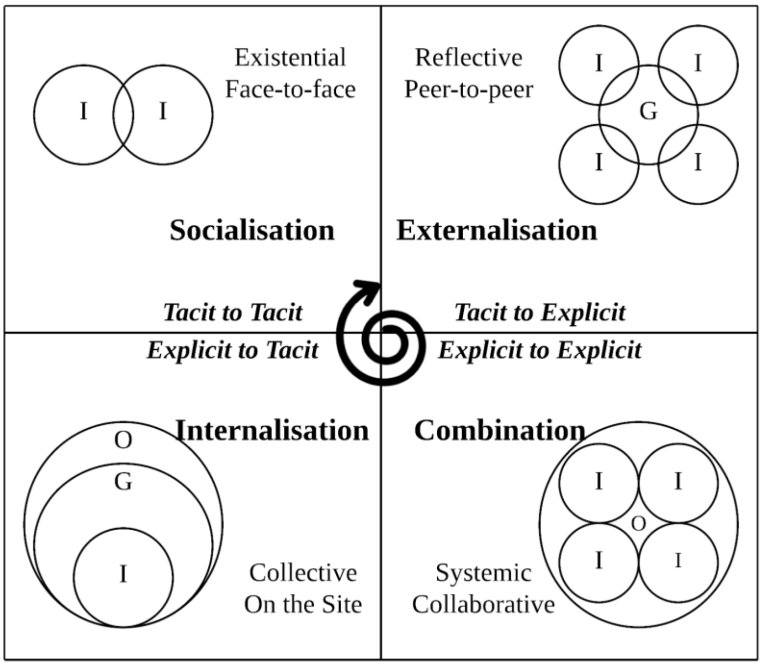


**Figure 10 The SECI model of Nonaka and Takeuchi (1995). It shows how the individuals (I), the Group (G) and the Organisation (O) shares knowledge during the learning process. Adapted from (Rice & Rice, 2005).**

The SECI model by Nonaka & Takeuchi (1995), given in Figure 10, has been widely recognised as a model for organisational learning, where each step must be present in the learning cycle (Rice & Rice, 2005). *Socialising*, to share tacit knowledge there must be made arenas and set of time for the members of the organisation to meet and exchange experiences (*externalisation)* (Nonaka & Takeuchi, 1995; Rice & Rice, 2005). *Combination*, the exchange of experiences, may lay the base for new ideas and concepts to form when experiences are combined. Ideas that align with the vision of the organisation may be brought further and presented to the rest of the organisation (*internalisation)*. The cycle would then repeat itself, developing and refining knowledge within the organisation (Nonaka & Takeuchi, 1995).

Understanding the principles of lean thinking can be essential when building a lean culture. First, when the organisation has learned to think lean, the right tools can be chosen or developed to live up to the principles (Lander & Liker, 2007; Skaar, 2019). A common view is that lean is a set of tools, but the case is that it is firstly a philosophy, and the tools and methods have emerged as a response to specific problems (Lander & Liker, 2007).

### 3.3.2 Lean tools and methods

Hines et al. (2004) emphasise that operational lean should be applied with caution. Tools and methods may be dependent on the situation, and it is crucial to understand lean both on a strategic and operational level to apply the right tools. Some suggest that lean can be applied in all types of manufacturing since some practices are universal (Birkie & Trucco, 2016), while others suggest some tools can be used if they are adjusted (Buetfering et al., 2016; Jina et al., 1997; Strandhagen et al., 2018). Powell & van der Stoel (2016, p. 296) emphasis the problem with HVLV manufacturers looking toward tools and methods popularised by the mass adoption of the Toyota Production System. Instead, they draw attention toward the need to establish HVLV-specific tools and methods, which can help substantiate the integration of lean principles.

Visual management is a crucial aspect to lean and is the concept of communicating the necessary information to perform a task or get an expected behaviour as quickly and efficiently as possible. The goal of visual management is to increase the transparency by making the information clear in order to eliminate waste in the form of time spent finding information and rework in the form of acting from the wrong information (Bicheno & Holweg, 2016, pp. 140–142). Since visual management tools are tools within the communication of information, they are less related to what type of manufacturing. They are more associated with the specific needs of one company. In the following section, there will be presented some of the most common tools within lean and visual management.

**5S**

5S is an organisational technique used in the workplace to create a workflow. Each of the five S's represents a step in the process: *(1) Sort*, *(2) Set in order*, *(3) Shine*, *(4) Standardise and*

*(5) Sustain*. Each of the steps should be performed in the given order. Bicheno & Holweg (2016, pp. 136–139) express the importance of introducing 5S in the right way. It is a mindset to create a more organised working environment and not a way to tidy up a messy workplace. Using the term 5S in a wrong way, may tie a negative correlation to the method, which can work against its purpose.

### Spaghetti diagram

A spaghetti diagram (or a string diagram) is a visual tool to improve the shop floor layout in the factory. The diagram is tracking the path of material flow, product and processes to find the optimal layout by visualisation (Bicheno & Holweg, 2016, pp. 166–167).

### SOP and One-point lessons

Standard operating procedures (SOP) is a detailed written standard describing the progress of a process (Bicheno & Holweg, 2016, p. 142). A more straightforward form of SOPs is one-point lessons. One-point lessons are simple visual documents for standardisation hanging on the place of a given activity. These are simple instructions based on knowledge from an experienced operator for the "method of right work" (Bicheno & Holweg, 2016). There are several ways to make a one-point lesson, but typically it contains a picture of the right and the wrong way of how something should be, and a short description.

### A3

A3 is a standardised method for problem-solving, based on simplifying information to a sheet of paper. The general A3 format consists of a current state on the left side and a future state and improvement plan on the right side (Bicheno & Holweg, 2016, p. 69).

### PDCA

Within the lean community, Deming's (1986) PDCA-cycle shown in Figure 11 has been popularised. PDCA is a commonly used method in continuous improvement of products and processes (Bicheno & Holweg, 2016, pp. 51–53). The first step in the cycle is the planning phase, where the group decides what they want to achieve and how to reach this future state. The second step is to do the planned changes. The third step is to check the results

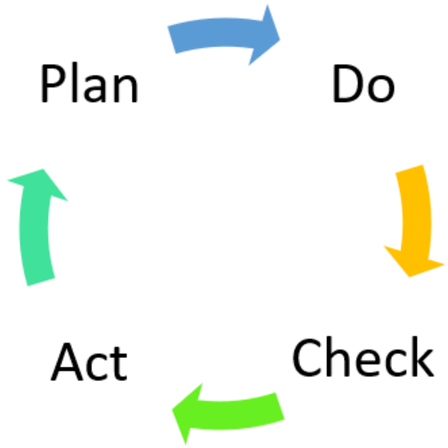


**Figure 11 The PDCA-cycle as developed by Deming (1986)**

of the changes, then into the fourth to act upon the results by learning and finding what to do next (Deming, 1986). Tyagi, Cai, Yang & Chambers (2015) suggest that the PDCA can support all the four different phases of the SECI-model.

**Kanban**

Kanban is a card-based method for creating a pull system in production while limiting the WIP (Bicheno & Holweg, 2016, p. 206). Traditionally, Kanban is applied in stable manufacturing environments with repetitive production but has also been taken into use in a wide variety of different sectors. Kanban has been seen as limited in non-traditional manufacturing, but Powell (2018) suggest that Kanban can be taken into use in more turbulent settings, such as HVLV manufacturing if the concept is reduced into its most basic form, a visual signboard.

The Kanban board is a visual representation of work, often separated into “backlog”, “to-do”, “doing” and “done”, but can also include other aspects if necessary (Powell, 2018). The board limits tasks in progress by putting a cap on how many tasks can be assigned to each stage and are managed by the workflow following the principle of “one-out-one-in”. As a task is finished, capacity is released, and a new task can start (Powell & van der Stoel, 2016, pp. 293–296). An example of a Kanban-board is given in Figure 12. Every day, all members meet by the Kanban board for “stand-up meetings” to discuss what was achieved the previous day, the plan for the day and problems that need to be addressed (Powell, 2018).

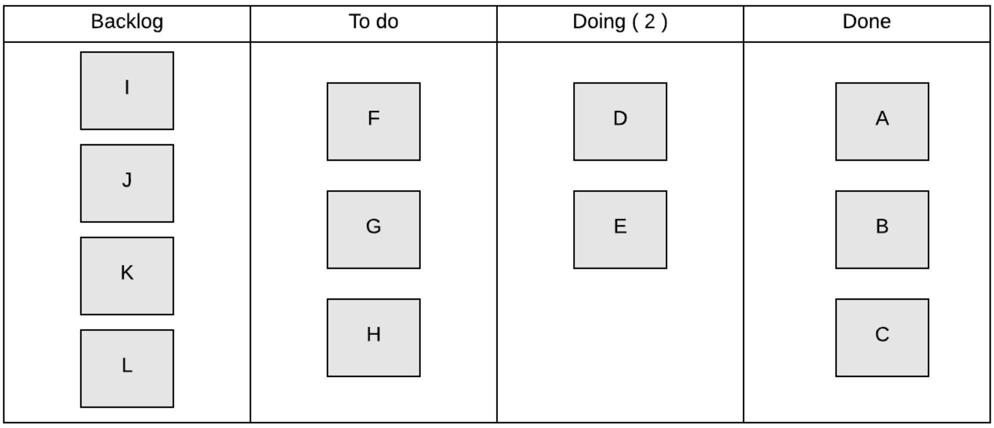


**Figure 12 Kanban board with a limitation of two tasks in “Doing”**

### 3.3.3 Summary of differences between HVLV and LVHV

To understand how lean can be applied in an HVLV environment, it is essential to know what differentiates it from the traditional LVHV setting. It can be argued that lean has emerged from Toyota, a highly standardised and repeatable production environment (Womack & Jones, 2003). Trying to fit an HVLV manufacturer, or even any other types of manufacturer, within the TPS framework, they might find themselves to have the impression of being "different". Toyota has spent decades perfecting their manufacturing system, and it has been integrated deep within their culture. To assume that what can be seen at the surface of TPS can be taken into Toyota is in most cases a recipe for failure (Lander & Liker, 2007). Instead of trying to copy what can be seen, it is more sensible to first seek guidance in their way of thinking. A summary of the differences found between HVLV and LVHV concerning the five principles of lean thinking is given in Table 2.

