Inventory Management: A case study at Volvo Construction Equipment

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ABSTRACT

• Introduction

In today’s world, manufacturing companies are keen to adopt lean methodologies to sustain an everchanging market. One way companies grow their business is by increasing customer satisfaction, customization and running the business in the optimal scenario. Inventories form a significant amount in applicable businesses, estimating around 30%, a number that has the potential to be decreased that would turn direct profits. The following two research questions were therefore answered.

Q1. What are the potential factors which affect the inventory size in the lean production facility?
Q2. What should be the inventory management approach in a lean manufacturing environment?

• Methodology

The literature review was performed to get an understanding of the current study on this topic. Further a site was visited, and the case study approach was adopted. While gathering data, semi-structured interviews were conducted with engineering, line management and operations. Observation technique was also used to collect empirical data.

• Theoretical framework

Theoretical study based on literature review helps authors to understand the complete system deeply from a lean perspective as manufacturing takes place in the lean environment. The theoretical framework helps in finding the right approach to the problem and showcases the potentially problematic areas to be focused on.

• Empirical data

Empirical data shows the actual image of the problem in the case company. It also shows the possible factors that are responsible for the present condition. These factors are represented with the help of the fishbone diagram.

• Analysis and results

Quantitative analysis was done based on data collected. Two approaches were proposed in which approach 2 answers the problem for sufficient buffer size. Cross-check analysis was also performed on the actual production plan from week 10 and 11 this cross-check analysis strengthens the reliability of the research work.
• **Conclusions and recommendations**

The conclusion is drawn based on the analysis performed with the foundation of data collected. Although significant challenges are answered with the help of research questions, human involvement and absence of monitoring policy limit the reliability of the proposed results. The future recommendation is to perform the proposed solution on simulation and check the validity of different scenarios.

*(Keywords: buffer management, lean inventory, inventory management, the theory of constraints, continuous improvement)*
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TO MY PARENTS WHO ALWAYS MOTIVATE ME
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1. INTRODUCTION

This chapter provides the general background of the main issues on which this master’s thesis is performed. The main research question, as well as the project’s goals and limitations, are explained further in this section.

1.1. Background

Lean manufacturing is one of the practices that many manufacturing firms are adopting to remain competitive in the global market (Abdulmalek & Rajgopal, 2007). The main focus of the lean approach is to eliminate non-value-added activities. This helps in saving time, lowering associated cost and in achieving a higher level of customer satisfaction (Liu, et al., 2007). The concept of lean originated from Toyota Production System. The concept had many tools and techniques, for instance, Just in time (JIT), total productive maintenance (TPM), single minute exchange of dies (SMED), and more. Today, these tools and techniques are widely used in the manufacturing environment.

The philosophy of lean production considers inventory as a form of waste that must be reduced. In recent years as companies adopted lean manufacturing system, management of inventory in this system became lean inventory management (Eroglu & Hofer, 2011). According to Kuhlang, et al., (2011) and Glock, (2012), inventory is associated with lead time, as it involves transport operations which result in higher idle time. Having long idle time results in loss of associated capital and in short, loss of business. The reason why many manufacturing companies adopt the lean manufacturing system is because it improves their business through for instance high productivity, reduced lead time, improved quality, reduction in space, reduce inventory and more (Ghosh, 2013).

In lean manufacturing, there are seven types of identical wastes mentioned, i.e. overproduction, unnecessary motion, inventory, transportation, rework, waiting, and over the process. Although each waste has its business impact, inventory is one of the least discussed wastes, a reality that needs to be addressed as it has maximum capital and resources associated with it (Upadhye, et al., 2010; Ghosh, 2013). According to Kuhlang, et al., (2011) more inventories cause higher lead time because of transport, operating times and idle time. Associated non-value costs are hence added and counted as potential causes for bottom line losses. While inventories are directly associated with performance, lean inventories increase the organization’s performance and also improve operational outcomes (Eroglu & Hofer, 2011). There are mainly two views present in previous studies on literature related to inventory, i.e. romantic JIT and pragmatic JIT. Romantic JIT suggests that there should not be any inventory which is in ideal condition. Whereas pragmatic JIT suggests that there should be an optimal level of inventory present in the factory and this optimal level is dependent upon its associated cost, operational processes and production plan (Eroglu & Hofer, 2011; Chen, et al., 2005; Chen, et al., 2007).
For many years manufacturing companies, whether having small scale or large-scale operations, have been searching ways to be a leader in their respective segment. Organizations are improving their business and competitiveness by understanding their inventory levels and implementing processes to reduce these levels. By reducing inventory, companies experience benefits to the bottom line, and less inventory means fewer resources associated with it. The resources saved by lowering inventory up to its optimal level can be used in different improvements initiatives (Brooks & Wilson, 1995). The American Production and Inventory Control Society (APICS) defines inventory management as the part of business management associated with planning and controlling of materials in the form of inventory (Toomey, 2000). Management of inventory is an essential part of supply chain management (SCM). Over the last three decades, much research has been done on SCM, and its integration with inventory management called `multi-echelon inventory theory´ (Quayle & Quayle, 2000). A survey of inventory management cost in Europe identified the cost of inventory management in the manufacturing setting which is equal to 28% of the total production cost (European Logistics Association (ELA) & A.T. Kearney Management Consultants, 2004).

Many large companies are engaged with inventory management to save cost and improve efficiency (Chapman, et al., 2000). Different businesses, small scale to larger ones, have varied resources at their disposal. Smaller ones have a different approach to management of goods on their shelves while the larger ones approach their inventory differently. Because of this difference in resources, and the subsequent varied approach to inventory management, the traditional view that smaller scale organizations look up to the larger ones is debatable (Welsh & White, 1981). Inventory management is very crucial as it plays a vital role in providing products (raw, semi-finished, etc.) at all levels required. Inventory is associated with many costs which generally includes purchasing cost, processing cost and other costs. Therefore, companies should practice achieving the optimal level of inventories from the business perspective (Vollmann, et al., 1992).

Balancing the flow of material according to demand is a critical factor to success. Inventory buffer should be designed in a way that it can sustain demand even if demand is flexible. Whereas holding much more inventory might cause loss in cost and resources. Hence, having sufficient inventory is the ultimate goal (Coyle, et al., 2003)

1.2. Problem formulation

In today’s global environment, companies follow the trend of lean manufacturing to sustain in the ever-changing market. This trend majorly involves management of resources and often is known as lean management; one of the majors of this management is on reducing inventory (Aqlan & Lam, 2015). Inventory management is that area in production planning and manufacturing research which applies wise mathematical models. These techniques aim
to find a solution to the problem, by using a variety of elegant mathematical techniques such as complete enumeration (Zinovy, 1998), branch and bound (Lu, et al., 1989) and theory of constraints (Hurley, 1996). Having more than required inventory is always a challenge which affects the business development in the companies, whereas having lower inventory increases the risk of having material shortage or production stop (Aqlan, et al., 2015). So, it is suggested to have an optimal size of inventory according to the company production requirement (Pakdil & Leonard, 2014).

Manufacturing companies are facing problems in managing their inventories and buffer sizes. Companies are doing their best to optimize this buffer size and achieve their lean goals which further help the companies to strengthen their business in the competitive market (Prasad, et al., 2016; Panwar, et al., 2018; Kroes & Manikas, 2018).

1.3. Aim and Research questions

This thesis project aimed to investigate and identify the potential factors which affect the inventory size in the lean manufacturing environment and how the optimal inventory size can be achieved. This research study was conducted at Volvo CE cab manufacturing factory in Hallsberg, Sweden. The chief assigned study area in the factory was the inventory buffer (Buffer out) between the paint department and assembly department.

Two research questions were formulated to achieve the aim of the study.

**Q1. What are the potential factors which affect the inventory size in the lean production facility?**

**Q2. What should be the inventory management approach in a lean manufacturing environment?**

1.4. Project Scope and limitations

The research project was focused on the automobile sector, where the active stakeholders from the company side are process engineers, line operators and lower-level managers. Limitation of the resources limits the study from a different perspective. The research study was focused on internal inventory management of Volvo CE, Hallsberg factory. The interaction with other departments in the factory is excluded and limited to only paint and assembly.
The suggested approach for inventory management is based on the data analysis performed on the data collected only from the case company, i.e. Volvo CE at Hallsberg, Sweden. That means the typical proposed buffer size might not satisfy the other case but can be calculated by the approach used. Moreover, the reliability of data used can be questioned as the data monitoring policy includes involvement from humans. However, these must not lead one to question the authenticity of the data. Further, there are certain limitations in the factory. These are that the factory works on the pull system, which means that the flow of material from the paint department is based on demand from the assembly department. In addition, there are certain human centered breaks during the day in the assembly shop when work comes to a standstill. One break is for lunch while the other is for coffee. The paint shop has no such breaks. For the purpose of this study, both these breaks in the assembly shop have been merged and assumed to be one break. There is no documented data for these breaks.
2. RESEARCH METHOD

In this chapter, a description of the research method used for this research study has been presented.

