Industrial look and feel – The combination of aesthetics and performance in production, a case study

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ABSTRACT

The increasing globalization of the market has rendered the competitive situation for companies worldwide fiercer than ever with order winners becoming order qualifiers and the demand continues to rise. Especially, the situation has become more complex for SME’s that are suppliers to large global companies. To ensure themselves that the suppliers are conforming to the high standards set by the large companies. In mediating the quality of the production as well as having a well-performing production, practitioners are using the term industrial look and feel to encapsulate a production that both deliver and looks the part. However, this term is loosely used, and a clear definition of it is missing, hence creating problems when the term industrial look and feel is used in production line design.

In this study, the authors aim to investigate the possibilities of providing a clear definition of the term industrial look and feel and what it involves. Further, the authors want to investigate what are the important aspects to consider when designing a production line considering industrial look and feel. The study was directed by these three research questions:

- How can Industrial Look and Feel be defined?
- How does Industrial Look and Feel contribute to increased performance of a production line?
- What is important to consider when designing a production line considering industrial look and feel in an HMLV environment?

To answer the research questions a case study has been conducted at a company producing the robust data communication equipment and a literature review was conducted with the aim of understanding the concepts included in the term industrial look and feel.

The study resulted in a definition of industrial look and feel, how industrial look and feel may contribute the production performance and important aspect to consider and include in the design of a production line considering industrial look and feel. Taking the newly defined concept of industrial look and feel into consideration, a concept assembly line was developed at the case study company.

Keywords: Industrial look and feel, workplace aesthetics, ergonomics, workplace design, assembly line
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ABBREVIATIONS

EPA  Electrostatic discharge protection area
ESD  Electrostatic discharge
GT   Group technology
HMLV High-Mix Low-Volume
IDT  School of Innovation, Design and Engineering
IEA  International Ergonomics Association
MDH  Mälardalen University
PCB  Printed circuit board
RFI  RedFox Industrial
RFIR RedFox Industrial Rack
RFR  RedFox Rail
SME  Small and medium-sized enterprise
TPS  Toyota production system
1. INTRODUCTION

This chapter presents the background of the thesis, the problem formulation as well as the aim of the study and the research questions to be answered throughout this thesis. Lastly, the scope of the project will be presented.

1.1. Background

Due to globalization and new technologies, today's industries must modernize their production processes to meet customer demands and to compete on the market. Flexibility, quality, and delivery precision has gone from being order winners to order qualifiers in the emerging global competition (Dombrowski, et al., 2016). One of the challenges small and medium-sized enterprises (SME) are facing is to increase their production volume to manage to remain as suppliers to the giant corporations on the market, in certain situations the increase in production volume must be twice compared of today’s production (Gammelgaard & Mathiasen, 2007). Drastically increasing production performance, in terms of increasing production output, decreasing quality deficiencies, and increasing delivery on time can render continuous improvements insufficient, therefore a major and radical change must be made focused on a specific area to achieve this goal. Further, many of the global corporations have regular visits and audits at their suppliers, therefore it is important that the subcontractors can demonstrate a production which is appealing to the corporations by displaying that the promised quality can be delivered (Smallwood, et al., 2014; Qi & Miller, 2011). To clearly instil the feeling of confidence in the customer or the auditor, workplace aesthetics must be considered in the workplace design, where workplace aesthetics mainly focuses on the physical appearance and the perceived feeling it induces. Not only does the appearance matter to the auditors but Berlin (2014) argues that consideration of workplace aesthetics may be important when attracting the younger generation to work within the industry. However, it is not only the workplace aesthetics that is important to retain the current workforce and attract the younger generation, ergonomics is important for the employee well-being and overall production performance (International Ergonomics Association, 2018). With the current situation of a need for the production performance, good ergonomic work situation for operators and a need to display it to both auditors and employees alike there is a need to link them all together to provide a production able of doing it all at once.

Workplace aesthetics is however limited by the demands set by the industry standard such as cleanliness in production and Electrostatic discharge (ESD) protection (Smallwood, et al., 2014). One of the easiest ways to mediate the feeling of confidence to the auditors is through observation where the strategic planning and workplace aesthetics plays a major part. However, to ensure that customer quality is met, standardized working methods must be implemented in this environment (Irani, 2011; Sprovieri, 2016). A case study was conducted at a company which produces data equipment with many different components, as a result, the final assembly line is a high-mix low-volume (HMLV) assembly line which complicates the use of a standardized working method between all different products and makes it challenging to implement traditional automated solutions (Bengtsson, 2017).

Currently, little empiric data exists on the link between workplace aesthetics and system performance (Schell, et al., 2012). In this thesis, the authors will try to find the link between workplace aesthetic and overall production performance as well as define the link which the authors will refer to as “Industrial Look and Feel”. Can a company with high demands on delivery precision and product quality provide a production with sufficient ergonomics and good workplace aesthetics?
1.2. Problem formulation

In a business characterized by the HMLV of products as well as the imperative need for quality of the products, it is of utmost importance to have a production line which enables quality, deliverability, and flexibility as well as being able to mediate it to auditors. Currently, it exists much research on the benefits of production performance related production rationalization, such as lean production, but empirical data regarding workplace design and its impact on overall production performance is scarce. Practitioners sometimes use the term industrial look and feel as a concept that includes both production performance and a good look of the line, but does not have a clear definition of what is included in the term. Practitioners’ use the term industrial look and feel loose since they want their production line to visually display what they are capable of but they often lack the understanding and knowledge to make it a reality.

1.3. Aim and Research questions

The aim of this thesis is to investigate if it is possible to define a concept, called “Industrial Look and Feel” which focuses on the synergy between the workplace aesthetics, ergonomics, and overall production performance. Further, it will be to investigate how a production line can be designed with the consideration of “Industrial Look and Feel”.

- How can Industrial Look and Feel be defined?
- How does Industrial Look and Feel contribute to increased performance of a production line?
- What is important to consider when designing a production line considering industrial look and feel in an HMLV environment?

1.4. Project scope

The thesis will focus on defining the term of “Industrial Look and Feel” and to further investigate whether there exists a synergy between the aesthetics, the ergonomics, and the performance of a production line. A case study has been conducted at one company within the industry of industrial data communication technology. Further, the case study has been conducted only on the final assembly line of the production system seeing as it is a reasonable delimitation considering the time limitations of the project. Due to time limitations, the proposed theoretical solution will not be implemented physically and there will be no specific implementation plan provided.
2. RESEARCH METHOD

In this chapter the research method used when conducting the thesis will be explained as well as why different approaches and design were chosen. Furthermore, the literature review and primary data collection will be presented and what was the purpose of it. The overall research process will also be presented.