**Table 2 Summary of differences between HVLV and LVHV in lean thinking**

| | HVLV | LVHV |
|---|---|---|
| **Lean thinking** | The principles of lean thinking is applicable in HVLV, but there are some limitations | The idea of lean thinking is said to have emerged from the LVHV setting |
| Value | Defining customer value is more challenging, as the product is customised for individual customers and tends be more complex | The product is produced in high volumes, with low customisebality and comlexity |
| | Customisability is not seen as a waste but a feature | Standardisation to eliminate waste |
| Value stream | Changing and iterating value streams | Repeatable and linear value streams |
| | VSM not applicaple when high turbulence | VSM is applicable |
| | Takt time becomes more uncertain as turbulence increases | Fixed pace / takt time |
| Flow | Constant change limits the possibility for standarisation | Highly standarised value streams |
| | High variation complicates the relation between resource and flow efficiency | Low variation, little restriciton on resource and flow efficiency |
| | Flexible and multifunctinal work teams | Highly specialised workers |
| | Capacity buffers | Reduce all buffers |
| Pull | High turbulence creates uncertainty and variation | Predictable systems |
| | New or modified pull-systems | Commonly traditional kanban |
| Perfection | Universal | |

## 3.4 Implementing lean

The main reason for failing to implement lean is due to not being able to establish a lean culture and unsuccessful change management (Achanga et al., 2006; Bhasin, 2012; Jadhav et al., 2015; Pedersen & Huniche, 2011; Scherrer-Rathje et al., 2009; Todnem By, 2005). Change is an element that will always affect every organisation and should be managed to ensure its success. The literature on change management and empirical studies from implementing lean seem to be coherent regarding the implementation process of lean (Pedersen & Huniche, 2011).

### 3.4.1 Change management

To successfully implement a change, the people in the organisation need to be convinced that change is needed, or to understand why the current state is not working (Burnes, 2004; Weiner, 2009). People need to have a clear vision of the future state to realise the status quo in the organisation. When the vision is clear, then the organisational changes can be explored, planned and executed (Burnes, 2004; Deming, 1986; Kotter, 1995; Scholtes, 1999; Weiner, 2009).

Change readiness is defined by the need for change, or the ability to see the desired and the current state and what is needed to be changed (Armenakis, Harris & Mossholder, 1993). Elving (2005) claims that effective organisational change will be shown in low levels of resistance to change or high levels of readiness for change by employees. Resistance to change can also be a positive opportunity to see potential contributions and to eliminate counterproductive elements and impracticalities (Ford, Ford & D'Amelio, 2008). By creating a debate in the organisation about the new topic, the participants will start to think about possibilities and to play with ideas and provide feedback to improve the changes.

By debating and resolving conflicts, the commitment to the change can be improved (Ford et al., 2008). Nadler & Tushman (1989) argues that people receiving negative feedback on the current situation can become defensive to criticism. To avoid people getting into a defensive state, people should be empowered to see that they can overcome the challenges, and the changes are possible to do (Bandura, 1982). A counteroffer should not be seen as a resistance towards the change, but rather trying to accommodate the change even though it might sound like too many questions, complaining or challenges. A counteroffer is an opportunity to listen to the new suggestions and to improve upon them (Ford et al., 2008). People that are treated unfairly have a greater tendency to "resist" changes, and a change agent; the individual who initiates the change may experience higher success if they focus on building relationships and fix broken deals (Folger & Skarlicki, 1999; Ford et al., 2008).

Resistance to change can come from uncertainties and job insecurities regarding how the change will affect the organisation which can be caused by communication breakdowns from the change agents trying to legitimise the change (Ford et al., 2008; Holmemo et al., 2018). In some cases, it might be the change agent themselves resisting by not being open to new suggestions made by the change recipients (Folger & Skarlicki, 1999). There is also a tendency that the change agent tends to take credit for successes and blame failures on other factors such as resistance to change instead of facing the real problem (Ford et al., 2008).

Involving the organisational members in the change process may enable the members to suggest changes themselves and discover where change is needed, giving the members more ownership over the processes (Armenakis et al., 1993; Lines, 2004). An opinion leader is people with a strong social influence over the group. The opinion leaders need to be on board with the change in order for it to succeed. It is essential to identify and address the opinion leaders to have a more significant impact on the rest of the organisation (Armenakis et al., 1993).

Who and how the message of change is communicated does also affect the change readiness. A person of high status in the organisation communicating the message may underline the importance of the message. Also, third party members, such as a consultant can help reach through with the change message to the organisation (Armenakis et al., 1993). However, consultants cannot lead the change; it is the management themselves that must take the lead in the change process. Consultants can be useful in the initial stages to be part of discussions and to give contributions from their experience since they usually have a multi-company experience (Holmemo et al., 2018).

When change is communicated, the goal should be to inform members about the changes, and how the change affects their work. The more information the recipients have, the more likely they would be to accept the changes (Elving, 2005). The message of change can also be misrepresented. Decision-makers tend to be optimistic about their decisions and are also encouraged to talk positively about the change. However, they might be seen as unrealistic by the rest of the group by doing so (Folger & Skarlicki, 1999). The way the message is communicated affects the feelings of the recipients (Elving, 2005). As a change agent, leaders need to strive for creating a community of trust where the change can be discussed, and information can be shared (Elving, 2005). To create a high level of trust, it is also vital that the leaders live up to and commit to the new changes themselves, and not only push the change on the other team members of the organisation (Larson & Tompkins, 2005).

### 3.4.2 Barriers for implementing lean

The barriers companies face when implementing lean seem to be generic, despite all lean projects being adapted to different companies and cultures (Pedersen & Huniche, 2011). One of the main issues is the lack of support from the top management. The employees perceive the lean project as more important and tend to prioritise it more when the management shows the importance of the project (Achanga et al., 2006; Bhasin, 2012; Jadhav et al., 2015; Pedersen & Huniche, 2011; Scherrer-Rathje et al., 2009). The implementation process seems to be more successful when it is run from the top down. However, there needs to be an awareness of that the lean project is followed up in word and action at all levels (Pedersen & Huniche, 2011). People need to be assured that a lean project will not affect their job security. People that are involved in changing their own processes are more likely to stick to them in the long term (Bhasin, 2012; Scherrer-Rathje et al., 2009).

External resources such as consultants and sending employees to develop their lean skills can be valuable factors for the success of a project. A good consultant will strive to teach the organisation, and make themselves redundant over time as the organisation learn how to run the lean programme themselves (Bhasin, 2012; Scherrer-Rathje et al., 2009). However, these resources can be costly, and many companies have financial constraints that do not allow them to bear the costs of such investments (Achanga et al., 2006; Jadhav et al., 2015). Empirical studies seem to show a benefit of choosing a smaller section or a pilot area of an organisation to implement lean at the beginning of the implementation process, as it is easier to control a smaller project. Seeing quick results from the pilot can help to convince the rest of the organising of the value of a lean project (Bhasin, 2012; Scherrer-Rathje et al., 2009). Kotter (1995) suggests in his model of change to create small wins during the change process, in order to convince the rest of the organisation to join the changes. However, the main issue is to create a culture for lean thinking, where the employees feel an ownership of the processes in order to make the changes stick and to keep improving (Achanga et al., 2006; Bhasin, 2012; Jadhav et al., 2015; Scherrer-Rathje et al., 2009).

### 3.5 Summary of the theoretical framework

Lean is an ambiguous concept, which can be interpreted differently depending on the setting. In order to find out how lean can be applied in CSUB as an HVLV manufacturer, it has been reviewed an extensive amount of literature concerning the use of lean in several environments dealing with productions with high variety and low volumes presented as a summary in Table 3. Results from the literature are then complimented with the findings from CSUB in section 5.

**Table 3 Summary of literature**

| Topic | Literature | Source |
|---|---|---|
| **Lean in HVLV** | HVLV manufacturers do often find themselves to be "different", indicating a lack of understanding of lean philosophy. | (Lander & Liker, 2007) |
| | Turbulence from variation and uncertainty may confine some aspects of lean. | (Alfnes et al., 2016; Jina et al., 1997) |
| | The research on lean in HVLV manufacturing is found inadequate. | (Buetfering et al., 2016) |
| **Lean thinking** | Lean thinking aspires to create greater value for the customer while simultaneously eliminating waste. | (Womack & Jones, 2003) |
| | Lean thinking is said to originate from repetitive high-volume manufacturing, and some has critiqued the concept of not being suitable for manufacturing with high variation. | (Hines, 2012; Koskela, 2004; Powell et al., 2014) |
| Value | Value in lean is traditionally seen from the perspective of the ultimate customer. It has been expressed a need to expand the principle to include all major stakeholders. | (Powell & Van der Stoel, 2016; Womack & Jones, 2003) |
| | Variation from customisation should be seen as a strategic source of generating customer value in HVLV manufacturing. | (Powell & van der Stoel, 2016) |

| | | |
|---|---|---|
| Value stream | A value stream consists of all value-added and non-value-added activities. | (Womack & Jones, 2003) |
| | Value streams in HVLV are prone to variation and iterations between different processes. | (Powell & Van der Stoel, 2016) |
| | Application of VSM is limited by turbulence. Takt time is not easily applicable due to high variation in products and demand. | (Alfnes et al., 2016) |
| Flow | Turbulence from variation and uncertainty in the value stream, creating challenges for continuous flow. | (Alfnes et al., 2016; Jina et al., 1997) |
| | High variation creates compromises between resource and flows efficiency. | (Modig & Åhlström, 2017) |
| | According to the Kingman equation, lead time increases exponentially with increased capacity utilisation in turbulent environments. | (Bicheno & Holweg, 2016; Powell & van der Stoel, 2016) |
| Pull | Pull means that the amount of WIP is limited within the production. | (Hopp & Spearman, 2004) |
| | Visual Kanban boards can be taken into use in HVLV manufacturing as pull-systems. | (Powell & Van der Stoel, 2016) |
| Perfection | There are two types of improvements: continuous and breakthrough. Both are essential in the concept of Kaizen. | (Harrington, 1995; Powell & Van der Stoel, 2016) |
| | To optimise organisational learning, there should be made a strong team culture where knowledge can be shared between the members. | (Wang & Ahmed, 2003) |
| | To create new knowledge, it is vital that the information is redundantly flowing in the organisation. | (Nonaka & Takeuchi, 1995) |