2.1. Research process

Management-related research usually showcases new findings. Along with that these studies also address management issues, business-related issues and practical problems (Saunders, et al., 2003). The process for research generally includes topic formulation, theoretical framework, data collection, empirical findings, analysis and conclusion. This process is not just one-time. Researchers break down the process into stages from time to time to meet the right ideas (Jenkins, 1985). This research study follows the vision of investigating the optimal inventory size and how it can be achieved with a scientific approach at lean manufacturing companies. According to existing literature, the research process consists of a loop with multiple stages that addresses the entire research project, and these stages relatively strengthen the overall research study in terms of reliability (Jenkins, 1985).

![Diagram of the research process](Yin, 2014; Jenkins, 1985)

Figure 1 Illustration of the research process (Yin, 2014; Jenkins, 1985)
This loop having multiple stages is further explained in diagrammatic form; these stages are followed thoroughly to the research. The reason for using this structured loop is that it helps the author to maintain a high level of authenticity of the data from different levels in the factory. Moreover, this feedback cycle strengthens the case study approach, especially when the majority of data collection is done from the monitoring processes where human involvement is high.

Illustrated project plan in Figure 1 considers five different stages which were acted as the foundation of this research project. A feedback loop was active throughout the project so that any new information during the project can be handled carefully and into the right slot in the project. This parallel feedback loop is essential for this project because the overall project plan is divided among different stages. With the high possibility of getting new information or data on different stages, this loop helps in connecting that information from different stages. These stages can be further described below.

2.2. Case study

A case study is defined as the systematic approach to perform research which includes empirical data analysis investigation of a particular system with actual existence in context with academic theories (Saunders, et al., 2003). The case study includes gathering data via different approaches from different sources by doing workshops, interviews, constant observations and adding stakeholders to the process of data collection this helps in building reliable conclusions and bridge the gap between literature and empirical studies. The case study research must be performed on multiple pieces of evidence (Gillham, 2000). This case study is further explained as a single case study as it involves only one case company. Employing this approach enables the author to deeply understand the context and help in staying focused on specific management issues (Yin, 2009).

This case study approach is an excellent blend of three different approaches within the case study, i.e. an exploratory, explanatory and descriptive study. These can be defined as follow.

Exploratory:

This approach is used when much of the current situation is unknown from academia perspective, or there is the unavailability of the solution to similar problems in the past (Saunders, et al., 2003). These kinds of studies are conducted by using extensive literature study, constant communication with experts, conducting interviews (Sekaran, 2003). The author has used partial use of this approach during the interview’s sessions, the reason behind the usage of this approach in the study presented is that it provides the freedom to the author to control the flow of information during the interviews (Prince & Felder, 2006).
Descriptive:

This approach is used to explain the set of variables in certain situations (Sekaran, 2003). Therefore, this approach is used to provide a platform to the researcher’s perspective in an industry-oriented research. This approach is used in this research mainly to strengthen the author’s hypothesis in the analysis and the reason behind it is the versatility of the descriptive approach. This approach helps the author to frame the reliability of the proposed results based on facts interpreted and generated (Barrows & Tamblyn, 1980).

Explanatory:

A study which connects the different theories with a single string of idea can be named as explanatory study (Saunders, et al., 2003). Furthermore, the explanatory study is divided between casual study and correlation study. The casual study is one where the problem occurs due to one variable, whereas correlation study is one where the problem occurs due to chain reaction in variables (Sekaran, 2003). The correlation study approach is used in one part of the empirical study, where the cause and effect study is explained. The objective of using this approach is to increase the understanding of the research study as it does not provide final, conclusive results but instead give a clear overview about the problem and its potential causes (Barrows & Tamblyn, 1980).

2.3. Literature study

The primary goal of the literature study is to demonstrate the theoretical framework of this thesis project and get an overview of the current studies on the research topic from the authors perspective (Yin, 2009). Different databases were used to dig into the literature study and present the concrete theoretical foundation for the thesis. The main databases used are Scopus, Science Direct and Google Scholar. Moreover, the keywords used to search the literature on these databases were inventory management, buffer storage management, continues improvement and lean inventory management. During the search for literature on the mention databases, some filters were used such as the language must be in English, content should be relevant to the manufacturing engineering field and priority should be to the case study research, which helps in understanding the issue very deeply. Another objective of this stage is helping to build an interactive bridge between the researchers and the business companies. However, this phase includes the in-depth study of literature from different sources, but it is a continuous process that goes on throughout the project whenever any information is added. Also, the visiting the company helped in understanding the problem from the on-ground perspective. The reason for this initial visit at the case company was that it helped the author to balance the problem from two different perspectives, i.e. academic or literature perspective and company perspective (Jenkins, 1985). The total number of visits to the case company was 12 for the total duration of the project.
2.4. Data collection

Collection of facts or information from different resources in form of number, alphabets image graphs, and more is called data collection. Valuable data must be reliable, authentic, simple to understand and accurate (Yin, 2009). Data collected in this research project is from different resources and is majorly collected by visiting case company through interviews, brainstorming sessions with mentors and stakeholders, meetings, observations and weekly reports.

The approach of interviews was used in a semi-structured way. The reason to use semi-structured interviews was to help the interviewer to continue the interview by asking questions based on answers given by participating persons (Jenkins, 1985). The questions asked during the interview were mainly framed in such a way that the interviewer got an opportunity to understand the viewpoint of the interviewee. Majority of people who participated in the interviews were line managers, process engineers and operators as these people are mainly involved in the process, so it is assumed that their viewpoint is crucial to understand. For the collection of data inside the factory, the MSA (measurement system analysis) approach is used. The reason behind using this approach is to ensure data validity (Dahlgaard & Dahlgaard-Park, 2006; Kumar, et al., 2006) as this approach includes operational processes associated with processing of different departments. Initial brainstorming sessions were conducted with operators and line engineers, which provided an overview of the process along with the deep insight of the possible potential causes. Data was collected with the help of project managers, which was then verified and based on the results of brainstorming sessions. Data study process chart was produced with top to bottom flow, which showed movement of product from start point to endpoint through different departments.

Other than that, the observational data collection process was also used in this study. This data collection process consisted of guided tours with engineers of the manufacturing facility. Attending the morning round table meetings for production planning helped in understanding the working culture of the company. All the data collected in this way comes under the process of observational data collection (Yin, 2014). Data collected from the above process is of great use in this report. Sources for the data were authentic and reliable, which helps in concluding a highly reliable result. Data from the literature helps in getting a deep understanding of the problem from the research perspective instead of a business perspective. Previously conducted researches for the same problem gives an insight into the real problem.

2.5. Data analysis

The data analysis process was started with organizing the data collected from internal stakeholders in the form of interviews, observational meetings and visits. The data was
arranged according to the date of the collection. After organizing the data, analysis was performed to see the standard information in all the interviews. These similarities were found based on some keywords. The reason behind finding the conventional strings among all the interviews helped in understanding the collective viewpoint of the internal stakeholder (Yin, 2014). Here the feedback loop acted as a reliable source. While analyzing the data some interpretations were made by the author which were discussed with stakeholder via a feedback loop. Data was used as part of this study only after receiving confirmation from the authorized representative of the company. After doing this analysis, some concrete facts were drawn which was further balanced with literature study with a focus on the research questions so that main essence of research must not be diluted (Miles, et al., 2014). On getting confirmation of this evidence with stakeholders through a feedback loop, a hypothesis was created. In further analysis, a conclusion was drawn (Saunders, et al., 2003).