2.1. Research approach

There are three main research approaches, these are the inductive, deductive and abductive approaches to research (Bryman & Bell, 2015). The inductive approach sees to develop a theoretical explanation based on the data collected and the analysis made during a research project. The deductive approach sees to test a theory where the researcher beforehand has a clear theoretical standpoint with the goal of testing the theory. The abductive approach has risen to prominence lately as it functions as a combination of the deductive and inductive research approach where the researcher seeks to explore a phenomenon and identify patterns with the goal of developing a new theory which is then tested during the same research period. The main benefit of the abductive approach is the ability for the researchers to keep an open mind towards their research and allow data to surprise them rather than just using the data to confirm a hypothesis based on preunderstandings (Bryman & Bell, 2015).

Based on the aim of the study which is to define a previously undefined concept and investigate whether or not it contributes to the overall production performance and investigate how a production line could be designed considering both the industrial look and feel as well as optimal production performance the suitable research approach was an inductive approach. Further, an abductive approach was considered due to its benefits from the other two approaches, however, since no testing of a hypothesis was made the abductive approach was discarded.

2.2. Research design

With designing the research, the approaches possible is the quantitative, qualitative and mixed-model which is a mixture of the quantitative and qualitative approach, utilizing parts of both (Creswell & Creswell, 2018). The quantitative research design is associated with the collection of quantitative data and also quantification of data in the analysis (Bryman & Bell, 2015; Saunders, et al., 2016). It is usually associated with a deductive approach which focuses on using data to tests theories and defining the relationship between theory and research (Bryman & Bell, 2015). However, a quantitative research design could also be used with an inductive approach when developing theory using quantified data (Saunders, et al., 2016; Bryman & Bell, 2015). Qualitative research is mostly associated with an inductive research approach and an interpretive philosophy where the authors have to interpret subjective meanings and socially constructed meanings about the studied phenomenon. Emphasis is often placed on the generation of new theory. The final stages of qualitative research often require a lot of attention as it is in the analysis the connections between research and theory are made (Bryman & Bell, 2015).

Case Studies are an often-used qualitative research design used with the intent of exploring a special situation or event in order to further construct theory through the collection of data. A qualitative research design requires a lot of effort during its last stages, especially the analysis and consequently the conclusion. This is due to the synthesizing of new theories on the base of finding patterns and making sense of them (Bryman & Bell, 2015).

The qualitative research design was chosen due to the need of interpreting people’s social situation and non-quantifiable values in order to achieve the purpose of the thesis. Further, a case study was chosen due to the ability to study a limited environment closely and obtain
information. A case study also makes it possible to use several qualitative methods which ensures the authors doesn’t rely too much on one single approach (Bryman & Bell, 2015). A case study is also applicable when the main research questions are formulated as “Why” or “How” (Yin, 2013). Further, the descriptive information alone received during a case study can be of importance as the data collected has previously been inaccessible, thus rendering the pure data collection valuable for future research (Yin, 2013).

2.3. Research Process

The research process started with a literature review based on keywords related to assembly, lean, ergonomics, and aesthetics. The authors began to conduct observations at the case company to gather primary data for the research, this was an ongoing process throughout the thesis. The overall process was characterized by iteratively revisiting process steps as a linear approach was not adequate due to new information being discovered and opening up new possibilities. As a result, the literature review was conducted during the entirety of the thesis due to the newly discovered information. After initial literature review and observations were conducted a concept of the workplace design was initiated. Throughout the course of the thesis, the concept was developed and modified with the help of SolidWorks to model the workbenches and Visual Components 4.0 to implement the models in a 3D environment. The 3D environment was a model of the current production line which the authors could experiment and visualise how a concept would look in reality.

2.4. Literature review

A literature has been conducted to gain knowledge of what has been done previously within our area of research. According to Saunders et al. (2016), a literature review should be a description as well as a critical analysis of previous research and findings within your chosen topic and should, therefore, be closely linked to the research questions. The authors used Mälardalen University (MDH) library as the primary search engine for knowledge because it was linked to a large extent of existing databases relevant to our research and its ability to search for books available at the MDH library. When searching for literature the following keywords were primarily used: workplace aesthetics, production ergonomics, high mix low volume, and ESD. Books were used primarily to give an overview of topics and where established ideas were to be referred to. As a rule of thumb no articles older than 2010 were included. However, within areas that have seen little to no new additions over the last years articles older than 2010 could be included. Saunders et al. (2016) state the importance of being able to explain how the selection of articles have been conducted as well as the search for articles. In Table 1 a complete description of the search words and number of hits are displayed as well as the number of articles chosen to be included in the literature review. Whilst the literature review is an activity started at the early stages of the project it is ongoing and continuous throughout the entirety of the project as new knowledge is gained and new search terms are generated (Saunders, et al., 2016).
<table>
<thead>
<tr>
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<th>Search Constraints</th>
<th>Search Engine</th>
<th>Hits</th>
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<tr>
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<td>5</td>
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<tr>
<td>&quot;High mix&quot; AND &quot;Low volume&quot; AND &quot;assembly line&quot; AND &quot;design&quot;</td>
<td>None</td>
<td>Mdh Library</td>
<td>36</td>
<td>6</td>
</tr>
<tr>
<td>&quot;ESD&quot; AND &quot;Manufacturing&quot;</td>
<td>None</td>
<td>Mdh Library</td>
<td>50</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 1 Article search results

2.5. Data Collection

Data collection has consisted of collecting primary data through interviews and observations conducted at the case study company.

Observations

The observations conducted during the study have been of both structured and unstructured character. Unstructured observations are useful when the question is concerned with what. Structured observations were used to measure the frequency of certain phenomenon.

Mainly the authors used participant observations, more specifically observer-as-participant observations, which are useful especially when conducting qualitative research (Saunders, et al., 2016). The key characteristics of observer-as-participant observations are that the observer makes the operator aware of the purpose of the observation and that the observer solely observes the actions without actually taking part in the tasks. The benefits of this approach to observations are the ability to focus all the attention on taking notes and being able to ask the operator that is being studied questions to clarify situations (Saunders, et al., 2016). The drawbacks are implied in the fact that you are not actually doing the work and hence never really get to really experience it. In Table 2 the reasons for observations, the number of observations conducted and description of the data collected during the observation is described.
Observation of current state 3

Initial observations were made to get an understanding of the current state of operations at the company and to get an understanding of the processes and what was needed in every step of the production to understand what equipment was needed at each workstation.