| | | |
|---|---|---|
| **Tools and methods** | Tools and methods must be applied with caution. They should be chosen or developed to live up to the principles, and not as a quick fix for a problem. | (Lander & Liker, 2007; Skaar, 2019) |
| | There is a lack of HVLV-specific tools. | (Powell & Van der Stoel, 2016) |
| **Change management** | Resistance to the change can come from uncertainties by the employees regarding the change. Not all resistance towards change is negative, as it might bring out healthy discussion to adjust the changes. | (Ford et al., 2008) |
| | Involvement of employees in the change process can help optimise the change process by using ideas and feedback from the employees. | (Armenakis et al., 1993; Lines, 2004) |
| | Use of a third party, such as a consultant can help to communicate the message of change. | (Elving, 2005) |
| Barriers for change | Lean philosophy should be integrated into the organisational culture for the organisation to succeed in implementing lean. | (Achanga et al., 2006; Bhasin, 2012; Scherrer-Rathje et al., 2009) |
| | Lack of support from the top management makes it hard for employees to prioritise lean projects. | (Achanga et al., 2006; Bhasin, 2012; Jadhav et al., 2015; Scherrer-Rathje et al., 2009) |
| | Financial constraints make companies not invest in training of employees and consultants. | (Achanga et al., 2006; Jadhav et al., 2015) |
| | Lack of ownership from the employees makes it hard to sustain lean in the long term. | (Bhasin, 2012; Scherrer-Rathje et al., 2009) |

# 4 Methodology

In this section, the research approach and design will be presented featuring how the design of the literature review, case study, data collection and analysis were performed. Lastly, the limitations and weaknesses of the study are discussed.

## 4.1 Research design

This research thesis follows the methodology of Straussian grounded theory. By the nature of the research question, a qualitative approach is needed to explore the empirical world to add to existing theory within lean in HVLV manufacturing. By following the abductive nature of Straussian grounded theory, the researcher has to take the data seriously and to question the validity of previously developed knowledge (Thornberg & Dunne, 2019). Theories, codes, and themes can be revised or developed whenever it is deemed necessary in the study to respond to the findings, as shown in Figure 13 (Thornberg & Dunne, 2019). Since the theory should fit the data and not counter wise (Glaser & Strauss, 1967, p. 261).

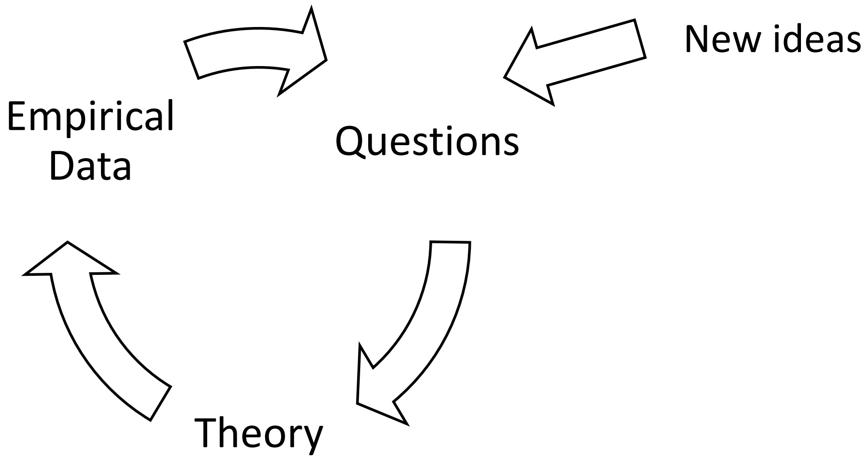


**Figure 13: The abductive methods allow new ideas that emerge in the research process to be explored and included**

The knowledge acquired from the case study affects the theoretical foundation of the thesis, and the theoretical foundation affects how the case study is performed, such as what questions are asked in the interviews. There were several iterations using circular reasoning whenever new knowledge was acquired, mainly because writing a master thesis is a learning process, see Figure 14. The data collection method and how to look for relevant theory was gradually optimised as the researchers gained experience (Kennedy, 2018; Reichertz, 2019; Thornberg & Dunne, 2019).

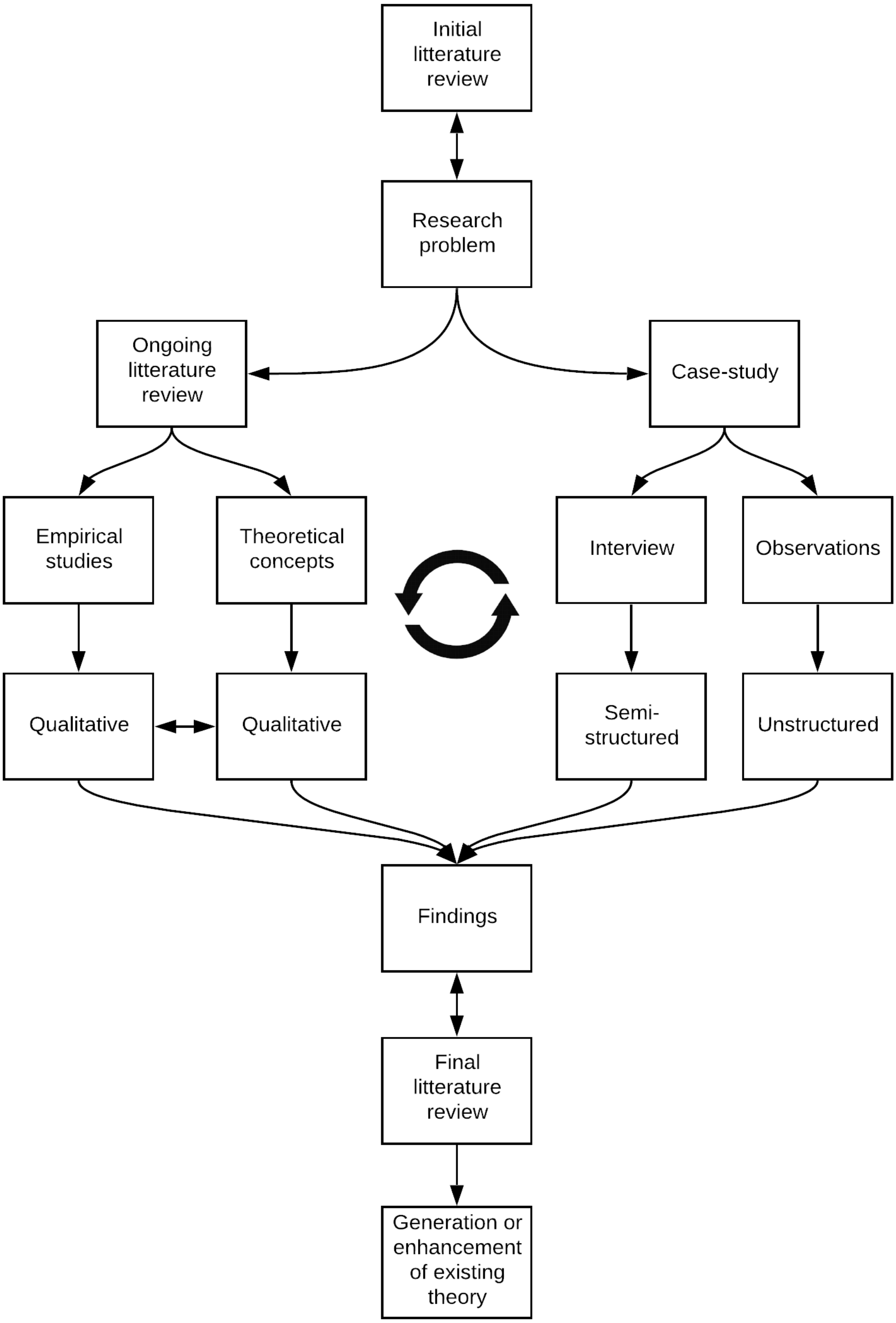


**Figure 14 The research design based on the Straussian Grounded Theory Method (Strauss & Corbin, 1990). Note that the theory and data collected will affect each other and will be iterated during the research project through the different stages of the literature review.**

## 4.2 Literature review

The literature review has been divided into three different phases as described by Reichertz (2019): An *initial literature review*, the *ongoing literature review* and the *final literature review*.

The *initial literature review* was made with the purpose to build up a particular sensitivity to how to collect data and what data to collect (Reichertz, 2019; Strauss & Corbin, 1990). By reviewing existing literature, the research question could be shaped and defined by considering the relevance to existing research and feasibility within the research period and resources available.

The *ongoing literature review* is conducted during the data collection, which allows exploring new directions that appear during the collection of data. The benefit of the ongoing literature study is that the findings will not be locked to the initial theoretical background, but let the data decide what additional theory is relevant (Reichertz, 2019). Also, it is challenging during an initial literature review to know what literature is relevant and to cover all relevant topics (Strauss & Corbin, 1990).

The *final literature review* was performed to establish a connection and compare with existing literature within different disciplines and theories to improve upon existing theories or generate new theories (Reichertz, 2019).

For doing the literature reviews, the 8-step method for doing a literature review by Gough (2007) was followed:

1. **Formulate review question**
2. **Define studies to be considered**
3. **Search for studies**
4. **Screen studies**
5. **Describe studies (systematic map of research)**
6. **Appraise study quality and relevance**
7. **Synthesise findings**
8. **Communicate and engage**

Following the 8-step method, the research question was set in order to define what studies to find. The following criteria for literature to be included is that it describes (1) HVLV manufacturing environments, (2) HVLV and lean, (3) lean thinking and principles, (4) implementing lean, (5) organisational learning, and (6) change management. These criteria were not all set initially, as some topics to be studied appeared during the data collection. As a searching strategy, Google scholar has been used as a search tool to find relevant articles together with the databases NTNU Open and AURA. Also, a "snowballing" method is used, where the work of relevant references and authors from the literature have been investigated. When looking for studies regarding HVLV manufacturing, other terms such as mass customisation, ETO, BTO, MTO, High Mix and Low volume, Unique manufacturing/production, Customised Production, Small batch production were included.