2.6. Quantitative and qualitative methods

Quantitative research, also known as numeric modelling, is used to model numeric data so that it is easy to understand the process. This modelling results in equations, graphs, tables, and charts. One limitation of this approach is that all variables used in this approach must be known (Jenkins, 1985). This approach includes numerical data, where researchers develop a different numeric system or facts-based concepts to measure and transform the systems (Grix, 2004). Qualitative research, on the other hand is explained as use of theories to investigate the trade-offs of the studied system. These approaches are more interpretative in nature. The strengthening factor of qualitative approach is that it is supported by specific phenomenon and expert statements and it stressed more on words than numbers (Yin, 2009).

Researchers argue that case study is a mixture of both qualitative and quantitative approach. During data analysis with case study numbers, explanations are supported by facts (Sekaran, 2003). Based on research questions, this case study research uses both qualitative and quantitative approach. The use of both approaches strengthens the research work and increases the adaptability of the proposed solutions. Moreover, the use of only one kind of approach gives limiting number of results and might end up having a vague solution (Onwuegbuzie & Leech, 2005; Sieber, 1973).

2.7. Validity and Reliability

The author built the foundation of this research by stating the approach used in the project and backing it up with extensive literature study. It is essential from the academic and
company prospective that the validity and reliability of the report must not be compromised. It ensures the quality of work done (Saunders, et al., 2003). For strong validity of this research study, the project author used the literature from multiple resources which are used as references for the project report. Moreover, the data collected from the company was discussed with the company representatives, which claims its validity by itself.

To maintain a high level of credibility the literature used is from credited articles and books in the mentioned field. When it comes to data collection and analysis, predefined approaches were used supported by literature. Company data is used as primary data and a feedback loop was used throughout the study. Feedback loop helped in refining the data in its best form. After the mutual agreement from the author and company stakeholders, data was used in the report and interpreted. This way of using a feedback loop helped in increasing the validity and reliability of the study (Yin, 2009; Saunders, et al., 2003). Data collected from the company was majorly through semi-structured interviews. These interviews were the primary source for this study to collect empirical data to maintain a high level of validity. Interviewees in this case were those who were in direct connection to the problematic area, for instance, line engineers, operators and junior managers. Questions asked during the interviews were quite direct to the problem to receive direct and clear information within a given time (Saunders, et al., 2003).
3. THEORETIC FRAMEWORK

In this section, the theoretical framework of the thesis is presented. First, lean methodologies and their characteristics along with definitions are stated. Second, the uncertainty and challenges faced by manufacturing companies while developing their production system are mentioned.

3.1. Definition of Lean Manufacturing

The concept of "Lean Manufacturing" (LM) originated from Japan after the second world war, when a manufacturer in Japan realized that they could not afford huge investments to rebuild damaged facilities. The same challenge was faced by Toyota who started producing automobiles with less inventory, less workforce, less capital and fewer errors while at the same time provided a variety of range in their products. This approach of manufacturing from Toyota gave birth to Lean Manufacturing (Jorgensen & Emmitt, 2008; Bhamu & Sangwan, 2014).

Explanation of lean manufacturing can be given as a philosophy of using a set of practices, i.e. Kanban, quality management, root cause analysis and more. These sets of practices are used to reduce waste in the company, i.e. rework, overproduction, excess inventories and more. The sole purpose of this philosophy is to improve the performance of the company (Womack, et al., 1990).

James Womack and Daniel Jones initially introduce lean manufacturing in their book Lean Thinking, and they define lean as a five-step process, i.e. (Womack & Jones, 2003).

- Define the values for customer

The first step defines values in terms of the total product, which defines the flow of product, which further aligns with the customer's needs.

- Definition for values stream

This step defines each step in detail so that the company can figure out which steps add value to the customer and which do not. This further benefits the end customer.

- Smooth flow of information and material

In the third stage the importance of flow of material and information in the production line is defined. It also defines how the one-piece flow system reduces lead time and increases production in batch flow production to single-piece flow.
• **Pull flow for the production.**

This step explains benefits from ordering, which means produce when there is an order from the customer. Furthermore, suggesting that companies introduce a pull system in their production system.

• **Aim for excellence**

The last section conveys how there is always scope for reducing time, reducing waste and ways to improve.

### 3.2. Lean inventory

For companies that work on lean manufacturing system, it is important to investigate where and how lean practices are most required to create a proper lean culture. This lean manufacturing system or lean culture has a deep-rooted connection with business performance (Panwar, et al., 2018). Being a manufacturing company, there are several opportunities where companies are forced to face high competition on local as well as global scale. To sustain in this competitive environment companies need to cope up with significant challenges. One such challenge is to have optimized inventory which is directly associated with business performance (Aqlan, et al., 2015; Jaiganesh & Sudhahar, 2013; Sacks, et al., 2010). Similarly Dogra, et al., (2011) found in his research that inventory in companies affects business performance and limits the company’s competitiveness in the market. This is mainly due to high investment of time and money tied up for a long time.

Moreover, Ghosh, (2012) presents a proven analysis in his research, where he mentions that having optimal inventories in the factories balances the supply chain and improves the operational and business performance of the company. Along with these improvements, it also lowers risk of overproduction, long lead times and delays. Although a lot of industries adopt lean manufacturing system because of its competitive advantages, a high competitive environment forces companies to deliver high-quality products at affordable prices with on-time deliveries. All these aspects are achievable by adopting a lean system (Alvarez, et al., 2017). As mentioned by Cheraffi, et al., (2016) the success of a company depends on its potential to eliminate waste and non-value-added processes, considering inventory as the potential waste.

There are many ways to have optimal or lean inventory according to the company needs as explain by Rohani & Zahracee, (2015). Kanban is a tool in the lean system which helps in managing inventory with optimal level by eliminating physical inventory. This elimination can be done by replacing physical inventory and setting up a signal card system to indicate when more inventory is needed. This helps in saving space associated with physical inventory and also reduce the risk of overproduction. Moreover, having more than required inventory
causes long waiting times between processes to lower these times. Alvarez, et al., (2017) suggested continuous flow method that was first explained in the Toyota production system. Such a system helps in having an optimal size of inventory by producing products using a batch size of one. This type of flow is advantageous when it comes to eliminating waste and having optimal inventory since the flow is of one-unit batch size.

Although inventory management is a broad topic, many different approaches have been presented in literature. These have helped in this management and assisted companies to reach their optimal inventory levels. As explained by Wei, et al., (2013) and Nallusamy, et al., (2017) inventory management is a never-ending process which allows change according to need of company’s manufacturing system is which further based on demand associated with everchanging market. Also, the management of inventory is the process of planning and control to reduce investment in inventory and to balance supply and demand. In general, inventories are divided into four categories, i.e. raw material, work in progress, finished goods, and operating inventory (Liu & Papageorgiou, 2013). If companies can manage their inventory system by achieving the optimal level, it reduces the overall operating cost.

The value of having lean inventory is explained by Kumar & Nallusamy, (2017). In their research they mention inventory management system as stock in the business. Proper management of stock maximizes benefits of a business. Furthermore, optimal inventory significantly improves the supply chain operations inside and outside the companies. Therefore, it is always the topic of discussion to have lean inventory in companies.

### 3.3. Toyota Production System

Lean production is the philosophy to manage at an optimal level, which was introduced by Toyota in Japan. It was also famously known as the Toyota production system. Toyota is a multinational Japanese automaker, one of the top ten largest companies in the world in terms of revenue and terms of production; it was the largest global manufacturer of automobile. The Toyota production system (TPS) is prevalent among modern manufacturing systems. This system is special because it involved workers in Toyota learning and applying lean in their production system, by actually practicing, implementing and improving on the production floor. As learning and improvising became never-ending, Taiichi Ohno and Fujio Cho developed the symbolized form of Toyota production system known as Toyota production house (Liker & Ross, 2016; Liker, 2004).
Figure 2 The Toyota production system (Liker, 2004)

The TPS house diagram is the most recognizable system in the world of manufacturing. The structure of the TPS house consists of roof, pillars and foundation and the house can only be secure if the mentioned parts of the house are substantial. A single weak window makes the whole system weak. There are many variables of TPS house available in the pieces of literature, but the correct values are the same in all. In the order from top to bottom, it starts with the roof processes to reach the best quality at low cost and short lead times. Then it comes to twin pillars on left and right with takt time improvement, continuous flow and promoting pull system and Jidoka (which means not pass a defected part to the next station).
respectively (Liker, 2004). At the center, there are workers of Toyota and company culture. Finally, the foundation focuses on involving standardization in the process to make it reliable and stable (Gao & Low, 2014; Kehr & Proctor, 2017; Liker, 2004).