Workstation observation 8

Observations of each of the workstations were made with the goal to find potential flaws in the current workstation design from a perspective of the look and feel of the workstation with RQ1 in mind.

Observation of material flow 4

The material flow in the final assembly was studied to further create an understanding of the production line and what possible improvements could be identified.

Observation of workplace aesthetics 4

Studies were conducted to examine the working conditions and the work procedure of the operators to see how they worked and how the workplace design contributed to their working conditions.

Table 2 Conducted observations

Issues concerning the participation-observation may occur when there is not enough knowledge regarding the system to observe or the system is over-familiar. With regard to this issue the authors, who had no previous experience from the company or its production, made sure to have a thorough walkthrough of the production the author were to observe before conducting the observations.

Another issue concerning the participant-observations is the “observer effect”. This may lead to variations in performance from the operator being studied. The authors took the approach of habitation to reduce the chance of the observer effect affecting the observations.

Interviews

Semi-structured, as well as unstructured interviews, have been conducted with personnel at the case study company and others, these are presented in Table 3.

The purpose of the semi-structured interviews was primarily to get empirical data on what was important in a production environment, in this case, the production environment is defined as the assembly line on the shop floor, as well as their view upon the synergy between the production performance and the design and aesthetics of workstations. The participants in the interviews were directly working with the studied production line although at different levels within the company. The semi-structured interview was chosen since that approach is suitable for qualitative studies and gather the thoughts and knowledge of the interviewed. The interviews were recorded because it gave the authors the chance to re-listen to the interviews to search for themes and revisit answers, Saunders et al. (2016) suggested that recording semi-structured interviews could because it allows the authors to re-listen to the interview to make sure what they heard was right. During the thesis, many unstructured interviews in the form of meetings were conducted with employees who possessed knowledge related to the case study and with suppliers related to the new workplace designs.
Semi-structured interviews with production management 4 Gather opinions from the production management related to production performance, ergonomics, and workplace aesthetics. The participants were also asked what was important to display within their assembly line to auditors as well as what they are looking for when visiting a supplier.

Interview with workbench suppliers 2 Gather knowledge about important aspects of workplace design considering production performance, ergonomics, and workplace aesthetics.

Unstructured interviews with operators 10 Getting a deeper understanding of how the operators work and interact with the workstations and how they perceive their working environment.

Unstructured interviews with production management 7 Further develop an understanding of the manufacturing process, material flow, production volumes, product demand and reasons behind quality issues.

Table 3 Conducted interviews

2.6 Data Analysis

To analyse the data gathered during the thesis the empirical data collected was organized and the semi structured interviews were recorded for the purpose of being able to re-listen to them. The authors then grouped the answers provided into main themes. After the interviews, the notes were compiled to see what the answers from the interviews had provided and see the gaps where more empirical data was needed.

The organized empirical data was then used in pair with the findings in the literature to firstly being able to argue for what to be included into the concept to be defined by the authors. The literature was further used in relation to the empirical data to argue for the importance and possibility of co-existence of the themes included in the concept. Furthermore, the literature was used to argue for or against the ability of the concept to help in improving production performance.

Due to the qualitative nature of the study discussion and reflections of the empirical data has been vital during the process of the thesis. The authors have discussed the findings to a gain consensus which have proven to be an important part of the data analysis.

2.7 Validity and Reliability

Because of the nature of the research being qualitative, the validity and reliability are hard to define (Bryman & Bell, 2015). The external reliability of the study, namely the ability to replicate the study is complicated due to inability to replicate the exact starting conditions and social settings. Although, the observations and interviews are possible to replicate in any setting yielding similar results. The internal reliability was secured through the fact that the authors conducted the interviews and observation together and further secured due to the authors agreeing upon the outcome and result of the interviews and observations conducted (Saunders, et al., 2016).

External validity which refers to the ability of the research findings to be generalized across multiple settings this is hard to adapt to the case study design (Bryman & Bell, 2015). However, Bryman and Bell (2015) presented transferability as a more fitting approach for qualitative studies than external validity. To ensure a good transferability a thorough description of the data
collection at the case study company was made. Making it possible for readers to assess the possible transferability of the findings into other settings.

Internal validity marks the connection between the observations and theoretical ideas developed by the authors (Bryman & Bell, 2015). The plentiful observations ensured the authors to have a thorough understanding and thus making sure in the synthesizing of the new theoretical ideas that the observation results were a strong connection between the two.
3. THEORETIC FRAMEWORK

In this chapter, the theoretical framework of the thesis will be presented.

3.1. High-Mix Low-Volume (HMLV)

The case study company has an HMLV production, causing the theory of challenges and solutions related to this production paradigm to be relevant when considering how to design a production line for the best possible performance whilst also including the industrial look and feel.

The defining characteristics of an HMLV production are a wide variety of products being produced in low quantities. Normally, there are many different products produced on a daily basis and the batches are relatively small.

HMLV production is associated with many challenges that are quite different from challenges faced in traditional production, which mainly consisted of a low mix and high-volume type of production (Irani, 2011). A high mix of products increases the chances of inefficiencies and production errors, especially when managing changeovers and trying to maintain production consistency (Sprovieri, 2016). Furthermore, Irani (2011) argues that the high mix of products causes a variability in set up times as well as cycle times, making it harder for production planning. Bohnen et al. (2011) agree with Irani (2011) in that an extensive variety of products may cause difficulty to plan and organize production in a satisfactory way. Sprovieri (2016) adds that an overcrowded work floor could be the result of poor planning and disorganization in an HMLV production. The product variety and fast response time needed to be an order winner are also associated with larger costs related to the material handling and the set up needed to produce the different products (Sprovieri, 2005). Additionally, the equipment needed to facilitate HMLV production has largely ruled out the traditional hard automation as a production option, seeing as this type of automation is suitable for a low-mix and high-volume production due to the dedication of the automation and the large effort needed to re-program it (Bengtsson, 2017). The focus of the managers and industrial engineers working in HMLV production may also be prohibiting success if they are focused more on the differences of the products rather than the similarities (Weber, 2016).