When screening the studies to use, peer-reviewed articles from journals and conference publishing were preferred in addition to books written by well-known scientists in their fields. It was essential to include both "state of the art" studies and the primary sources for existing theory. An overview of the most relevant literature and their findings were made in section 3.5. To ensure the quality of the studies, background and context of the articles and the authors were briefly checked. Some findings in the literature were discarded since the primary source for these studies could not be accessed. In particular, this study could not be found nor accessed, despite being a central source within the literature of lean and HVLV manufacturing: *Lean production implementation: a comparison between repetitive and non-repetitive companies* by Portioli-Staudacher, A. and Tantardini, M. (2008). After the quality was checked, the studies were synthesised in order to write the theoretical framework for this thesis.

## 4.3 Case study design

The use of lean in HVLV environments has been the subject of various research papers, but research on the application in these types of environments is shown to be sparse. Hence, Eisenhardt (1989) argues that the use of case studies is useful to develop new theory, while Benbasat (1987) view case studies as a method to capture the actual practice. Yin (2009, p. 18) defines case studies as;

> *"A case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident."*

When conducting a case study, Yin (2009) emphasises the importance of developing a research design to avoid situations where the data does not address the initial research question. Yin (2009, pp. 26–34) suggests five essential components for developing a research design:

1. **A study's questions:** This concerns the *form* of the question which regards the case study. For this case study, the question concerns *how* Lean can be applied in CSUB, as an HVLV manufacturer.
2. **Its propositions:** Lean is a well-established concept in serial production, while in HVLV environments have the implication of lean been explored to a lesser extent. The question in the case study relies on the proposition that concepts from lean can be implemented in HVLV environments, but the application seems to have some restrictions.
3. **Its units of analysis:** This component address what the definition of the *case* is. The research aims to recognise the synergy between lean thinking and the environment found in the HVLV manufacturing environment at CSUB. The unit of analysis, in this case, will be the organisation operating within an HVLV environment.
4. **The logic linking the data to the propositions:** In this case, the constant comparative method was used. The pattern found in the literature was used to compare the pattern found in the case. Identifying matching patterns between existing theory and the new findings, help with creating a more definite conclusion.
5. **The criteria for interpreting the findings:** Data was used to understand the synergy between lean and HVLV environments. The goal is to display how lean can be applied in CSUB.

### 4.3.1 Case selection

This research seeks to explore lean practices in the HVLV environment by exploring the setting in one case company. CSUB was chosen because they operate within the make-to-order and engineer-to-order setting, both falling within the HVLV term. The company had a department in proximity, which allowed for direct observations at the production site. They have three facilities, two located in Norway and one in Lithuania. More information about the case company is given in section 2. Due to distance, was the emphasis put on the departments in Eydehavn and Arendal, allowing for both observations in the production facility and interviews. The department at Bokn was only subjected to interviews concerning their earlier experience with the implementation of lean.

The case selection was confined by the scarcity of local HVLV manufacturers with the capacity to take on a master thesis. It was decided to limit the case study to CSUB, to get a greater understanding of their operations. Voss, Tsikriktsis & Frohlich (2002) argue that choosing to examine a single or a small number of cases allows for exploring the cases in greater depth but points out that the small number limits the generalisation of the findings, as the observer can misjudge single events. The term of HVLV contains several manufacturing structures, which complicates generalisation of observations. To generate a strong fundamental for generalisation, it could be beneficial to generalise based on findings from studies on several more HVLV manufacturers.

## 4.4 Data collection

To get an overview of the production, it was first given a tour of the facility. As an initial introduction to the company, observations were used to gain an understanding of how the different processes in the production are conducted. The data was gathered from both interviews and observations to ensure a holistic view of the operations taking place in the company. Interview objects ranged from all levels in the organisation, from project managers to shop floor worker. Observations were done in the working environment, both in the office space and the factory shop floor in Eydehavn and meetings conducted with the management. Also, it was granted access to the TQM system containing many documents regarding procedures and processes in CSUB. By combining, observations and data from the documents with interviews, a more realistic picture can be made of the company and the current state. Having different methods of data collection or triangulation, the researchers hope to find more accurate findings than relying on only one method of data collection (Thomas, 2017). Due to the outbreak of the SARS-CoV-2 pandemic, our presence at the office in Arendal and factory floor was limited to only the initial period of the thesis project.

**Table 4 Methods of data collection**

| Interviews | Observations |
|---|---|
| Longer unstructured interviews (recorded and transcribed) | Passive observations of the production |
| Informal interview at the factory shop floor | Document and information flow |
| | Logging of active observations in CSUB |

### 4.4.1 Interviews

Interviews were conducted with a selection of people from the production, sales, engineering and project management departments. The interviews were semi-structured, some prepared interview questions but with the opportunity to explore new topics as they occur in the interview. Due to the risk of SARS-CoV-2 contamination, several interviews were conducted by video calls rather than meeting face to face. To get multiple perspectives, the ideal situation would be to get interviews with a minimum of two persons per department. Because of limited time scope, the relatively small size of the company and the unnecessary risk of exposure to SARS-CoV-2, it was conducted eight interviews with approximately six to seven hours of interview material. Information about the date and length of the interviews is given in Table 5.

**Table 5 Overview of interviews**

| Informant | Date | Duration (min) |
|---|---|---|
| Economic | 28.01.2020 | Ca. 60 |
| Production | 24.02.2020 | Ca. 50 |
| Project management | 27.02.2020 | Ca. 70 |
| Lean experience | 03.03.2020 | Ca. 60 |
| Engineering | 13.03.2020 | Ca. 40 |
| Market | 13.03.2020 | Ca. 40 |
| Manager of production sites | 19.03.2020 | Ca. 50 |
| Lean experience | 21.04.2020 | Ca. 40 |

Each interview was conducted with an interview schedule made with each interview object and their position in mind. An interview schedule is a list of topics that can be covered during the interview (Thomas, 2017). Using an interview schedule allows for exploring thoughts and adding new topics as the interview progresses. It was necessary not to have a too rigid structure on the interviews, in order to explore new data as they appeared.

The selection of interview objects was decided to include one representative from each of the departments directly involved in the production process. As a reference for the lean experience in HighComp, two representatives were interviewed in order to increase the validity of the data. The research method is taking an abductive reasoning approach, which means that data gathered in the earlier interviews and learnings from the theory were brought up in later interviews to follow up on these new learnings. The interview schedule was adapted to target each of the interview objects. The reason for changing the interview schedule was to customise it to target the given discipline. The given frames guided the interview, but the interview object was also free to elaborate and to add new aspects to the conversation.

It was allocated one hour for each interview, were some interviews lasted longer and others shorter. Interviews conducted in a controlled environment were recorded and transcribed for further analysis. Interviews in the production facility were only noted down by one person while another person performed the interview in concern of privacy intrusions. The project was approved by the "Norwegian centre for research data" in advance of conducting the interviews. Several of the interviews were conducted by video call, some due to distance, while others because of the outbreak of SARS-CoV-2. Interviews done by video call tended to be shorter, which may be due to the loss of human interaction. Interviews done face to face seems to ease the communication, and let the observants speak more freely.

The interviews were conducted in Norwegian since all participants spoke Norwegian as a first language or could communicate it fluently. Quotations were translated from the transcriptions and later sent to the given participants for approval of translation and context.

### 4.4.2 Observation

To further improve understanding of the production process, it was initially spent several hours observing the production floor. Field observations were noted down and if necessary, asked for clarification from the production staff. Thomas (2017) refers to two types of observations; structured and unstructured. For this study, an unstructured approach to observations was used. The observers were actively immersed in the production setting, observing, and engaging in dialogues with workers. By being present in the given environment can help the observers to understand the processes better when experiencing it first-hand.

Unfortunately, the observation plan for march and April came to a halt due to the SARS-CoV-2 outbreak. It was supposed to be spent more time out in the production, observing and interviewing the staff. Therefore, the observations are based on what was observed in January and February. The data gathered from interviews is mostly based on the viewpoint of the management, which is a limitation when discussing the application of lean in the production environment. It would have been an advantage to get more first-hand viewpoints from those working in the production. It was also initially planned to visit the facility at Bokn, to observe their lean practices, but the visit could not be done due to restrictions on travel at the time of writing.

### 4.4.3 Anonymity

Due to the relatively small size of the company, it was chosen not to refer to interview objects by name or title. In terms of statements and direct quotes, the interview objects will be referred to as interview object 1-8. To ensure anonymity, it will not be used any information that can be directly connected to individuals or violate privacy. The number will be consistent with the given person and do not follow the same order as given in Table 5. Anonymising the information is not believed to have any effect on the validity of the information, nor affect the conclusion of the findings.

At the beginning of each interview, it was informed that all data collected would be anonymised when presented in the thesis. Informing about anonymity may help participants to talk more freely and share information and personal experiences.

## 4.5 Data analysis

In this study, it is chosen to use the constant comparative method from grounded theory approach created by Glaser and Strauss (1967) described by Thomas (2017). It is chosen to use grounded theory since the participants have different backgrounds and viewpoints, then the different viewpoints from the data sources can be compared within the same themes as they might show different things. The approach we followed is as described below:

1. Read all the data collected and sort them to get an overview.
2. Make sure all handwritten notes are digitalised, and all data is stored safely.
3. Read through the working files and make temporary constructs of the different themes.
4. Read through a second time together with the list of temporary constructs.
5. Eliminate temporary constructs that do not seem to help answer the research questions.
6. Come up with second-order constructs.
7. Look through the second-order constructs once more.
8. See how the themes connect together.
9. Use network analysis to structure the data.
10. Take out good quotes to illustrate the themes.

To help structure all the data and to perform the data analysis, the programme NVIVO has been used to make all the themes and to identify how they are related. The type of network analysis used is of Bliss and Martin and Ogborn (1983) but is based on the description of Thomas (2017, p. 245). The network analysis separated lean into three different main themes; *production, continuous improvement and learning,* and *change management,* which is then separated to sub-themes, as illustrated in Figure 15.