Philosophy of TPS is based on two facts (Sugimori, et al., 1977; Kehr & Proctor, 2017)
1. Reduction in cost by eliminating waste.
2. Optimal utilization of resources.

The use of JIT can achieve the first fact of cost reduction by eliminating waste, i.e. pull system, one-piece flow, levelling and Jidoka. The second fact of optimal utilization can be achieved by the culture of respecting each other efforts, by ensuring their safety and giving them the responsibility of improvement, the main component of Toyota production system (Rüttimann & Stöckli, 2016).

### 3.4. Volvo Production System

Volvo Group is the largest Swedish multinational manufacturing company, manufacturing sustainable transport solutions with its range in buses, trucks, components of aircraft, construction equipment and drive systems of marine applications. Globally Volvo has more than 90,000 employees, facilities in 19 countries with sales operations in more than 180 countries. Since its founding in 1927, Volvo has attracted researchers from different fields, particularly from operations, management and human resource management (Netland & Arild, 2013).

The Volvo production system (VPS) is inspired by the Toyota production system (TPS), Volvo visited the facility of Toyota to get a deeper understanding of their management and production system in the late 1970s (Berggren, 1993). Volvo launched the VPS in 2007 after two years of extensive study on its development. This study on VPS majorly focused on benefits of the system to the company by optimal utilization of resources, clear communication between departments and operators, sharing of best practices and reduction in rework (Hill & Svenningstorp, 2006; Netland & Arild, 2013).

Taiichi Ohno describes each process related to the development of the Toyota production system in his book *Toyota Production System*, the development phase of the TPS was from 1945 to 1975. The main focus of the TPS is added value from the customer perspective by adding the principals of JIT, continuous improvement/jidoka and elimination of waste (Sugimori, et al., 1977; Ohno, 1988). The ideology behind TPS was adopted by companies in the US and Europe in the 1980s in its odds and ends of JIT, total productive maintenance and total quality management, six sigma, etc. (Schonberger, 2007). In the 1990s international automotive program outlined the findings of the book *The machine that changes the World* (Womack, et al., 1990) and concluded that the Toyota production system was more superior to the production system of the companies in western countries. After that,
TPS was adopted by the manufacturers globally as the lean manufacturing system (Holweg, 2007). With their production system, Toyota can produce more customized products with higher quality and fewer efforts at a lower cost than their automobile competitors in Europe and the United States (US). 2008 was the year when Toyota became the most significant manufacturer globally. This proved the high level of competence and potential of having a production system that proves its real value to Toyota and its followers. During the last three decades, TPS became accessible to the public through many platforms from scientific journals and research literature to online portals and websites. Toyota's key for being a leader in the automobile sector was because of its deep-rooted culture (Liker & Hoseus, 2008).

Volvo was the pioneer in the European market to adapt lean production. Volvo not only adapted but also developed the TPS further in their adaptation by introducing a human-centric or reflective production system in the automobile industry (Berggren, 1992; Wallace, 2004). Volvo's human-centric production philosophy has no clash with lean ideology; instead, it's more of an adaptation of the system in the local settings (Berggren, 1993). Volvo's CEO Pehr Gustaf Gyllenhammar draw attention to employee ownership to the final product during the time of the early 1970s. He also emphasized the supportive role of the union and its relation with employees (Wallace, 2004).

Volvo explained its production system as the image of its value incorporated in the foundation of its VPS pyramid as The Volvo Way. This foundation works on the ideology of reducing the cost associated with the production and increase the quality at the same time by identifying and eliminating the processes which are not adding any value to the end customer.

- **The Volvo way**

The Volvo way focused towards the deep-rooted values of the Volvo group that are reflected in its culture and leadership. In addition, the following five guidelines define the DNA of Volvo.

1. Successful Customers Globally.
2. Bond of trust and respect.
3. Hunger for passion.
4. Adaptability to change.
• **Teamwork**

Success-driven multicultural teams which explain the diversity at Volvo, where everyone is appreciated for its efforts.

• **Process stability**

The stable and well-organized flow of work, with a focus on adding value to the customer.

• **Built-in quality**

This part of the VPS focuses on total quality management, which promotes the ideology of getting the quality from the very first step of the process.
• **Continuous improvement**

As per VPS, CI is defined as the non-ending long term program which helps in developing the process.

• **Just-in-time**

This lean philosophy guides the VPS to get the right things in the right amount at the right time.

• **The focus of VPS (customer)**

The highest level of the VPS pyramid is highly concentrated towards its customers and continuously adding values to the customer.

The presented definition of the VPS pyramid explains the whole concept of the Volvo production system. Work-related to VPS is never-ending, and Volvo promotes this pyramid not as a tool but as a way of thinking and developing to sustain the market as the leader (Volvo Group, 2008).

### 3.5. Just-In-Time

JIT is the system for making and delivering at the right time with the right amount (Narusawa & Shook, 2009). Under JIT, organizations are concerned with continuous improvement to identify non-value-added activity and remove it, eventually to benefit end customers and reduce cost (Chen & Tan, 2011).

Just-in-time means to supply to each process with the delicate balance of what is needed, when and in what amount (Lu, et al., 1989). After the second world war, Toyota planned its production at the beginning of the month. But the parts were gathered somewhere in the middle of the month and the requisite plan was implemented by the end of the month. It was a hard time for Toyota workers to produce a car with ten workers. To cope with this challenge Mr. Taiichi Ohno started observing the supply trends in the Japanese supermarkets and tried to figure out, how can the trend of delivering products in the supermarket be connected with the manufacturing industry. He observed that at every supermarket customer selected items in quantity according to its need and put them into the shopping cart and paid for everything (services) at the billing counter and went home happily (Lai & Cheng, 2016).

Mr. Ohno figured out the trend in shopping by observing that a customer bought items from supermarkets according to several family members - space in the refrigerator and time duration the food lasted to feed the family. Mr. Ohno utilized this idea of supermarket purchases to the production system of Toyota. Although it is mentioned in the existing
literature that the JIT was invented by Mr. Kiichiro Toyoda, the first president of Toyota, it was Mr. Ohno who came up with these challenges and created TPS (Lu, et al., 1989; Liker & Ross, 2016).

Presently many manufacturing companies face intense financial competition in terms of revenue generation. To be cost-effective, employees in a production process need to be inspired by TPS and able to produce high-quality products. These lean tools from TPS result in effective manufacturing at lower lead times with fewer inventories and high quality (Gandhi, et al., 2018). Manufacturing industries mainly use JIT; however, the trend is changing, and companies have begun, including JIT in supply chains, purchasing and more. Implementation of JIT is mostly dependent upon ground workers of the company; their daily task is to work on continuous improvement, understand quality and solve problems (Green, et al., 2014). The main idea of JIT is to use a pull system instead of the push system, which means that the process of production starts when the customer places an order. According to customer order, the raw material is realized to the production floor and in the right amount.

3.6. Continuous Improvement and Iceberg Challenge

After the second world war, it was hard for Japanese manufacturers to compete with western companies as their factories were damaged with a significant loss in terms of resources and infrastructure. Toyota being globally known, needed to work on identifying waste in their production lines so that they could produce better quality goods with fewer resources and in less time. To achieve that Toyota did not hire new consultants or new managers. Instead they started with Kaizen or continuous improvement (CI). They formed teams with particular work zones or cells and asked to perform better every day and look for improvements. Managers to these teams were asked to support the teams instead of ordering them and think for them. The Japanese word `Kaizen´ is the addition of two words. First is `Kai´ which means continuous benefit and second is `Zen´ which means improvement, wisdom. Translated as change for excellent or continuous improvement. In Japanese, it is written using two logograms, i.e. kai & zen (Medinilla, 2014).

True Kaizen comes from an extensive and very vast background, which is not just a process where workers need to find the scope of improvements and work on it or where managers need to do some reengineering. It is much deeper and more explanatory and can be present into many definitions from the lean world. It is a fact that literal translation of Kaizen is the change for good or continuous improvement, but it has a very complex concept as well, some researchers explain Kaizen as the state of being uncomfortable with the things in the present situation. This further means were striving for an ideal state of perfection, even after knowing the fact that it is not achievable, i.e. Kaizen is all about walking the path of learning. It implies that companies are doing better today than yesterday, but tomorrow they are expected to do more better than today (Medinilla, 2012; Berger, 1994).
Kaizen is deep-rooted to Japanese culture in many ways; people devote their life to get perfection at par and help others to get perfection in their lives. Excellent examples can be given as (Kendo) Japanese Sword, (Kyudo) Archery, (Chado) Serving tea, and many more. Many of these practices are ends at ‘do’ for Japanese people. ‘Do’ means, the road or the path (Bessant, et al., 2001; Medinilla, 2014). Soon Toyota came with a lot of tools and techniques which helped companies improve their production units and develop the culture of standardization and honoring them.