Whilst an HMLV poses a lot of challenges there are ways to succeed when dealing with HMLV production. Having many different products causes difficulties in planning the production. However, the use of group technology (GT) has proven beneficial in HMLV production (Irani, 2011; Bohnen, et al., 2011; Weber, 2016). GT means grouping together products into families, making it fewer families to deal with rather than all the products individually (Weber, 2016). The families should be created based on the similarities in the production- or assembly process and the similarities in material requirement (Bohnen, et al., 2011). Irani (2011) and Bohnen et al. (2011) both stresses the need for group technology in HMLV to ease the production planning process. Weber (2016) announces the importance of focusing on the similarities of products in order to successfully implement group technology.

Furthermore, standardized work is imperative to ensure the consistency of quality in production despite having a larger number of products (Irani, 2011; Sprovieri, 2016; Sprovieri, 2005; Weber, 2016). Standardized work is viewed as one of the most important lean principles to be applied in the HMLV production (Irani, 2011; Weber, 2016; Sprovieri, 2016; Shook, 2007). Also, the principles of mistake proofing, or poka-yoke, is important in order to reduce the number of faults in the production (Irani, 2011; Sprovieri, 2016).

When dealing with a lot of products it becomes of utmost importance to have short set-up times between work in order to deliver on time (Irani, 2011; Sprovieri, 2016; Weber, 2016). Utilizing quick changeovers means there is a need for flexible production equipment that allows
for quick changeovers (Sprovieri, 2016). Overall when dealing with HMLV production there is a need for flexibility in equipment (Bengtsson, 2017). Quick changeovers are not only limited to the production equipment but also includes the pace at which the materials needed for the production or assembly can be changed (Weber, 2016).

Further, the organization of the workplace is imperative for handling an HMLV. If improperly organized it causes for a chaotic environment without the process control needed to ensure product quality and delivery time (Sprovieri, 2016; Weber, 2016).

Lastly, information and work instructions are pinpointed as a crucial part of companies succeeding in HMLV (Weber, 2016). Weber argues that a large number of different products requires the work instructions to be thoroughly informative and useful seeing as there is a large mix of products which will be very hard just keeping track of through memory alone.

Shook (2007) states that to excel in HMLV and to choose where to focus your attention when working with such a wide variety of products the focus should be on the products with reoccurring orders and a relatively high volume. Through streamlining these processes and reducing the time needed to produce these articles it will give more time to the set-up and other actions associated with the low volume articles.

3.2 Lean Production

Lean production is one of the most prominent production rationalization methodologies and companies worldwide are trying to adopt Lean principles with the objective of making their production more efficient. With the aim of the thesis to investigate how to design a production line with regard to industrial look and feel it is of importance to have a review on relevant parts of Lean production, which is closely linked to production performance.

Lean production has its roots in Japan and heirs from the Toyota Production System (TPS). The primary objective of Lean production is to reduce non-value adding actions, often referred to as “waste”, in order to become the more effective (Liker, 2004). Further, Modig & Åhlström (2016) states that the focus of Lean is to achieve a high flow efficiency. As highlighted by Raghavan, et al. (2014) a clear and linear material flow is important to achieve lean production due to non-linear flows tends to add non-value-added time which contradicts the lean fundamentals.

A common mistake regarding Lean is to believe that it equates TPS, the case is rather that TPS is Toyotas way of achieving a Lean production (Modig & Åhlström, 2016). Further, Lean should be treated as a company philosophy that must be deeply rooted in the organization to achieve its true potential (Liker, 2004). All the tools and techniques associated with Lean are useful but using a Lean tool does not make an organization Lean (Liker, 2004).

If Lean production principles are adapted and used in the right way they can have a positive impact on the organization such as increased profitability and an improved competitive position on the market through a good production. However, a lot of the organizations trying to implement Lean does not reach the desired results most likely due to a lack of understanding of what Lean truly is (Shook, 2007).

To provide a clear and visual picture that displays quality in an assembly line to the auditors, organization, and cleanliness of the workplace is important, in lean this is the concept of 5S which consists of the five parts: sort, straighten, shine, standardize and sustain. The heart of the 5S concept is to organize a workplace and keeping it organized (Shook, 2007). An organized workplace offers a disciplined and clean work environment (Chapman, 2005). This is done primarily to reduce time spent looking for the right tool and the right material which is regarded as waste as it does not actually add value to the product (Shook, 2007). A thoroughly organized workplace has the possibility of reducing defects, furthermore, in an unorganized environment, it is hard to assess the status of the operations (Chapman, 2005). It is common for
organizations to only embrace the first three S’s, which will yield immediate results but in a longer perspective, the 5S effort will fail since it will not be maintained and a part of the organization (Chapman, 2005).

**Sort** – Remove all none essential materials and tools from the workbench until there are only the truly necessary items left.

**Straighten** – Organize the materials and tools that are to remain at the workstation so they have given places to minimize the time for looking.

**Shine** – Daily cleaning of the workstation. It is determining what is to be cleaned, how and by who.

**Standardize** – It is maintaining an organized workplace. This is an ongoing step.

**Sustain** – Taking steps towards developing deep roots for 5S within the organization. Making 5S part of the job.

Further, the principle of standardized work is an important base for continuous improvements especially regarding the manpower (Shook, 2007). Standardized work is the current best way of producing a product with the best quality and should be the way every operator is conducting his or her work tasks. Whilst standardized work may appear as rigid it is actually changeable, as improvements are made and prove to be making the process more efficient it is incorporated into the standardized work (Shook, 2007).

### 3.3 Production Layout

Several different types of production layouts were researched to develop an understanding which is most applicable to an HMLV environment and could be used when designing a concept for a new assembly line.

Production layout refers to the physical arranging of the production resources in order to efficiently manufacture or assemble the products produced by the company (Krajewski, 2016). There are four different types of basic production layouts, where three of them are plausible alternatives for manufacturing within the given size of the products (Jonsson & Mattsson, 2016). The different layouts are listed below.

**Functional layout**

The production resources are organized according to the function of the equipment. It is suitable when there is a large variety of products due to its flexibility and ease of adaption to new products and quick changes. However, the functional layout causes the material flow to become very complex and the internal transports of material will become plentiful. Further, it may become a hard-to-understand flow because of the irregular movement of materials (Jonsson & Mattsson, 2016).

**Line layout**

The production is organized with respect to the products and the processes are arranged in the order they are performed. It is a flow-oriented layout with short throughput times and often beneficial by not binding capital. Although it is sensitive to disturbances and is less flexible than
the functional layout (Jonsson & Mattsson, 2016). Line flows are normally recommended when designing lean layouts due to its inherent ease of removing none value adding time. It can be used even when the product mix is seemingly high through the utilization of GT (Krajewski, 2016). Therefore, it can be beneficial to apply GT in an HMLV environment to be able to use the line layout and thus creating a clear and straight material flow which is beneficial when designing for a Lean production (Raghavan, et al., 2014).