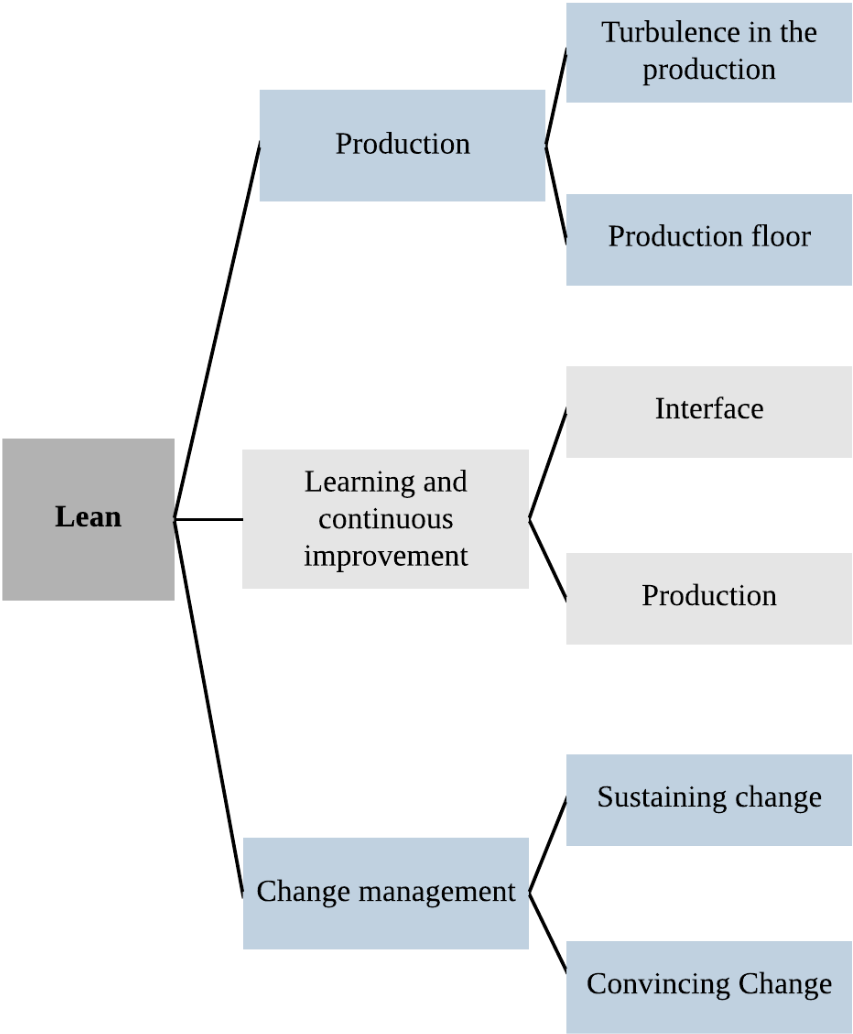


**Figure 15 Network analysis of the themes found analysing the data in NVIVO.**

The relevant quotes were translated into English and then highlighted in the discussion to illustrate the different theme. Some of the quotes have been modified to have a more "formal" language in order to emphasise the data and not the use of language.

## 4.6 Limitations and weaknesses

Due to time constraints in doing the master thesis, it was not possible to explore the subject to the same extent as other scientific studies. The research was also limited from the outbreak of SARS-CoV-2, which restricted our presence in the production facility. It was conducted in a total of eight interviews, where only one of the interview objects was working in the production. The validity of the research could have been strengthened by conducting several more interviews with people working directly in the studied environment. This was not possible, as visits to the facility came to a sudden and unforeseen halt at the beginning of March.

The study is based on a single case study and could have been strengthened by including other companies operating within HVLV. It could also have included interviews with more people with direct experience with lean and lean in HVLV manufacturing. Interviews were conducted with two employees which has some earlier lean experience from the department at Bokn. The production is similar to the one at CSUB Eydehavn but having additional viewpoints from other contexts could have strengthened the understanding of the subject and the findings.

Having a clear structure and method for the literature review makes it possible for other scientists to replicate the study or perform similar studies in other companies, in order to compare results. It might be argued that a qualitative study cannot be repeated with the same results (Thomas, 2017). Also, due to the abductive nature of this thesis, all the interview guides cannot be planned initially, they develop more and more after each interview as the authors gain more knowledge.

# 5 Findings and discussion

Lean is an extensive subject which is hard to confine. Modig & Åhlström (2017) express that there are as many definitions of lean, as there are authors to define it. Lean is a long-term philosophy, and before thinking of what tools and methods should be implemented the fundamental values and visions need to be set (Liker, 2004; Skaar, 2019). How should CSUB look like as a company? What behaviour or culture is desired to be present in CSUB? Lean is not an initiative meant only to increase shareholder value but should be beneficial to all parties involved (Modig & Åhlström, 2017). It is not about the hunt for the right results, but creating the right processes that will in time yield the right results (Bicheno & Holweg, 2016; Liker, 2004; Modig & Åhlström, 2017). These processes are unique to every company, where Toyota has TPS, CSUB needs to find its own CSUB-way of lean to strive towards their visions and goals.

During the analysis of the data from the case study, the main themes for applying lean in CSUB as a manufacturer were identified and analysed. The connection between the themes was identified and visualised by doing the network analysis shown in Figure 15 in section 4.5. These themes or constructs of the findings provides the structure for this chapter, which will be discussed in view of the theoretical framework in section 3.

## 5.1 What to implement in CSUB?

In order to find what can be applied at CSUB, the manufacturing facility at Eydehavn has been observed, and interviews have been conducted with the department in Arendal and HighComp at Bokn. The findings are presented in Table 6 and will be discussed in light of the theoretical framework given in section 3 with emphasis on the five principles of lean thinking.

Table 6 Findings in the production and learning processes

| Category | Theme | Findings |
|---|---|---|
| Production | Turbulence (Variation and uncertainty) | Customisability is an essential aspect of customer value at CSUB. Every product is one-of-a-kind, explicitly customised for the given customer. |
| | | The value stream at CSUB is variating depending on the given specifications for the product. However, most of the main processes are the same, but the activities within the process are changing between projects. |
| | Production floor | The floor area is viewed as a bottleneck in the production. Workflow is congested. |
| | | At HighComp it was claimed that flow was not always the best option. |
| | | There is a potential for visualisation in the production at CSUB Eydehavn. |
| Learning and continuous improvement | Production | The operators in the production are making some improvements as they face problems, but this is not a structured process. |
| | | There is a lot of tacit knowledge or 'know-how' in production. |
| | | Seasonal employment creates a challenge with sharing tacit knowledge with new employees. |
| | | Easy to get people to talk together, but hard to get a "constructive" discussion within the production. |
| | Interface | Global production forum where representatives from the production sites are meeting up to discuss issues and solutions, but it only occurs a few times a year. |
| | | Lessons learned have not been performed on many projects due to the high increase in production volume, even though the company routines mandate the procedure for all projects. |

### 5.1.1 Production

CSUB is operating in an environment prone to much variation and uncertainty. Every product is unique. The uniqueness of the products affects the flow of the production by creating turbulence. In order to suggest what to implement in the production, it is helpful with understanding of the production flow and its different factors. By taking the five principles of lean thinking into regard, has the production environment at CSUB Eydehavn been evaluated and discussed.

## Turbulence in the production

Turbulence is described by Jina et al. (1997) as the degree of variation and uncertainty found in the manufacturing environment. HVLV manufacturers are prone to high turbulence due to frequent changes in the schedule, product mix, volume, and design.

**Value**

The level of turbulence at CSUB Eydehavn is summarised in Table 7 and is found to be relatively high. The high turbulence is a result of responding to the market needs by offering fully customised products. Working with reducing some aspects of turbulence may be a sensible approach. However, Powell & van der Stoel (2016) express variation from customisation to be an essential strategic source of generating customer value. Hines & Holweg (2004) emphasis that what is seen as waste, depends on the understanding of the customer. Turbulence cannot always be seen as something negative; it has to be seen in light of what is generating value for the customer. Research has found that high turbulence can cause challenges in introducing some aspects of lean in HVLV environments (Alfnes et al., 2016; Browning & Heath, 2009; Jina et al., 1997).

**Table 7 Description of turbulence at CSUB Eydehavn**

| Factors | Turbulence | CSUB Eydehavn |
|---|---|---|
| Schedule | Medium | Since the production is based on bespoke products, it is difficult to know the exact scope of production. Schedule changes happen, and some products may be delayed. |
| Product mix | High | Producing to several markets but are mostly selling to offshore oil and gas and aquaculture. These markets are seasonal and demand different types of products. The one-of-a-kind nature of the production creates high product mix turbulence. |
| Volume | Medium to high | Volume varies between periods, with both relatively short and long projects. Changing volumes creates a need for seasonal employment. |
| Design | Medium | Design turbulences increase with the degree of customisation. Producing with GRP does not allow for substantial changes during production, so changes must be managed in the sales and engineering process. It is expressed a need for "clean-cut" between engineering and production. |

**Value stream**

Turbulence can especially create challenges in the second principle of lean thinking, specify the value stream. Value stream is described by Rother & Shook (1999) as all the value-added and non-value-added activities currently required for producing a specific product. In contrast to LVHV manufacturers, do Powell & van der Stoel (2016, p. 288) argue that HVLV manufacturers often are prone to higher product variations and iterative value streams. This causes difficulties in mapping the value stream for specific products in HVLV, as it is continuously changing. Constantly changing value streams is the case at CSUB Eydehavn, as their products are variating depending on the specifications of the given project.

The traditional way of mapping the value stream in LVHV manufacturing is by using value stream mapping (VSM). The concept of using VSM to identify the value stream in HVLV manufacturing has been argued to be problematic due to the level of turbulence in the production (Alfnes et al., 2016). It makes little sense to use VSM to map the value stream at CSUB Eydehavn when every product is different, there is not a clear takt time, and the demand is changing between periods. It would be little correlation between the data from different projects.

When HighComp faced the problems with streamlining a production with a large variety of products, they worked with finding activities which could be done differently or by removing waste within processes. HighComp chose to split their production into sections and work differently with each of the sections, finding what would be the best approach in the given situation. Instead of emphasising on the traditional VSM approach, measuring value-added and non-value-added time in the value stream, HighComp chose to focus on smaller sections with time and material measurements.