Although kaizen has numerous advantages, it does have some criticisms. One of the main criticisms is that this approach always promotes the ideology of improvement rather than innovation due to this solving all problems still the issue. Some other criticisms are if a company is lagging in the market in terms of its services and its product variety than continuous improvement will not be enough to sustain in the market or make an impact-full come back to the market. Other criticism, the process of CI is more culture-oriented and very well merged into Japanese culture, as explained above. In the Japanese industry, CI is more developed, and every employee work for kaizen from top management to operator their relationship is involuntary, i.e. make this kaizen successful there. Whereas in the west this ideology needs to implemented as a program with some incentives and perks or program rewards, another criticism to kaizen is that it comes with the removal of non-value-added processes, which indirectly brings up an inter-organizational change as the removal of the
process leads to removal of employee or reallocation of the employee in the factory (Delers, 2015; Köksal, et al., 2011).

Even having the ideology of continues improvement problems are still there and can be described in the form of an iceberg. Companies from the sea perspective at the surface of seawater only see the tip of the iceberg. From that level they are unable to see the hidden part of the iceberg that are the hidden problems and challenges. The change initiatives taken by the companies are only for those problems which lie on the surface of the water; this is a common practice that can be easily observed in the companies. Where companies do not think about the hidden problems and end up having the loss in business and resources. There are many factors for the iceberg situation, which happens in the industries. One of the major in that is communication, in lean thinking communication is the tool to bring up the hidden issues to the surface that can be solved and analyzed as part of the continuous improvement process. The way through the ‘iceberg’ is not smooth, and it always depends on the companies and which approach they took to cope up with these challenges (Yankelevitch & Kuhl, 2015; Leopold & Kaltenecker, 2015; Hines, et al., 2008).

Figure 5 Continues Improvement Iceberg (Hines, et al., 2008)
3.7. Root Cause Analysis

Modern theories of problem-solving are the result of the methodology used to solve real case problems in manufacturing companies. These modern theories incorporate tools and techniques to analyze the problem on an initial level before getting into the core of the problem (Dobrusskin, 2016). From the profession, the viewpoint is not straightforward on how to link analytical tools with the problem. Therefore, some tools are fixed to use for specific scenarios, for example, Ishikawa diagram for analyzing the root cause of the problem (Rosario, et al., 2015).

There are two methodologies which are mainly used to perform root cause analysis in the manufacturing companies, i.e. five whys and Ishikawa diagram (Kumar, et al., 2018). 5 whys is a questioning technique used to reach the root cause by asking a question about the particular problem. The questions are framed with repeating term why, which are used as an iteration based on the previous question answer (Kumar, et al., 2018). Five whys method was initially developed by Sakichi Toyoda and was used for Toyota motor corporation. The inventor of TPS Taiichi Ohno describes the five whys method as one of the foundations of Toyota scientific approach by repeating why five times (Kumar, et al., 2018; Rosario, et al., 2015; Mergner, et al., 2003). This approach is now widespread use beyond Toyota and is now used within Kaizen, lean manufacturing and six sigma. This five whys approach do have some limitations which restrict its use in every case, for instance, there are high chances for the investigators to stop at symptoms instead of going to lower-level root causes, different people and their different answer to whys cause problems in quality results, inability to beyond current investigator knowledge (Dobrusskin, 2016; Kumar, et al., 2018; Hicks, 2007).

However, the Ishikawa diagram, also known as the fishbone diagram, was created by Kaoru Ishikawa. This diagram shows the potential causes which can lead to the failure in the system, product (Ishikawa, 1991). The reason for using the fishbone diagram is that it clearly shows the relationship between causes and its effects, fishbone diagram as a tool helps in prioritizing actions taken by management and considerably increase the value of those actions (Oikawa, et al., 1995). To perform a fishbone study where more than three groups are considered, a study must be done by the team, not from a single source. Otherwise, it weakens the credibility of the fishbone diagram (Abdolhamidzadeh, et al., 2012). The main problem is shown on the central bone and the factors or causes related to that problem are shown on the other attribute bones. A fishbone chart is not be considered as the solution to a problem. Instead, it is considered as a part of the process for solving the problem as it approaches in segregating the critical causes for the potential failure which helps in providing the clear vision to company on the problematic area (Yazdani & Tavakkoli-Moghaddam, 2012; Tegegne & Argu, 2014). The reason behind the popularity of fishbone diagram is its highly visual tool, easy to understand aspect, presentation of all potential causes simultaneously, identification of root cause methodology, found multiple times in different casual trees (Kumar, et al., 2018). There is a different model which are used in doing root
cause analysis these are, 3M (man, machine and material), 5M (3M + method and measurement), 8M (5M + mother nature, management, maintenance).

3.8. Inventory & Theory of Constraints

Inventory management can be defined as an issue of how much to keep in hand and how much the company needs to order to work smoothly. Many companies have big buffers of their inventory for their manufacturing operations. These buffers can be of raw material, can be of partially finished goods or finished goods depends upon companies planning and controlling strategy. According to lean methodologies having significant inventories is also seen as waste in terms of time and money. To reduce the cost associated with inventory hold or work in progress (WIP), the ideal case will be not have any inventory, which is not that practical due to many factors. However, inventory size can be reduced with the ideology of going lean, by implementing JIT philosophy as this will result in low inventory cost (Bessant, et al., 2001). Having too much and too little inventory is not an optimal idea for fulfilling customer needs. In case of having much inventory, we must have more space among other operations and this will lead to higher capital investment, an investment that can be used within other areas of the company (Hines, et al., 2008). For more inventory company needs more resources, which will be an indirect cost to the company. Whereas having lower inventory leads to not fulfilling customer demand on time, lowering the sales in the market and for manufacturing unit fewer inventory causes stop in the production line (Mercado, 2008).

Many engineering programs and approaches from managers in the companies are focused on reducing inventory and become a specific desire for the company workers from low to top management. Furthermore, this desire is not only limited to the company atmosphere instead is also reflected in academic works of literature and scientific journals. However, having zero inventory usually is an impossible goal. Instead of considering this as a plan it should be considered as a practice towards perfection (Eroglu & Hofer, 2008). Lean inventory is considered as the symbol of lean management. Nevertheless, the decision about inventory is always of high risk and has a significant impact on the supply chain of the company, such as sophisticated logistical strategies, warehouse distributions, insurance and taxes and many more (Ballou, 2003). In general, companies do not have control of inventory management as it associates with many other factors like uncertain demands, planning, procurement and technologies in the companies. Therefore, companies use a different type of approaches and tools to work on their lean inventory to make their business successful, some of the popular tools and tricks that are described in the literature are the theory of constraints (TOC), Just in time approach, pull system and material requirement planning (MRP) (Watson & Patti, 2008; Koh & Bulfin, 2004).
The traditional approach of material planning and control is replaced by just in time and theory of constraint approach in the companies due to many reasons. In terms of JIT, it reduces the buffer sizes or inventory sizes it promotes pull system which is driven by continues improvement, some of the typical improvements in JIT system are reducing setup times, scrap rate, repair times and more (Hall, 1983; Monden, 1993; Radovilsky, 1998).

Whereas TOC has its own goals, it maximizes the profit by identifying the bottlenecks in the system and eliminating them from the system. In TOC, system inventory acts like a buffer element of the drum- buffer- rope (DBR) system. Here in this approach, coordination and moment control of inventory to the production facility are focused on lean inventory and optimal production to the variety of demand (Gardiner, et al., 1993; Umble & Srikanth, 1995; Renn & Stevens, 1991; Reimer, 1991).

TOC performs the best among the JIT and MRP systems with system output at different inventory settings. TOC system produces a large number of products than JIT or traditional systems at lower flow time, which gives the advantage to companies to predict the shipment time for a product. Additionally, TOC systems have lower inventories due to the usage of different sized batches in transportation and process, while JIT promotes equal-sized batch. TOC results in better performance of the system compare to JIT and requires fewer efforts to implement (Blackstone, 2001; Bolander & Taylor, 2000; Boyd & Gupta, 2004; Cook, 1994; Glodratt, 1988; Gupta & Snyder, 2009; Miltenburg, 1997; Watson & Patti, 2008; Alvarez, et al., 2017; Kumar & Nallusamy, 2017; Wei, et al., 2013).
4. **EMPirical DATA**

In this section, the author has presented the empirical findings from the case company studied and the significant issues that need to be addressed in the lean inventory management system.