**Cell layout**

Cell layout is making use of the ease of material handling like the line layout whilst also retaining some of the flexibility associated with the functional layout. The layout setup is useful when there is low volume as well as higher volume. But, it is troublesome to utilize the capacity in all cells since most of the cells will be idle during production (Jonsson & Mattsson, 2016).

### 3.4 Workplace Aesthetics

With an aging industrial workforce, companies face a new challenge to retain their current workforce while making it attractive to the younger generation (Berlin, 2014). Considerable amounts of empirical data exist on ergonomics in a healthy workplace environment which prevents physical fatigue and work-related injuries. Further, metrics to measure the amount of stress at workplaces have been used in the industry, although this has not decreased the number of people on sick leave due to stress, with mental disorders such as burnout, depression, and anxiety potentially being occupational diseases (Westgaard & Winkel, 2011). Lowe et al. (2003) and Schell et al. (2012) states that a healthy work environment is based on the employees’ perception of the workplace and thus people being the psychosocial and cognitive factors needs to be accounted for. With aesthetics originating from the Greek word “Aisthanomai” which can be translated to "I perceive, feel, sense" (Harper, 2018), workplace aesthetics is important to promote employee well-being and job satisfaction. However, Schell et al. (2012) stress that little data exist on the prevention of psychological fatigue caused by the workplace aesthetics.

Large organizational changes or changes in the production facilities can have a negative impact on the employees’ health, especially since when such a change is made the company tends to focus on their key performance indexes or earnings (Lowe, et al., 2003). Further, these negative impacts on employee health can be increased stress and more psychological demanding tasks due to learning new processes. Schell et al. (2012) state that a correlation between stress and the perceived need for aesthetic improvements exists, thus agreeing with Lowe et al. (2003) that workplace aesthetics should be incorporated in the health management plans within a company since it may be beneficial to employee health. Schell et al. (2012) stress that it will have a greater importance in the future due younger persons had a higher sensitivity to the need for workplace aesthetics.

Another important aspect of workplace aesthetics is to visually help customers and especially auditors to understand the manufacturing processes (Smallwood, et al., 2014). Many major corporations perform supplier audits in the supplier qualification process to validate if the supplier is able to deliver according to their demands (Pfeiffer, 2017). Further, Qi & Miller (2011) states that during audits it is important for the supplier to mediate their values in quality and lean to the auditors and as Schell et al. (2012) mentions psychological fatigue can be an issue with poor workplace design and thus employee well-being can mediate wrong types of signals. Pfeiffer (2017) stresses that to ensure maximum value from the audit both the supplier and the auditor needs to be well prepared before the visit to the supplier. This also includes preparing the employees in the sense of informing them that an audit is to take place, otherwise increased stress levels among the workers can affect their health which may result in negative effects during an
audit. (Schell, et al., 2012). Workplace aesthetics is a major part of the concept of an industrial look and feel but it does not take pure production performance into account thus only focusing on the employee well-being.

### 3.5 Electrostatic discharge protected area (EPA)

Since the case study company handles sensitive electric components it had to be considered when developing a concept for a new line to ensure that overall quality was kept to the required standard. Many electronic components placed on printed circuit boards (PCB) are vulnerable to ESD and with decreasing component size in electronics, the susceptibility of ESD damage is increasing (Paasi, 2005). Smallwood et al. (2014) state that the most common cause of ESD on a component is caused by contact between an operator or a tool and the component. To minimize the risk of ESD damage on components manufacturers must use ESD protected areas (EPA) to secure the quality of their products since without the use of EPA the overall quality of the production will be questionable, and costs will increase due to product failures, delays in production, failure analysis and other quality related issues (Smallwood, et al., 2014).

With an increased focus on product quality, international standards for EPAs have been developed which require companies to document their ESD protection measures and with this several companies focused on ESD protection equipment has emerged (Smallwood, et al., 2014), this also helps in reducing one of the major sources of failure in electronic device manufacturing which is caused by ESD (Paasi, 2005).

The leading EPA distributors mainly focus on highly standardized solutions which can be used by any company in need of an EPA. These standardized solutions may have a higher price tag than specialized and specifically tailored solutions due to the need for it everywhere and not being specialized for the specific tasks performed at the workstation. However, the simpler and standardized ESD control solutions are easier understood by personnel which can reduce training costs over time along with providing a clear picture for visiting auditors (Smallwood, et al., 2014).

### 3.6 Ergonomics

The ergonomics is of importance since it is closely related to the production performance, especially in a manual assembly setting where people are carrying out the assembly processes manually. Ergonomics also have a severe impact on the workstation design and how it should look in order to facilitate operators with different physical attributes and allowing them to safely and efficiently perform their task, thus having an impact on how the industrial look and feel should be manifested.

Ergonomics, or human factors as it is more commonly referred to in North America, derives from the Latin phrases “ergo” and “nomos” which translates into “the science of work” (Berlin & Adams, 2017). Ergonomics is a broad term and commonly misunderstood. In general, any task that involves human activity can be viewed from an ergonomic perspective and falls under the description (Berlin & Adams, 2017). The International Ergonomics Association (IEA) defines ergonomics as the following:

“Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance.”
Practitioners of ergonomics and ergonomists contribute to the design and evaluation of tasks, jobs, products, environments, and systems in order to make them compatible with the needs, abilities, and limitations of people.

Ergonomics helps harmonize things that interact with people in terms of people’s needs, abilities, and limitations.”  
(International Ergonomics Association, 2018)

The definition provided by IEA declares the importance of ergonomics from both a perspective of the worker's well-being and organizations competitive goals such as the overall production system performance (Dul & Neumann, 2009; Berlin & Adams, 2017). Dul & Neumann (2009) continue to claim that ergonomics helps in allocating tasks to either humans or machines to meet company goals while avoiding adverse effects on the human operator. In the assembling industry, the main purpose of ergonomics is to design the workplace as to proactively remove the risks of injury, pain, discomfort, demotivation, and confusion to ensure the operator's safety and the productivity of the production. Safety initiatives concerning the ergonomics have shown to increase such things as productivity, quality as well as reducing the cost of production (Falck & Rosenqvist, 2014). Further, poor assembly ergonomics have shown to affect the failure rate of performing a specific work task (Falck, et al., 2014). However, if presenting ergonomics from a sole health and well-being perspective the motivation for the managers might be negative. It is of great importance to be able to show the managers how ergonomics can contribute to the company strategy and hence getting the ergonomics embedded into the organization to help realize business goals (Dul & Neumann, 2009). Despite evidence that suggests the positive effects of considering ergonomics in early stages of the production design, the lack of such efforts is often explained by lack of knowledge at the companies (Falck & Rosenqvist, 2014).