> *We thought that implementing lean in our production would be very difficult since none of our products is basically the same. Streamlining and optimising the processes seemed to be impossible, but even with large varieties in our products, it was possible to get things to work even better.* (Interview object 7).

## Production floor

It is on the production floor the physical realisation of the product occurs. As discussed in the previous section, the value streams at CSUB is constantly changing. Variating value streams is causing a dynamic production layout, with rapid changes. When observing the facility, it could be observed that ongoing projects occupied much of the floor space. From the interviews, five out of eight interview objects mentioned the floor capacity to be the bottleneck of the production. The facility at CSUB Eydehavn was observed during the spring season, which is the time of the highest demand and workload. It was also observed that units were taking up the place without any value-creating activities being performed. The limitations on floor capacity may be a symptom of poor flow in the production.

> *The capacity is essential, especially when all our sites are full. We need to consider the number of hours needed compared to our workforce when taking in new projects. As it is now, everything is full, so the work floor area is more limiting than the available*

*workforce. We have to consider this before taking in new projects, so now only projects taking little space can be initiated.* (Interview object 3)

### Flow

Flow is the third principle of lean thinking and is explained by Womack & Jones (2003, p. 21) as the product moving through the system with as little non-value creating time as possible. There are several aspects to creating flow, where concepts such as resource and flow efficiency and the Kingman equation are central. Both of the theories can be seen in the light of creating flow in the manufacturing facility at Eydehavn.

#### *Resource and flow efficiency*

The discussion of resource and flow efficiency is a central topic in creating flow. Modig & Åhlström (2017, pp. 100–106) express that LVHV manufacturers can achieve both high resource and flow efficiency, but as variation in the production increases, the relation becomes more ambiguous. HVLV manufacturers cannot have both high resource and flow efficiency at the same time, and a compromise must be made. Powell & van der Stoel (2016, p. 290) suggest that HVLV manufacturers should emphasise high flow efficiency ahead of resource efficiency.

Working with resource and flow efficiency is a continuous process of finding new ways to improve. Modig & Åhlstöm (2017) express that the ultimate goal is to achieve both high resource and flow efficiency, but in the case of HVLV manufacturers, the high turbulence cause difficulties in having both. As illustrated in Figure 16, must HVLV manufacturers make a compromise when improving efficiencies. In the case of CSUB Eydehavn, it can be argued that emphasising flow ahead of resource efficiency as they find their working space to be limiting. It is not necessarily emphasising 100% flow efficiency that is the most reasonable approach, but a finding a compromise between the resources and flow. Modig & Ålström (2017) do also suggest the possibility to reduce the variation in the production to confine the relationship between the two efficiencies. However, reducing product variation must be approached with caution and evaluated against the value proposition.

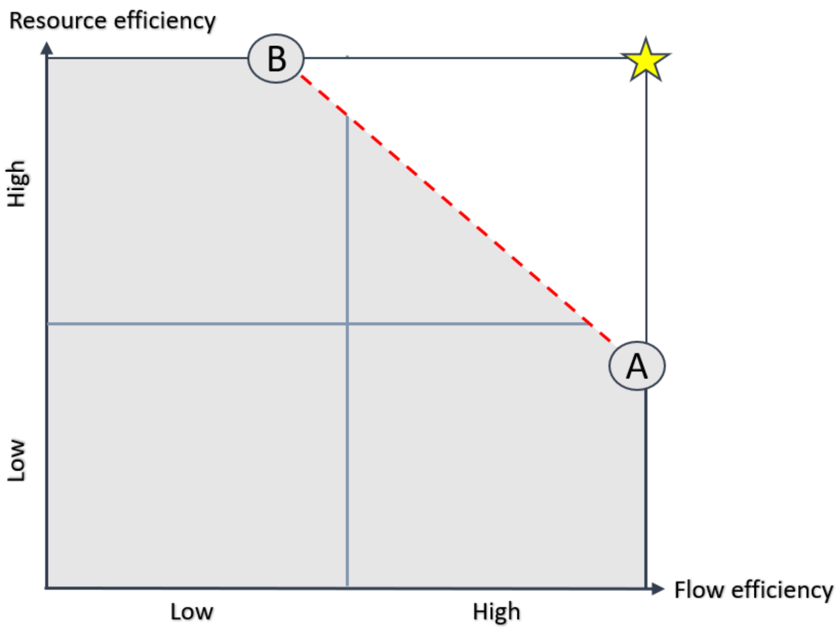


**Figure 16 The compromise between resource and flow efficiency in production with high variety. Emphasising high flow (A) cause a significant reduction in resource efficiency and the opposite for high resource efficiency (B). Based on (Modig & Åhlström, 2017)**

HighComp approached creating flow in their production by having more of commonly used equipment. Having more equipment in the production reduces the time needed for searching and allows for improved workflow through the reduction of non-value creating time. On the contrary, having more equipment will naturally cause a reduction in the total resource efficiency, as the equipment will be used less often. However, HighComp found flow to not always be the best option:

> *Flow was not always the best option for us. You cannot deliver the product before everything is finished. When one part is finished, it may lay for three months before the customer picks it up or we send it. We found it useful to do one operation on several products, before moving on to the next operation. It was not vital to get a part finished as fast as possible, but that the entire batch was finished on the date of delivery.* (Interview object 7)

HighComp emphasis that the product cannot be delivered to the customer before the delivery date. When producing in batches, it was found to be more reasonable not to move the product as fast as possible through the production, but rather finish several units in one operation, before moving on to the next one. It was claimed that by doing so, the effectiveness on the given activity would be better than if they mainly focused on flow. Reducing the total hours spent on the project was more important than reducing the lead time. However, CSUB Eydehavn operates with smaller batches or one-of-a-kind products and has less space than HighComp for storing products both outside and inside the facility. This may indicate that CSUB Eydehavn could benefit from making their production flow to free up workspace, but that would at the same time require better coordination with the customer to get the products out.

***Buffering***

Powell & van der Stoel (2016, pp. 289–290) argue that only buffering against capacity has any effect in HVLV environments. Buffering against inventory and time will not have any substantial effect due to high variation in products and already long and uncertain lead times. In the case of CSUB Eydehavn, it can be argued that buffering against uncertainty in inventory is necessary. CSUB operates with a high variety of bespoke products, but the material used in the production is mostly the same. Usually, it makes little sense to buffer the inventory in HVLV, when products are customised, and purchasing is tied to the order. For CSUB Eydehavn, the material is much the same regardless of the project.

Focusing on high capacity utilisation do according to the Kingman's equation cause longer lead times due to queueing of work. Powell & van der Stoel (2016, p. 290) suggest that HVLV manufacturers should move away from a capacity utilisation mindset and instead work with improving the flow. Keeping buffers on capacity utilisation can reduce the risk of overburden and allow for increased emphasis on creating flow. Reducing the capacity utilisation may also free floor space, which allows for more effortless movement within the facility. It was observed that material and equipment sometimes had to be transported further than necessary because of space limitations from WIP. Eliminating these wastes in transportations can help improve workflow.

**Pull**

It was observed from the production in Eydehavn that there are no pull-system. When a product moves from one section to another, it could be standing still for more extended periods, without any value-creating time. There is no one pulling the product to the next activity. It is instead pushed by a new part or product being started up. It is the people that flow on the product, while waiting time adds up. As the flow stops, the WIP builds up, and the floor capacity becomes limiting. A pull system can limit the amount of WIP in the production, freeing up space and allow for a better flow to shorten the lead time (Hopp & Spearman, 2004). However, due to the seasonality of the industry, there is not a need to reduce the total lead time on all products since some are temporarily stored before shipped to the customer. The real objective is to improve the organisation as a whole, and not to create pull just for the sake of pull, because every improvement has a cost and need to be evaluated in the greater perspective (Hopp & Spearman, 2004).

The principle of creating flow involves creating work progress where the product can flow through the system with as little non-value creating time as possible (Womack & Jones, 2003, pp. 19–21). When the product stops between activities, there is no value created. To support the principle of flow, it can be established pull-systems that visualise the workflow. Several methods for pull-systems has been suggested in the literature. Still, the simplest way to establish pull in a more complicated system is suggested by Powell (2018) to be a Kanban system reduced to its simplest form, a visual board. The Kanban limits the WIP and creates a meeting point for discussing the daily schedule and potential problems needed to be solved.

CSUB Eydehavn meets problems with the use of the Kanban system. Their production team consists of people with multinational backgrounds, which are not able to communicate well with each other. It is not a problem for the daily use of the board, as it is visual, but it limits the potential for the daily stand-up meetings. It is important not to overcomplicate the pull-system since CSUB is dependent on seasonal labour with varying backgrounds and education. The Kanban board should, therefore, be designed to accommodate the needs found in the production environment. Trial and error can be used to find the best activity schedule, and continuous improvement is engaged through daily discussions.

**Visualisation**

There are other perspectives in creating workflow. Mainly, tools and methods from visual management have been found useful in most environments. 5S is a commonly used method in the workplace, but it can be taken into use in most settings. The method aims to establish systems for organising the workplace, to create an environment that improves the flow through standardisation and visualisation. Bicheno & Holweg (2016, p. 136) express that the method often can be confused with cleaning, which may create a negative correlation with the concept of 5S. HighComp does already have some experience with the method and has expressed benefits from taking it into use. "*It is clear that proper use of 5S, standards, and continuous improvement has great potential in companies working with customised products, it will have* *an effect no matter what the situation."* (Interview object 2). From observing the production at CSUB Eydehavn, 5S could potentially be used to reduce waste in production and improve the workflow. By systematically working through each of the 5S's, can operators themselves systemise their working section to create flow. In working with 5S, it is essential to understand that it is not a one-time action, but continuous progress to further improve.