4.1. **About Case Company**

The Volvo Construction Equipment was established over 180 years ago in Eskilstuna, Sweden. In mid-1800s, three men raise the foundation for Volvo Construction Equipment. These are Johan Theofron Munktell and the brothers Jean and Carl Gerhard Bolinder. This case study was held at Volvo Construction Equipment (Volvo CE) in Hallsberg, Sweden.

This location is one of the most significant cab manufacturing units of Volvo CE, the entire factory at this location divided into three significant departments; these are welding department, the paint department, and the assembly department. Work in these departments entirely based on forecasting. Process of forecasting done into three phases, i.e. yearly, monthly and weekly that is because of high accuracy in forecasting. As production in this factory of Volvo CE is driven by forecasting, the accuracy plays a crucial role to avoid overproduction and maintain a smoother production environment.

![Final products of our manufacturing](image)

*Figure 6 Final Products at Volvo CE Hallsberg, Sweden*
As the factory works on lean methodology, where buffer stock or inventory is a type of waste, the thesis work is focused on inventory management and trying to reduce this waste up to the optimal level achieved. The company is tackling this problem and trying to achieve a sufficient level of inventory for almost eight years as there is enormous space and resources associated with the present inventory size.

4.2. Case Description

The case company, VOLVO CE is located in Hallsberg, Sweden, and has approximately 1000 workers working in different shifts. The company manufactures cabs of their construction pieces of equipment and some other accessories like fuel tanks and many more. The company mainly consists of three central departments, i.e. welding, painting and assembly and all the primary operations are done in these departments. The process of manufacturing starts from the welding department, and then products move to a buffer called BUFFER IN which feeds the finished welded goods to the paint department which deliver the finished products to another buffer called BUFFER OUT, which further feeds the finish welded and painted goods to the assembly department.

Here comes the main objective of this case study, as Volvo production system (VPS) works on lean methodologies which means eliminating the non-value adding times and processes from the whole system to make end customer beneficial.

In the same manner, having extensive inventories is defined as one out of seven types of wastes in lean manufacturing. In support of this ideology this case study focuses on one big buffer in the company, i.e. Buffer out, at present buffer out can hold up to 42 products which are several types of cabs along with details (front/roofs), but the majority is cabs. Over the years, while the company worked with continuous improvement, they figured out the inventory size as potential waste.

The main objective of this case study is to find out the optimal requirement of the buffer out and which can provide flexibility to the company with their production plan and flexible demand while maintaining the existing takt time at the assembly line which is 7.5 mint.

4.3. Process Description

In this case study the focus is on inventory management and inbound logistics, which in this case is big inventory rack named as buffer out which holds the incoming painted products of higher quality from the paint department and supplies these products to the assembly department. It is an automatic buffer operated through a crane that is operated by a worker remotely from the assembly line. Every product in the buffer out has a unique code on it, which is called welding no, which is given at the time of the welding process which provides help in traceability and also helps in maintaining FIFO (First in First Out). So, whichever type of cab required according to the production plan, the operator gives the command to
crane and crane picks the same type of product which is closest to the crane from that particular position. The same crane also receives the incoming products from the paint department and places them into the buffer out in available empty places.

Figure 7 Current inventory scenario with 46 products at VCE Hallsberg, Sweden

The adjacent picture shows the current scenario of the buffer out at the factory, where crane moves along the buffer, which is 61 meters long and 6.6 meters in height. In terms of geometry, it will be X-axis equals to 61 meters and Y-axis equals 6.6 meters. According to the present situation takt time of the assembly line is 7.5 minutes which means the production rate of the assembly line is eight products per hour. Whereas supply from the paint department to the buffer out is five products per hour which are equal to 12 minutes takt time from the paint department to buffer out. The reason behind this short supply of products from the paint department is that in the paint department they process all produced products in the factory, for instance, tanks, cabs, details and more. All these products are not sending to buffer out, only the selected type of products is sent to buffer out these are all cabs and their variants for an example wheel loader, excavators, articulators and details of the wheel loader. Whereas all the tanks and some other details sent to different assembly. The working process of paint is designed in a way that with the takt time of 6 minutes it delivers the product, in the majority of cases it paints one carrier with cab and next one with tanks and
details which means every second carrier is sent to buffer out as it contains cabs which led to 12-minutes takt time to the buffer out.

4.4. Root Cause Analysis of the Problem

Root cause analysis is the process of searching for the root cause of the problem or challenge. The root cause is vital to find because it could be the leading cause of the failure of the product, system or process. In the same manner, a root cause analysis is performed, and an Ishikawa diagram is represented, which shows the potential causes for the unwanted inventory in the case factory Volvo CE.

In the presented fishbone diagram, the author focused on 3M approach, i.e. man, machine, material. The reason being a study on these three potential groups is that a single author conducts this study.

Figure 8 Ishikawa (Fish bone) diagram for Volvo CE, Hallsberg, Sweden
It can be seen from the fishbone diagram that there are several reasons for the inventory stock in the buffer out in the factory, but there is one reason which seeks attention is continuous improvement. This cause can be easily relating to the kaizen iceberg almost eight years ago the company decides to improve its production system as they have much demand from the customer and existing production output is not sufficient to meet those demands. So, the company decides to develop their production process, and the company had different assembly lines for the different products at that time and upper-level management and the team of production engineers and leaders come to the mutual decision of merging all the assembly lines into one and give advantage in lower production time and high output by reducing lead time. To maintain the balance in the new assembly line company, fix the takt time for all the stations, i.e. 7.5 mints. This takt time is based on the forecast of the company and its been the same throughout the study. This decision made the company flexible over different demand patterns throughout the year and helped in producing with higher throughput with a shorter time.

As mentioned above, meeting the demand was the issue that the company had faced earlier this can be related to the tip of the iceberg that the company observes from the surface later on the solution to this comes with its pros and cons. The primary objective to meet customer demand is achieved successfully with the help of the new system of the production line, but at the same time, it brings up new hidden challenges, i.e. unwanted inventory. To solve this new challenge approach of continuous improvement, the soul of the Volvo production system is used. As explained above VPS is inspired by Toyota in that ideology having inventories is considered as loss of capital and resources which make a negative impact on the company’s business and results in hard to sustain for the company in the market. To figure out the reason behind the cause for this inventory stock fishbone diagram is presented which self-explanatory and shows the factors which cause the inventory stock. These potential causes are:

- **Quality in the welding area**

While conducting brainstorming sessions with the managers of the welding department it was observed that welding department worked in three shifts which are 06:00 to 14:00, 14:00 to 22:00 and 22:00 to 06:00 as shift 1, shift two and shift three respectively with different availability of workforce in all the shifts. The 3rd shift has the least number of workers, approximately 12 workers for the whole third shift. Having discussions with operators and engineers at the welding department, it came to light that the majority of quality failures were due to the welding splatters. Moreover, this quality failure rate was higher than in the 3rd shift. The products which failed the quality had to go through the rework loop depending upon the type of rework other than that one more factor which comes to notice is that passing of products through the quality gate, products which were not up to the mark of quality had been passed to the buffer in through the quality gate check. This led to longer delays and overproduction, as due to quality failure, they needed to produce more to meet the demand on time.
- **Quality in paint area**

The system paint department comes after the welding department and works for two shifts with the same number of workers during the shifts. The first shift in the paint department operates from 05:30 to 14:00, and the second shift operates from 14:00 to 23:00. Discussing with line engineers and operators helps to figure out the potential cause in the quality failure. This cause is air and dust particles in the paint, which leads the product to the rework loop. Here in this system rework loop is managed internally and externally depending on the amount of rework and have different timelines. Moreover, there are products which are passed through the quality gate and which are not up to the mark in the quality which cause delays, rework and overproduction, which resulting inventory stack at buffer out.