Companies are generally most concerned with achieving the company goals and hence rationalizing the production. However, the rationalization of production may result in a reduction of the ergonomics (Winkel, et al., 2017). This is referred to as “the ergonomic pitfall” by Winkel, et al. (2017). To avoid such things there is a need for the concurrent consideration of ergonomics in production as well as the operator well-being. Having a proper dialogue when developing the production between ergonomics experts and production engineers is vital for organizational sustainability (Winkel, et al., 2017).

Ergonomics have been divided into two major fields, physical ergonomics, and cognitive ergonomics which will be presented in the sections below.

3.6.1 Physical Ergonomics

Physical ergonomics is defined by Arbetsmiljöverket as “The part of the larger concept of ergonomics that is concerned with how physical loading in work affects the musculoskeletal system” (Arbetsmiljöverket, 2018). The physical load that the operator is exposed to during work can be viewed as a combination of three factors: posture, force and time (Berlin & Adams, 2017).
Posture means the way the body is aligned, and good posture is signified by balance and symmetrical distribution of force (Berlin & Adams, 2017). Further, a suitably designed workplace have the design traits allowing for a majority of the work being performed in an upright position, with lowered shoulders and the upper arms close to the body (Arbetsmiljöverket, 2018). A very important factor to consider when considering good posture is the appropriate work height. Appropriate work height is displayed in Figure 1 which is adapted from Arbetsmiljöverket (2018).

Furthermore, when conducting work tasks in the horizontal plane a majority of tasks performed should be within close proximity to the body and only occasionally reach to the outer zone. The horizontal work zones are displayed in Figure 2.
When performing work tasks, it is important that the physical loading of the task, or force, is suitable for the operators’ body tissues. Further, the importance of sufficient rest between performing tasks must be stressed as insufficient rest can lead to operators injuring themselves (Berlin & Adams, 2017; Arbetsmiljöverket, 2018). Tasks performed with little to no rest in between is normally referred to as monotonous work, also stating that the task to be performed is always the same. Monotonous work is primarily risky due to the lack of rest between tasks, not the force exerted when performing the said task (Berlin & Adams, 2017).

Further, the interaction between the three factors can either increase or decrease the risk of musculoskeletal damage (Berlin & Adams, 2017). For an example, heavy lifts, which are normally considered dangerous from an injury perspective can be safely performed if done with a proper posture and a given enough time to recover between the lifts. At the same time, light force tasks can become harmful if performed in a repetitive manner and with a bad working posture (Berlin & Adams, 2017). However, the most harmful part of repetitive work is considered to be the lack of recovery if the task is to be performed over and over again with only short to no rest in between (Berlin & Adams, 2017). Arbetsmiljöverket (2018) suggest proactive actions can be taken to reduce the risk of harmful repetitive work. Such proactive actions are job rotation, expanding the work and breaks for recovery.

### 3.6.2 Cognitive Ergonomics

Cognitive ergonomics are concerned with the human mind and senses, more specifically about its capabilities and limitations in work-related situations (Berlin & Adams, 2017). Within a manual assembly, an operator is continuously exposed to cognitive demands such as; handling information from e.g. instructions, a high variety of component flora, system complexity and the layout of the workstation. Whilst these factors independently, and in a stress-free environment, would be manageable that is rarely the case. With today’s high demand for both quality and delivery, there is almost certain to be pressure in terms of time and the need to do things correctly. Both which add to the mental workload of the operator (Brolin, et al., 2017). Further, studies have shown that increased product variation in the assembly has a negative effect on the cognitive performance as well as the overall performance of the production (Brolin, et al., 2017). However, things can be done to ease the mental workload of operators to gain in terms of both productivity and quality (Berlin & Adams, 2017). The use of instructions and communication within the work area can be of great help when performing manual assembly operations. The majority of signals used to communicate within a production environment are a combination of visual, auditory and tactile cues (Berlin & Adams, 2017). With vision being the dominant sense, it is especially useful for displaying instructions on how to assemble the product and what materials to use. It is also important to provide proper lighting when operators are performing assembling task in order for the operator to properly see what he is doing. Lack of light may cause tensions in neck and shoulders as the operator tries to focus (Arbetsmiljöverket). A sound is more often used to signal a change in the process such as warning for danger or confirming right actions.

Furthermore, the attention, as well as the perception of the operator, are of importance. The attention functions best when the operator gets to perform work with frequent intervals. Too low frequency and the operator may enter a state of boredom which may lead to quality deficiencies slipping by. Perception is the ability to take in and associate information with meaning and to mentally organize actions to reach the desired state. Whilst perception can be of great use it can also be the cause of confusion if the associating and expected outcome may not match reality (Berlin & Adams, 2017).

Table 4 shows the 13 design principles for cognitive ergonomics suggested by Boghard (2009).
### Support attention

<table>
<thead>
<tr>
<th>Minimizing time and effort for finding information</th>
<th>Regularly used information must be easy to find and access. Motivation decreases when information search becomes a time-consuming task.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximity/closeness</td>
<td>Related information should be linked and uniform.</td>
</tr>
<tr>
<td>Engage multiple senses</td>
<td>When the operators are exposed to a large amount of information it is beneficial to engage multiple senses.</td>
</tr>
</tbody>
</table>

### Supporting perception

<table>
<thead>
<tr>
<th>Legible displays</th>
<th>Make sure the text is possible to read. This can be done through contrast or strength of the light.</th>
</tr>
</thead>
<tbody>
<tr>
<td>The appropriate number of information levels</td>
<td>Have enough levels of detailed levels of information. Three levels of information are generally the rule.</td>
</tr>
<tr>
<td>Avoid only knowledge-based data</td>
<td>Make sure unexpected signals are distinguishable.</td>
</tr>
<tr>
<td>Redundancy</td>
<td>Reinforcement of signals through using multiple senses or several modalities.</td>
</tr>
<tr>
<td>Avoid similar objects</td>
<td>Make sure not to use objects with similar looks that have different functions. It will give the opportunity for quality deficiencies.</td>
</tr>
</tbody>
</table>

### Supporting memory

<table>
<thead>
<tr>
<th>Minimize the amount of short-term memory data</th>
<th>As far as possible free the short-term memory from loading.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Show anticipated system status</td>
<td>Removes the mental load of trying to calculate what will happen next. This also supports proactive actions.</td>
</tr>
<tr>
<td>Consistent representation</td>
<td>When using new designs, they should correspond to the learned rules of operators and interpretations.</td>
</tr>
</tbody>
</table>

### Supporting mental-models

<table>
<thead>
<tr>
<th>Illustrated realism</th>
<th>Use visual cues that correspond to reality when designing information.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Show movable objects for dynamic information</td>
<td>Use dynamic representation when indicating status changes.</td>
</tr>
</tbody>
</table>

Table 4 Design Principles by Boghard
4. RESULT (Empirics)

This chapter will present the data gathered during the course of the thesis, it will start with a short introduction of the company followed by an overview of the current state in the factory and in the latter part the interviews will be presented and summarized.