When establishing a workflow process with 5S, it could be useful to map some other forms of waste. By using spaghetti diagrams to see how the workers move around in the working environment, it can be detected how waste is accumulating in the form of unnecessary movement and transportation. The work environment should be systemised in such a manner that workflow is not disrupted from the need to search for equipment or barriers for transporting effectively. Further, it was expressed that HighComp had great benefits from standardising activities through one-point lessons. These lessons are made of the operators and should be a short and visual presentation of an activity. These lessons should reflect the best practice from the operator's perspective and be improved when necessary as a part of the continuous improvement process. Visualising the activity by creating one-point-lessons, helps to communicate knowledge and skills throughout the production, and to ensure that everyone has easy access to the latest standards.

CSUB Eydehavn could have great potential for improving flow through visualisation. At the current state, there is little information shown visually out in the production. An ideal workspace should be self-explanatory through visualisation. This is especially important in HVLV environments, as Jina et al. (1997) and Koskela (2000) express the importance of flexible teams and workers. Visualisation allows the latest information to be communicated quickly to ensure workflow. There is no universal system for optimal workflow or best practice; CSUB must develop their own system through finding new ways to continuously improve.

### 5.1.2 Perfection - Continuous improvement and organisational learning

Perfection is the last principle but may also be the most important one. The concept of "continuous improvement" originates from the Japanese word Kaizen, which Liker & Convis (2011, p. 36) describes as an idea that nothing is perfect, and everything can be improved. To seek for perfection may seem like an endless journey, but new knowledge and improvements can be found all along the way. A misconception commonly found, is that becoming lean is an end goal when the reality is more that there are no end goals, but rather several achievements in the pursuit of perfection.

The principle of perfection applies to all environments because the concept is to engage people to look for new ways to improve. HVLV manufacturers may struggle with the thought of improving a dynamic environment, as they are prone to high turbulence. It may make it even more important to understand the environment and how to work with the turbulence. The system as a whole may seem chaotic, but as the production is separated into sections, the situation may seem more manageable. *"As we started to separate the processes and activities, we could see that it was actually a lot that could be done."* (Interview object 7).

**Continuous improvement in the production**

The operators in the production are making some improvements as they face problems, but the improvement process is not a structured process that gets logged. The disadvantage when the work with continuous improvement is not formalised is that it makes it difficult for the rest of the organisation to follow the process and learn from it (Nonaka & Takeuchi, 1995). Furthermore, there might be employees that are not empowered or see it as their task to take responsibility for the improvement processes. Another reason might be that people do not see the need for improving the processes if they think the current way of doing things is somehow working well (Elving, 2005; Wang & Ahmed, 2003).

> *It would be nice to get inputs from the operators on how to improve solutions and how we work continuously. We do discuss different things from the different production sites, but if we can get the improvement loop to be shorter and more efficient and be done by the people that do the job. Because that is my problem today, that there are many, that does not like or want to write.* (Interview object 5)

A lot of the knowledge in the company is tacit knowledge, built up by years of experience. "*There is a lot of tacit knowledge, the production knows what to do, and not all are drawn up. They just know it from old learnings."* (Interview object 1). There are few other companies within this type of products, which means that new employees often have very little previous knowledge of the product. The challenge is when this tacit knowledge should be transferred to the new employees. Not all "how-to" can be written down and standardised. Four out of eight interviewees emphasised that there is a challenge with sharing tacit knowledge, both to new employees and between the production sites. In the production, there are large fluctuations in the amount of workforce, with a lot of temporary employees in the high season. *"It can be challenging with new people because there are several tips and tricks on how to do it."* (Interview object 6). This creates a challenge with running a lean programme, where CSUB needs to be dependent on the regular employees to carry the weight of running it.

In order to mitigate the effects of having new employees, it should be focused on creating a strong team culture, where knowledge can be shared with the new members (Wang & Ahmed, 2003). There should also be a focus to create information transparency in the production (Nonaka & Takeuchi, 1995). This can, for example, be done by using tools and methods of visual management in the production (Bicheno & Holweg, 2016).

Manufacturing at CSUB is a labour-intensive process which requires people involvement in making change. Engaging the people in creating a culture for continuous improvement is essential to work toward perfection. Powell & van der Stoel (2016, p. 291) suggest gathering for daily improvement activities. One manager expressed that it is easy to gather people for meetings, but it is challenging to engage people. *"Daily meetings are easy to achieve, but it is extremely difficult to engage people in creative, constructive and honest discussions about deviations"* (Interview object 2). It is essential to make sure that everyone is heard and show that new ideas are taken seriously (Armenakis et al., 1993; Wang & Ahmed, 2003). The threshold for suggesting and testing out new ideas should be low (Bicheno & Holweg, 2016, pp. 64–68).

**Continuous improvement in the interface between the production and CSUB**

By having both the engineering, market and production within one company, CSUB Eydehavn has a unique position regarding learning. When training new engineers and other people in the administration, they try to send them to the production site for the first week, to get to know the product from the first-hand experience and to assure that there is a shared understanding of how the product works.

People engagements need to occur all along the value stream. Bicheno & Holweg (2016) refers to Gemba as "the place of action", which is an essential concept in TPS. The engagement between engineering and production is an important aspect. In CSUB Eydehavn, the gap is bridged by having an engineer present at the manufacturing several days a week. However, the engagement from other departments could be beneficial in increasing the overall knowledge in the company.

*It is an advantage for the company to have engineers present on the production site to respond to changes quickly, even though they tend to get caught up by the production and made unavailable for the engineering department.* (Interview object 1)

During the last year, CSUB has created a Global production forum. At this forum, representatives from all the production sites meet at one production site to get to know each other and share experiences and to learn from each other and to solve common problems. The initiative has had a positive effect, creating a base for sharing knowledge more easily between the production sites, both within the forum and outside. *"There are small ideas and opportunities for improvements that are impossible to see without visiting the other sites."* (Interview object 5). The ideas are afterwards being followed up with the relevant parts of the organisation. However, the global production forum is only a few times a year. Meetups, such as these, are important for the organisational members to socialise and to create an arena to share knowledge (Nonaka & Takeuchi, 1995; Rice & Rice, 2005). Here new ideas can be formed and afterwards shared with the rest of the organisation (Nonaka & Takeuchi, 1995).

CSUB has a lesson learned procedure, where all parties are involved in collecting the learnings at the end of the project. Here even the customer may be invited to participate. The process ensures that there is a continuous improvement by always learning from every project. However, there are some problems with the procedure at its current state. Lessons learned have not been performed on many projects due to the high increase in production volume, even though the company routines mandate the procedure for all projects. Sales are often not directly included in the process and normally receives a report after each lesson learned session.

*We are getting too little feedback to the sales from the lesson learned sessions. To know how the projects are doing, what goes well and what goes wrong. It is extremely important for me to get feedback from the projects when I will calculate for new similar projects…*

*…I would actually prefer to get feedback during the project as well. My worst nightmare is dealing with a customer when the project is going poorly, the customer is dissatisfied,*

> *but me as a salesman is unaware of the entire situation thinking it is all going fine and well.* (Interview object 7)

Looking at Nonaka & Takeuchi's (1995) SECI model, the lessons learned session is following the cycle having the socialising and externalising part with the different parties coming together to discuss and create new concepts, then to create the report to be shared within the organisation. However, if the learnings are not successfully shared with the rest of the organisation, and if the rest of the organisation do not learn from what is shared, the learning cycle is not completed. To ensure the learnings from each project, the lessons learned procedure needs to be followed up to a more considerable degree, or there needs to be a different procedure that can be pursued.

The last step of Deming's (1986) PDCA-cycle – Act, implies that when a change is done, they need to be acted upon or learnings need to be collected. This can be creating a single point lesson which is easy to share with other members of the organisation, especially with new employees. Tools such as the A3 has integrated the PDCA-cycle and are easier and quicker to use to manage small changes since they focus on drawing and simple, clear phrases to address the problem. After a change, it can be useful to do a root cause analysis of why things happened the way they did  (Bicheno & Holweg, 2016). The use of PDCA can also apply all the phases of the SECI model (Tyagi et al., 2015). The change prosses can be initiated through events where resources are allocated in solving a specific problem, leading to breakthrough improvements (Harrington, 1995). However, none of this will work in the long term without a mentality change. People need to see the usefulness and value of it in order to commit to the changes (Bicheno & Holweg, 2016; Burnes, 2004).

## 5.2 How to implement lean in CSUB?

A lean transformation demands both resources and time, and the pursuit would only bring value if it is successful. The daughter company of CSUB, HighComp, have formerly been trying to implement lean into their production. Due to the similarity of both the culture and production, it has been chosen to look at some of the challenges that HighComp has faced when implementing lean, as the same issues may apply to the rest of CSUB as well. The results showed that there were three problematic areas for implementing lean: To convince the organisation to change, cultural challenges, and to sustain the changes. These areas are presented below in Table 8.

**Table 8 Findings within change management**

| Theme | Findings |
|---|---|
| Convincing change | HighComp found it challenging to convince and to make people understand the changes. |
| | HighComp faced insecurities initially among the employees regarding that the changes would lead to a reduction of jobs and needed to be convinced that lean was in their best interest. |
| | (HighComp) Finding the opinion leaders within the organisation and working on convincing them to participate in the lean process, helped to influence the rest of the organisation. |
| | External consultants helped spread knowledge in the organisation and could more easily communicate the change message to the employees. |
| | HighComp found it useful to separate the production into sections when implementing lean and to work back and forth with those sections which had the greatest promise for improvement. |
| Sustaining change | Work with continuous improvement is not always prioritised in the organisation even though it is perceived as value-adding. |
| | Especially within the production, it is hard to prioritise working with continuous improvement rather than working in the production. (HighComp) |
| | Employees in the production felt more ownership to the processes that they had contributed to themselves (HighComp) |
| | It was more difficult to sustain the lean programme when the consultants were gone. (HighComp) |

CSUB also has the advantage that there is some knowledge about lean in the organisation. Six out of eight interview objects were familiar with the concept of lean from some basic knowledge to more profound knowledge and experience. The already existing knowledge about lean may ease a potential transition in to lean in regard to learning as an organisation would be easier.

### 5.2.1 Convincing the organisation to change

When previously implementing lean in HighComp, one of the significant challenges was in the initiation of the lean programme to convince people to commit to the changes. It was hard to convince the management to spend time in reading groups to study lean and lean thinking, and it was difficult to get operators out of the production to learn about lean and to work with continuous improvement. These challenges also reflect the challenges of trying to achieve continuous improvement in CSUB today, with struggles to get people to prioritise doing the lesson learned procedure and to get operators to participate in the change processes of the organisation. There are many reasons for these challenges which will be discussed in this section together with some tactics to face them.