- **Overproduction**

Due to quality failure in the different departments before the buffer out, the other departments need to produce more to meet required demand the rework loop takes time to depend upon the amount of rework most of the time quality fail products send out to the external stakeholder for the rework which further increases the waiting time of the product to arrive. Although the factory follows the FIFO process but due to quality issue, sit to break down at many stages. Moreover, the process in the paint department is also designed in a way that breakdown the FIFO, for instance, high-speed tracks and low-speed tracks in the ovens and cooling tunnels. To maintain the FIFO system every product is given a unique code (welding number) in increasing order during their manufacturing and the crane at the buffer in or first buffer priorities the product which has the smallest welding no. Whereas the crane in the buffer out, which is the focused area for this research priorities the closest product to the crane in the buffer. Due to rework, because of the quality issue when these products come back to the system are priorities because of lower welding, which leads to the stack of the products having higher welding no. The result is inventory accumulation.

For more deeper understanding, the process flow chart is presented below, which represents the operational processes Volvo CE factory at Hallsberg, Sweden.
Figure 9 Process chart at Volvo CE Hallsberg, Sweden
4.5. Approach for Lean Inventory

VPS works on continuous improvement, which is further inspired by the Toyota production house where continuous improvement is considered as organizational culture, where every employee is involved from upper management to operators. This case study performed at the Volvo CE factory in Hallsberg, Sweden. Where almost eight-year ago production system was developed to meet customer demand as the primary focus and the decision is taken by management and the line engineers to merge the assembly lines from three different lines to one, which was very successful after the implementation company can meet customer demand on time. Solving this issue brings up a new CI iceberg challenge to the surfaces, i.e. inventory stock. As mention above production system at Volvo is inspired lean methodologies where having inventories are considered as waste which leads to waste of space, resource, and capital. Following the same ideology, Volvo CE Hallsberg starts looking at the inventory as the potential which is needed to examine and removed as early as possible.

To address the problem approach of TOC is used and the explanation behind using the TOC for this case is explained in the section Inventory and Theory of constraint. Theory of constraints is used to determine the optimal size of buffer required for buffer out.

They are considering the schedule in the paint department and assembly department. In the paint, department work starts at 05:30, which means the first product comes to the quality gate and after successful inspection goes to buffer out. Whereas in the assembly department work start at 06:48, and first product entre the assembly line is at 07:00 the window of 12 minutes is for operators to get onto their workplaces and reads day agenda and be prepared to start with work at 07:00.

Takt Time in Assembly line 7.5 minutes

Total working stations at assembly line 28

For line balancing, every station has the same production time 7.5 minutes

No. of products consumed by assembly line in one hour from buffer out.

\[ \text{No of product in 1 hour} = \frac{60 \text{ minutes}}{\text{takt time of assembly line}} = \frac{60}{7.5} = 8 \]

(Equation 1)

Eight products in one hour are consumed by assembly line from buffer out.

Takt Time in paint department sending products to buffer out only 12 minutes
No of products send by paint department to buffer out in one hour.

No of products in 1 hour = 60 minutes / takt time of paint department = 60/12=5
(Equation 2)

5 Products are sent to buffer out in one hour from the paint department.

Present size = 46 products in the buffer out.

TOC mathematical approach for calculating buffer size.

Consider the buffer as time buffer where the total buffer is equal to the sum of takt time of all the products at any time.
For instance, if a buffer has 20 products and takt time of buffer is five mint

Then the total time buffer will be (20*5), which will give 100 minutes.

Which means the buffer will sustain for 100 minutes when it is maximum.

The author is using the same approach for VCE Hallsberg problem.

Let us consider the input rate per hour for buffer out, which is given by (Equation 1

Let (α) be the input rate per hour = 5

Let us consider the input rate per hour for buffer out, which is given by (Equation 2

Let (β) be the output rate per out = 8

The consumption rate of buffer out will be given by (ρ)

Therefore, (ρ) = input rate / output rate = 5/8 = 0.625 ≤ 1
(Equation 3)

Value of (ρ) in is less than 1,
(ρ) ≤ One if this is the case, that means demand is more than the capacity of incoming. This means that the buffer is not the CCR (capacity-constrained resource) which is essential to TOC, and this finding leads to the result that there is no bottleneck in the system.

However, there is another twist with the approach of TOC considering the takt times of the different departments as the constant constraint.

Let us consider the takt time of the assembly line is a constant constraint, i.e. 7.5 minutes.

Let us consider the takt time of the paint department is constant, i.e. 12 minutes.

With these constant takt times, a conclusion can be drawn that in the one-hour assembly department needs eight products from the buffer out with takt time 7.5 minutes whereas the paint department can supply only five products for the same hour to the buffer out with takt time of 12 minutes. Therefore, every hour there is a shortage of 3 products.

Assembly line works from 07:00 to 16:00 one shift excluding 1 hour of food break, including breakfast and lunch. This gives a total of 8 hours of production. There is no production during the lunch break. With the explanation mentioned above in the previous paragraph about the shortage of 3 products every hour, a conclusion can be drawn that for the shift of 8 hours of production total shortage of the will be given as:

\[ \text{Shortage every 1 hour} = 3 \text{ products} \]
\[(\text{Equation 4})\]

\[ \text{The shortage for 8 hours (1 shift)} = 24 \text{ products} \]
\[(\text{Equation 5})\]

From the above expression, it is clear that the shortage of products should be the buffer size. As the paint department works two shifts, it is quite natural for paint department to maintain the buffer when the assembly is not working so that the buffer will be full the next day when assembly starts working. The graphical representation can explain this hypothesis.
In the presented graph it is defined that how the buffer works including its utilization from the paint department end at the rate (takt time) of 12 minutes and how the filling up takes place from the assembly department end at the rate (takt time) of 7.5 minutes. Graphs represent the ideal condition, i.e. producing 64 units in an 8-hour shift on the assembly line with the mentioned takt time. There is a catch assembly that has two breaks in the total working shift from 7 to 16 on weekdays, i.e. Monday to Friday. Where in this hypothesis, those two breaks are merged into one break for 60 minutes which in total gives 480 minutes of production, which is equivalent to 8 hours of production. The reason behind this merging is that the two actual breaks are of 30 minutes each and they happen in a time frame for example first break of 30 minutes can happen any time between 8:00 to 9:00 depend upon the production on that particular day. Similarly, the second 30 minutes break can take place from 11:30 to 12:12 time frame depends upon the leader on that day. As there is no production during these 60 minutes break in total, so the merging of these breaks is considered to make a real impact.

The company follows the pull system on the production line. Therefore, the paint department paint the products and sends them to the assembly via buffer out in coordination with demand from the assembly department. The presented graph shows the product, for instance, on Tuesday it starts production on the assembly line (orange line) having 24 products in the buffer (dark blue line). Every hour production line produces eight products as per their takt time of 7.5 minutes. The blue line goes to zero from 11:00 to 12:00 as there is no production during the break.

Similarly, when the assembly line is not operated, i.e. after 16:00 paint starts filling up the buffer for the next day for the better production flow. Also, there is safety buffer (light blue line) accumulation on Thursday evening and Friday morning when the assembly is not operated this safety buffer helps in maintaining the buffer for Monday next week for the production process. The reason for having the safety buffer on Thursday and Friday is that
these production cycles are just before the weekend and the company can have more accurate production planning concerning the type of products they need on Monday, as the safety buffer will be utilized every Monday.

4.6. Evaluating the Approach for Lean Inventory

In this section validation of the new buffer size is proved by using the production plan from the company. Considering the production plan of week ten and week eleven from 2019, this selection is made randomly.

<table>
<thead>
<tr>
<th>Assembly Production Plan (2019)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 10</td>
</tr>
<tr>
<td>Proposed production</td>
</tr>
<tr>
<td>Actual production</td>
</tr>
</tbody>
</table>

Table 1 Assembly production plan from week 10 & 11, 2019 at Volvo CE Hallsberg, Sweden

This mentioned assembly production plan from Volvo CE, Hallsberg is checked with the proposed buffer size to see whether the prosed solution is capable of producing the same amount of production or not. The checked result is shown in the graph below. The study was focused on the buffer size from an assembly perspective as the company follows the pull system, which means the paint department produce the products according to the demand from the assembly.