4.1. Case company description

The case study was conducted at Westermo Teleindustri AB which classifies as an SME according to standards set by the European Union. Westermo manufactures and designs robust data communication devices used in rough and demanding environments and thus state of the art product quality is a must. Westermo has several global corporations as customers such as ABB, Alstom, Bombardier, and Toshiba, among others with the need for Westermo products in the heavy-duty mining industry, energy production, and railways process industries (Westermo, 2018).

Westermo has sales offices and technical support offices in the United States of America, China, Singapore and several countries in Europe. Ever since Westermo was founded in 1975 all product development and production has been conducted in the plant located in Stora Sundby, Sweden. Beijer Electronics Group AB acquired Westermo in 2008 which led to increased investments into the production development and product development which has made Westermo into a strong and well-known name within the market for data communication, a market that is currently expanding more rapidly than predicted (Westermo, 2018).

The demand for the products produced in the studied line is rapidly growing and there is a pressing need to expand the workforce. Hence a lot of inexperienced operators need to be able to work in the studied line.

4.2. Current State

The current state of the assembly is described in this section containing the product description, production layout, material flow, assembly process, and workplace design. All data gathered below has been collected via regular observation at the production line. All the observations have been made on the RedFox assembly line since it is outdated and in desperate need for improvements, therefore, it made a suitable candidate for the case study and it was also suggested by the case study company.

4.1.1 Product description

The different models assembled in the RedFox assembly are numerous, however, they can be divided into five major product families. Even though the name suggests that only members of the RedFox family are being assembled in the RedFox assembly line other product families are assembled here as well since this is the last process step before becoming a finished product the authors will refer to this as the final assembly in some cases. Each product family contains a larger set of different sub-models however these sub-models are often separated by only minor differences. For example, each of the product families makes use of the same set of torque screwdrivers as well as similar material requirements for the assembly process. A typical variant for each product family is displayed in Figure 3
The yearly order quantities assembled in the RedFox line are displayed in Table 5 from the past 12 months, the studied company divides the orders in the line as Viper and non-Vipers. The non-Vipers consists of RedFox Rail (RFR), RedFox Industrial (RFI), Wolverine and RedFox Industrial Rack (RFIR).

<table>
<thead>
<tr>
<th>Product family</th>
<th>Order quantity/ year</th>
<th>Average order quantity/ month</th>
<th>Percentage of total order quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viper</td>
<td>19343</td>
<td>1612</td>
<td>78</td>
</tr>
<tr>
<td>Other</td>
<td>5478</td>
<td>457</td>
<td>22</td>
</tr>
</tbody>
</table>

Table 5 Order quantity

As displayed in Table 5 the product family Viper accounts for 78 % of the total order quantity with the rest of the product families’ together accounting for 22 % of the total order quantity.

An unexpected increase in demand for the company’s products, with respect to products of all product families, has increased the demand on the final assembly. This has been disruptive to the expected demand and put a strain on the production as it was not prepared for an increase in demand at this magnitude. There has been an extraordinary increase in demand for products in the Viper family since it has already reached the demands projected for 2020 and is increasing with each week. Newly formed forecasts predict a further increase in demand of all products, and product family Viper is forecasted to have the largest increase of all the products which means that the percentage presented in Table 5 will further skew towards more Vipers being produced in the production line. Shown in Table 6 is the material requirements for final assembly of each product.
Table 6 Material requirements by product

<table>
<thead>
<tr>
<th>Product Family</th>
<th>Big Mechanics + PCB</th>
<th>Small Mechanics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viper</td>
<td>Front Housing</td>
<td>Screws</td>
</tr>
<tr>
<td></td>
<td>Back housing</td>
<td>Toothed washer</td>
</tr>
<tr>
<td></td>
<td>PCB cards</td>
<td>Distance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Washer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pads</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Isolation film</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Front foil</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Isolation plate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Feathers</td>
</tr>
<tr>
<td>RFR</td>
<td>Profile Housing</td>
<td>Screws</td>
</tr>
<tr>
<td></td>
<td>Front Housing</td>
<td>Isolation Pad</td>
</tr>
<tr>
<td></td>
<td>Back Housing</td>
<td>Feathers</td>
</tr>
<tr>
<td></td>
<td>PCB cards</td>
<td>Front foil</td>
</tr>
<tr>
<td>RFI</td>
<td>Profile Housing</td>
<td>Screws</td>
</tr>
<tr>
<td></td>
<td>Back Housing</td>
<td>DiN clip</td>
</tr>
<tr>
<td></td>
<td>PCB cards</td>
<td>Spring</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Front mechanics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Feathers</td>
</tr>
<tr>
<td>RFIR</td>
<td>Bottom housing</td>
<td>Screws</td>
</tr>
<tr>
<td></td>
<td>Top Lid</td>
<td>Feathers</td>
</tr>
<tr>
<td></td>
<td>PCB cards</td>
<td>Plastic details</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Isolation tape</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Toothed washer</td>
</tr>
<tr>
<td>Wolverine</td>
<td>Profile Housing</td>
<td>Screws</td>
</tr>
<tr>
<td></td>
<td>Front Housing</td>
<td>DiN clip</td>
</tr>
<tr>
<td></td>
<td>Back Housing</td>
<td>Spring</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Front foil</td>
</tr>
</tbody>
</table>

4.2.1 Layout

The current production layout is a cell layout based on the assembly of the product families, as described in the previous chapter the products are divided into five product families and each is assembled at its own dedicated workbench as shown in Figure 4, except for RFI and Wolverine which share workstation. At the current state, the workbenches are stationed close together, between 80 cm to 100 cm between the workbenches, marked by the yellow area in Figure 4. When the observation was conducted the operators struggled to fit in the same space when there was a need for more than two operators working at the same station simultaneously.
All products go through the functional testing and programming area before moving forward to the packaging area, which is not included in Figure 4, regardless of the product family. Storage shelves 1-3 contains PCBs and shelves 4-6 contains smaller mechanics such as screws, front foil, and miscellaneous item needed in the assembly process. There is also a storage area about 25 meters away which is not included in Figure 4. At the storage area not shown the figure, called the mechanic storage, the housing of the products are stored in pallets for all products. The overall storage is not optimized and is missing a strategic plan for the layout according to the operators and the production management department. One reason for the lack of a strategic plan according
to the operators is that more shelves have been added gradually when new products were introduced and when the volumes increased, contents of the shelves are presented in Table 7 below.