> *People choose to do what they perceive as important and fun. Organising tools and new and challenging procedures are easy to ignore when other things are more urgent. Although we know, it will save time in the long run.* (Interview object 5)

One of the explanations for this tendency for not prioritising continuous improvement is that it might not be seen as value-adding for the organisation (Burnes, 2004; Weiner, 2009). Even though working to improve processes can be seen as useful in the long run, it might be hard to prioritise it when other important matters are pushed on as urgent, not allowing time to work on continuous improvement processes. To face the issue, there needs to be established a view of urgency concerning these matters and to set time to mark them as important and to be prioritised (Kotter, 1995). There needs to be made a mentality in the organisation that if making improvements are left out, it would lead to high future costs in the long term.

In the production, it was hard for the management to make the employees understand that the employees themselves needed to be active in this process and to take ownership of the change initiatives. One of the reasons for the change resistance was that there were insecurities and uncertainty among the employees regarding how the changes would affect their work.

> *It was all about coming to the point where the employees understood that doing lean was for their own good and in their best interest, and not because that the management wanted to make things more efficient with fewer employees needed.* (Interview object 7)

To reduce the uncertainty and insecurity, Ford et al. (2008) and Holmemo et al. (2018) suggests communicating the changes clearly to make the participants understand what effects it will have on them in order to reassure their worries and doubts. Hosting discussions with the change recipients can be a golden opportunity to both reassure and to get useful feedback to adjust the changes (Elving, 2005). Involving the operators in the change processes can also make them feel more ownership of the process and help sustaining it in the long term (Armenakis et al., 1993; Lines, 2004).

A tactic that is supported both in the literature and by the experiences by HighComp is to identify the opinion leaders in the group; the ones who were having a strong social influence, and working on convincing these to participate in the change process of becoming lean (Armenakis et al., 1993; Elving, 2005). The opinion leaders together with the leaders would then create a "snowballing effect" throughout the rest of the group, setting an example for the rest of the organisation to follow (Larson & Tompkins, 2005).

> *When suggesting lean, companies do often claim that they are 'different'. Then I find it useful to find a somewhat similar company that has changed and to take the 'opinion leaders' to meet the 'opinion leaders' at the other company. When they meet, I usually ask the question; who of you was the most sceptical to lean in the beginning?* (Interview object 2)

**Using consultants**

CSUB is currently considering whether to hire a consultant to help initiate and support the process of implementing lean or if they should do the lean initiatives themselves. HighComp used a consultant and experienced the consultant to be a neutral third party. The consultant's message was having more credibility than the management among the employees. The cost of hiring a consultant gave the management a feeling of pressure to succeed with the implementation due to the high investment cost of the project.

> To *begin with, many people see lean as abstract and difficult to understand. The external consultant was a great help. He had an industry background, and he spent much time on the factory floor with the operators and the foremen to do this gradually, step by step.* (Interview object 7)

The literature does support the claim that in the initial stage, a consultant can help to deliver the change message and operate with more credibility (Holmemo et al., 2018). However, it is essential that it is not the consultants that take the role of change agents since it can create a dependency on the consultant. With a dependency on the consultant, it is hard to sustain the change when the consultants are gone (Armenakis et al., 1993). It is the management that needs to be the change agents and communicators of the change. If a consultant is used, he or she should only be used as a teacher or a "mentor"-role to avoid creating any dependency of the consultants. However, if there is a lack of knowledge about lean, it might be hard to initiate the process without any external support. None of the interviewees outside of HighComp had much experience with lean, which can make it hard to initiate the process when still learning the basics themselves. Another possibility as well is to hire an internal lean coordinator, that would have the same role as the consultant on a more permanent basis to assure the sustainability of the programme. No matter what alternative CSUB choose, it is important that the management are showing their full support of this process if they are going to do it.

> *The consultants came typically twice a month and worked with all levels in the organisation. With the management, they had reading groups, where they discussed literature and solutions to relevant problems. Further, we worked with employees at an*

> *operational level, with understanding 5S, creating new one-point lessons and making improvement groups. These groups worked together once or twice a month to create continuous improvement progress. It was highly rewarding and exciting. We could see significant improvements on all levels.* (Interview object 2)

Another question to be considered is to what extent should the lean programme be implemented. In Kotter's (1995) model of change, he recommends creating small wins to convince the rest of the organisation. Empirical studies on implementing lean supports this approach, cases of successful implementations have often implemented lean in smaller sections or in pilot projects, to begin with in order to convince the organisation of the value of lean (Achanga et al., 2006; Bhasin, 2012; Jadhav et al., 2015; Scherrer-Rathje et al., 2009). However, the positive lean experience from HighComp may be enough to convince the rest of the organisation. In addition, not implementing lean at all sites can be a loss of opportunity to optimise the production at a higher rate.

> *We took an overview photo of the production and separated it into sections. Then we worked with one and one section and left the others until we were happy with the result, and then we moved on to the next section. We decided on which sections we found to be most interesting, and which sections had less potential for improvements from reviewing it internally. We moved back and forth between the sections we had the most confidence in having the greatest potential for improvement.* (Interview object 7)

### 5.2.2 Making lean stick

After running the lean programme for a few years in HighComp, it became difficult to sustain it in the long term, and several of the lean processes had disappeared. The first reason was that it was more challenging when the consultants were gone. At this stage, it was entirely up to the organisation and the management to sustain the change, which leads to the second cause of the demise of the lean processes. When HighComp joined CSUB, the management focus was on making the transition on becoming one company with shared processes rather than focusing on internal lean processes. To sustain the changes, it is crucial that the management is supporting this and pushing to keep it (Achanga et al., 2006; Bhasin, 2012; Jadhav et al., 2015;

Pedersen & Huniche, 2011; Scherrer-Rathje et al., 2009). After doing the initial lean initiatives, the management needs to keep pushing for continuous improvement a part of the everyday behaviour (Bicheno & Holweg, 2016; Modig & Åhlström, 2017).

Culture is the behaviour in the company from day to day, which means that in order to create a lean culture, lean needs to come into everyday behaviour. Culture is something that develops gradually, day by day. A lean culture cannot come overnight (Bicheno & Holweg, 2016, p. 91).

# 6 Conclusion

Highly competitive environments have led to an increased interest in lean in HVLV manufacturers. However, the research on this area seems to be sparse. In answering the research question "*How can lean be applied in CSUB, as an HVLV manufacturer?*", has the literature on lean thinking, lean in HVLV environments, learning and change management been reviewed, and a case study of CSUB was conducted to obtain insight in their culture and manufacturing environment.

High product variation and uncertainty creates difficulties in the application of some aspects of lean in HVLV environments. This thesis has found that the principles of lean thinking to be applicable in HVLV environments, but the principles must be interpreted and adapted. HVLV manufacturers cannot look toward the traditional LVHV setting when adopting lean. They need to identify their own vision. Lean transformation is based on creating processes aligning the company with its values and philosophy. What is traditionally seen as waste, can for HVLV manufacturers be a strategic resource for generating customer value. Instead of confining variation by limiting customisation, they need to create a culture eager to find new ways to improve. By focusing on improving flow through standardisation, visualisation and limiting work in progress, can productivity be increased. Tools and methods of lean can be used to increase flow but should be seen in the light of the principles and help to sustain the long-term vision of building a lean culture.

Working with continuous improvement is essential to any organisation. However, it comes especially into play in HVLV manufacturing, where the variation of the products demands more problem solving within each project. It should be strived to maintain and create structured learning processes in the organisation in order to share knowledge. The goal, in the long run, should be to create a culture for continuous improvement and learning, where all members of the organisation are involved and empowered to contribute towards perfection.

In order to do a lean transformation, the organisation must be convinced to participate and contribute to the lean initiatives. Convincing the organisation requires that each member is educated and informed about how their role and the organisation will be affected, and the ability to influence the processes affecting them. External sources such as consultants can be useful resources in learning and creating a platform for constructive discussion. At the initial stage of the transformation, it is beneficial to do projects that can offer quick wins or positive results in order to inspire and motivate for further transformation. To sustain the transformation, in the long term, the management must be supporting the initiatives and keep pushing towards a culture of continuous improvements. Lean culture is not self-sustained and need continuously work to keep progressing.

If CSUB chooses to implement lean, they need to find a way to transform into a lean culture. It is essential for CSUB to engage people in the transformation, and to ensure that those undergoing the change feel an ownership of the new system. Since there is limited knowledge of lean on the different sites, they may need external support or someone internal with a strong understanding of lean and the ability to convince the change. It could be useful to use consultants since they already have experience with lean transformations in other companies. It is essential for CSUB to emphasis on engaging people in continuous improvement processes and creating structured systems for learning. They should increase the transparency in the production through visualisation by engaging in 5S and one-point lessons. Focusing on improving flow efficiency at some expense of resource efficiency could possibly help improve workflow and manage the strain on floor capacity. CSUB is operating in a dynamic environment prone to much variation. Finding the right processes and balance between resources and flow may seem ambiguous, but the way to become lean is a step by step process, with trials and errors along the way.

The lean journey is unique for every organisation by virtue of having its own values, culture, and processes. It is not about finding the right way in itself but creating the processes that keep looking for the right ways in the ever-changing world.

# 7 Further research

This research has investigated the what and the how of applying lean in HVLV manufacturing, limiting the research to centre around the physical part of the inbound supply chain. To get a more holistic view of the supply chain, it is necessary to investigate the implications of both the outbound supply chain and the non-physical part of the inbound supply chain.

The emphasis of this research has been on exploring HVLV manufacturing in light of the five principles of lean thinking. There are many other principles and approaches to lean, which has not been explored. A prominent approach to lean in other environments with high variety and low volumes is lean construction. To further explore the implication of lean in HVLV manufacturing, could the framework and principles of lean construction be considered.

The research is only based on one case study, limiting the generalisation of the findings. To achieve a broader basis for generalisation of the application of lean in HVLV manufacturing, it is needed more research on the subject and other studies verifying the findings.

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