<table>
<thead>
<tr>
<th>Paint Production Plan (2019)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 10</td>
</tr>
<tr>
<td>Proposed production</td>
</tr>
<tr>
<td>Actual production</td>
</tr>
</tbody>
</table>

Table 2 Paint production plan from week 10 & 11, 2019 at Volvo CE Hallsberg, Sweden
Figure 11 Graphical representation of inventory stock in actual condition

The represented graph shows the attractive curves; for instance, there is a similar trend between ideal (blue) and actual (orange line) buffer curve. For instance, on Wednesday in week 10, actual production was 51 products which are achievable having 24 products in the buffer same goes for whole week production plan. It can be seen from the graph that there is a possibility of producing more as the maximum possible production with the takt time of 7.5 minutes is 64 products, and the proposed buffer is capable of supporting the production at its full throttle, i.e. producing 64 products in assembly with 8-hour production shift as mention earlier Volvo CE at Hallsberg follows the pull system which means in this case that paint produces according to the demand from the assembly line.
5. ANALYSIS & RESULTS

In this section, the author will answer the formulated research questions in an analytical context. Potential improvements and results are also mentioned in this section.

5.1. Research Question 1

*What are the potential factors which affect the inventory size in the lean production facility?*

In the present literature, there are many factors presented which affect the inventory size in the manufacturing company. This research study figures out some of the potential reasons which affect the inventory size in the companies and limits the companies to go leaner. These reasons are traced out with the help of root cause analysis, lean manufacturing tool. Further, these reasons are presented in the form of a fishbone diagram. The primary reasons which cause the inventory size in the case company are:

1. Quality in the welding area
2. Quality in the paint area
3. Overproduction

It has been found out that these reasons are mainly causing the inventory size in the case company associated with man, machine and material. To effectively reduce the inventory size of a company, they need to work on their quality issues mentioned in section 4.5 Root Cause Analysis of The Problem. One finding which has a considerable impact on the entire production system of the company is overproduction. It was found out that overproduction becomes the part of production planning which leads to losing control over the production scheduling and results in a high level of inventory on the production floor.

5.2. Research Question 2

*What should be the inventory management approach in a lean manufacturing environment?*

There are different approaches available in the literature to work with inventory management, differing from case to case. To be competitive in the global market companies are adopting lean manufacturing system and inventory management is the art of being lean as it has been treated as waste in the lean methodology. The approach used in this research study for inventory management is called the theory of constraints this approach has enormous benefits when using in the inventory management system.
In the research study, two cases were discussed associated with TOC in inventory management, i.e. when the inventory consumption rate is higher than one and other is when the inventory consumption rate is lower than one. The second approach was suitable for the case company because their inventory consumption rate is lower than one. Considering the takt time as a constant constrain based on the forecasting system of the company, a mathematical model is proposed for inventory size. This model shows the reduction in inventory by 27%. However, this model was based on some assumptions/limitations which are discussed in section 1.4 Project Scope and limitations. Graphical representation of the mathematical model, as shown in Figure 10 Graphical representation of inventory stock in ideal condition based on the discussed limitations.

Furthermore, the proposed model was evaluated with the production plan of the company, and it shows interesting trends in the graphical representation in Figure 11 Graphical representation of inventory stock in the actual condition. It can be seen from the graph that the proposed buffer with 27% less inventory supports the production having an original inventory of 46 products in the buffer. Proposed inventory size not only reduces the inventory size also give other advantages to the company for instance:

A significant improvement, in this case, is the reduction in the buffer size, as shown in Figure 11, this calculation for future buffer dimensions can be given as:

Currently, the buffer can hold up to 46 products and 61 meters long.

For 1 product = 61/46 = 1.32 meter

For 34 products it will be

\[34 \times 1.32 = 44.88 \text{ meter}\]

Therefore, the requirement of the buffer which can hold 34 products in the future instead of 46 is 44.88 meters. This is equivalent to a 27% reduction in infrastructure.

Another significant improvement will be the availability of crane, with the proposed buffer size availability of crane will increase significantly.

Crane speed = 1.3 meters/second (approx.)

In the current scenario, crane takes 46.92 seconds to travel 61 meters, whereas in the future scenario with the proposed buffer size this time will reduce by 12 seconds which is equal to 34.52 seconds by travelling 44.88 meters.
By reducing the buffer size, the company can also start reducing the expenditure of financial capital and resources on the buffer. Hidden costs associated with buffer as mentioned above can also be reduced by reducing buffer size. Small buffer size also limits the overproduction both in the assembly and paint departments.
6. DISCUSSION

Proposed inventory size has its foundation over certain assumptions and limitations. Those assumptions were made due to non-availability of the data in the case company. These assumptions are subject to discussions since there is a weak monitoring system in the company. Nevertheless, the company should try to strengthen their monitoring policies by having a system that must be designed for constant monitoring of the buffer size, and if the number of products goes beyond assigned number, a message must be sent to the operator or a red light shown on the floor and process which leads to buffer must be stopped at the same time.

However, the result generated is majorly based on takt time and production rate of the different departments in the factory. These two data parameters are more of the standard data parameters which can be treated as the foundation of any production facility. These parameters are compulsory parameters which helps in having a smooth production flow throughout the factory in a lean manufacturing setting. By optimizing the buffer sizes, companies are tending to increase their benefits by reducing overproduction, having good quality, lowering the work in progress and have an optimal use of space associated with the buffers.

Moreover, financial budgets associated with the buffer management also be optimized by optimizing the inventories. Having these benefits by optimizing the buffer strengthens the company’s business and gives competitive advantages to the company in the global and local market. It is quite evident from the literature that many manufacturing companies, whether a small scale or larger scale, have been using the approach of TOC for the inventory management system due to its variety of advantages and easy adaptability.

Moreover, it is quite early to say that TOC is the best approach or method for inventory management system in order to optimize the buffer sizes in the lean production environment. Many companies use different approaches other than TOC to optimize their buffers on the production facility in the lean setting and have same set of competitive advantages as provided by theory of constraints. The vital factor that needs to be understood is that to get competitive advantages in the market companies should focus on the inventory management system by using the right approach which suits to their production system and their manufacturing techniques. Before concluding, a discussion should be made, which should address the more details benefits about use of theory of constraints as an approach to inventory management over the other approaches used in the inventory management systems in lean manufacturing setting.
7. CONCLUSION AND FUTURE RECOMMENDATIONS

This research study aimed to analyze the potential causes which affect the buffer sizes in the lean manufacturing environment and to come up with the generic approach which helps in optimizing the inventory systems in the manufacturing companies. During the study it was found that there were many factors that influence the buffer size in the factory. These factors are mainly categorized into three main categories, i.e. factors due to human resources (man), factors due to machinery used in the factory and factors due to materials used in the factory. The detailed study of these factors is represented in the fishbone diagram. The primary outcomes of the fishbone diagram were the overproduction which means overconsumption, and this overconsumption leads to the accumulation of the products in the buffer and increases the buffer size.

Intensive study of literature from different resources helps in understanding the problem. After the literature review, it was found that the theory of constraints is the most suitable and efficient approaches to use in this case as the method inventory management. However, it also has its limitations when respectively applying to an inventory management system where the buffer consumption rate is lower than one it limits to predict the optimal buffer size. Authors applied the theory of constraints approach but in a different manner by considering the takt times as the constant constraints of the system. This is true to consider in this case as it is constant for the case company. In general, takt time is always defined in production environment in order to achieve high level of on-time deliveries and help in maintain the controlled flow of material in the processes. Analysis of the production planning considering the constant takt time with the help of theory of constraints it was found out that reduction in buffer size by optimizing it helps the company to achieve its planned production goals.

The proposed buffer size was evaluated with the production plan from week ten and week eleven of 2019 these weeks were randomly picked and evaluated, and the result showed that the actual number of products produced during week ten and eleven, the same number of products could be produced having the proposed size of the buffer. Implementing the proposed buffer size helps the company to reduce the buffer space or infrastructure by nearly 27%, reducing overproduction, lowering the work in progress and it will also reduce the cost associated with inventory management operations. Moreover, proposed buffer size helps in increasing the availability of the crane for buffer operations.

Lastly, an excellent way to test the proposed buffer size before implementing it to reality could be by doing the simulation since the company had used simulation as the process optimization tool in one of the processes in the factory. Moreover, the company needs to improve its quality as the higher rate of quality failure might bother the proposed buffer size. Recommendation for future research would be to do a fishbone diagram more profoundly and must be in the team which include more study areas. Along with that in-depth study can be conducted, which only focuses on the equality issues.
8. REFERENCE


9. APPENDICES

- Proposed buffer size
  
  H:\thesis final\Proposed buffer size.xlsx

- Validation buffer size with production plan from week 10 & 11 (2019)
  
  ..\Validation sheet.xlsx