<table>
<thead>
<tr>
<th>Storage</th>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage 1</td>
<td>Dedicated to PCBs for the Viper family</td>
</tr>
<tr>
<td>Storage 2</td>
<td>PCBs for all products but mostly RedFox</td>
</tr>
<tr>
<td>Storage 3</td>
<td>PCBs for RedFox</td>
</tr>
<tr>
<td>Storage 4</td>
<td>Storage for screws, fronts and assorted components</td>
</tr>
<tr>
<td>Storage 5</td>
<td>Assorted components for many lines</td>
</tr>
<tr>
<td>Storage 6</td>
<td>Miscellaneous items</td>
</tr>
</tbody>
</table>

Table 7 Storage description

4.3.1 Material Flow

Each of the five product families has similar material flow, the main difference is the four separate benches used for each family. In Figure 5 the material flow for the Viper family will be presented and all products have similar material flow, the only difference is where the final assembly takes place. The initial part of the production referred to as “kitting”, is the same for all product families. At a glance the material flow in the production line is unclear and non-linear, the RedFox line manager experienced difficulties explaining the material flow to visitors and auditors due to the current layout.
Kitting: The first step of the final assembly is initiated by a production order that tells the operator which product and what quantity to assemble. The operator takes a cart and walks to the mechanic storage to gather the housing for the designated product. From there the operator walks to storage 4, as depicted in Figure 5, to gather the required front foil, screws and other smaller components needed in the assembly process. Lastly, the operators gather the required PCB’s from storage 1, 2 or 3 depending on the product being assembled.
As the assembly process proceeds there will at times be a shortage of material. When this happens, the operator assembling the products will walk to storage 4, see Figure 5, to gather more of the material required. However, current storage solution is disorganized and therefore operators do at times have difficulties finding the required materials.

When the product has been assembled at its designated workbench it is put on the conveyor to transport the products to the test/programming station. However, observations have shown that the conveyor is rarely moving and have become a storage between the assembly stations and the test/programming station rather than a way of continuous supply to the test/programming station. Many times during observation products other than the ones on the conveyor had to be tested and programmed first due to it being a more urgent order and thus a cart was used to bypass the conveyor, when this occurred carts was placed in the testing area and since the conveyor was full of newly assembled products was also placed on carts, further increasing the are needed for storage before the testing. During observations, authors noted this issue many times and found it to be a problem but according to operators and production planners, this was not something done regularly but more of a one-time occurrence.

![Figure 6 Assembly Process Viper](image)

4.4.1 Assembly process

In this chapter, the assembly process for each of the product families will be presented. The assembly processes have been investigated due to gaining knowledge over the process order and what equipment is needed for each step. This was done to see how to distribute the different processes more evenly across the workbenches to improve the overall utilization of the equipment. The assembly process for the Viper family is described in Figure 6.

The assembly process in figure Figure 6 depicts the possible assembly process where the front and the back are assembled parallel to each other, this is possible when there are two operators manning the Viper assembly process. Observation shows that one operator usually does both processes. In that case, the preparatory work for both front and back is done first. After that the pressing of the front foil and the assembly of the PCB’s in the back and front housing. Then the front and back housing will be assembled before moving on to the testing and programming. When the final assembly is manned by a single operator this operator will go back and forth between the assembly station and the test and programming station.
A color scheme was introduced based on which bench the operations are conducted at to provide a more detailed process overview dividing the processes to the different benches they are performed at presented in Table 8.

<table>
<thead>
<tr>
<th>Color</th>
<th>Work</th>
<th>Workbench</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>Preparatory work</td>
<td>Preparatory workbench</td>
</tr>
<tr>
<td>Yellow</td>
<td>Assembly operations</td>
<td>Family specific workbench</td>
</tr>
<tr>
<td>Blue</td>
<td>Front foil pressing</td>
<td>The press bench</td>
</tr>
<tr>
<td>Green</td>
<td>Functional testing and programming</td>
<td>The programming bench</td>
</tr>
</tbody>
</table>

Table 8 Color scheme for different processes

Currently, this process is performed at four different workstations with one being the functional testing area which is common between all products. The remaining processes are divided between the workstations according to the Figure 7.

As mentioned earlier space between operators is an issue when multiple operators are working on the same workstation, this becomes especially clear between the workstations marked in yellow and blue in the figure due to the operators are working the same confined space.
The assembly process for product family RFR is described in Figure 8. The assembly process starts with preparatory work of the PCB cards where springs, used to hold the card in place, are mounted on the cards before the cards are placed within the profile. Then the cooling paste is applied. All this work is done on the preparatory bench. The profile is then moved to the assembly station where cards are mounted in the front and back housing before the back housing and front housing are assembled with the profile.

The assembly process for product family RFI is described in Figure 9. The assembly process starts with preparatory work of the PCB cards where “feathers” are mounted on the cards before the cards are placed within the profile. Then the cooling paste is applied. All this work is done on the preparatory bench. The profile is then moved to the RFI assembly station.
A Din-clip is mounted on the back housing. Cards are mounted in the front and back housing before the back housing and front housing are assembled with the profile.

The assembly process for product family RFIR is displayed in Figure 10. Springs are mounted on the PCB cards, this is done at the preparatory workbench then it is moved to the RFIR workbench. At the assembly workbench plastic frames are then mounted in the housing. The cooling paste is then applied to the housing. PCB, back and power cards are mounted in the housing. The lid is mounted on the main housing and front foil is placed on the product before a grounding screw and washer is mounted.

The assembly process for product family Wolverine is displayed in Figure 11. Firstly an isolation pad is mounted inside the profile housing. Then the PCB cards are equipped with “feathers” and the cards are then mounted inside the profile housing. All of the previously mentioned assembly stages are performed at the preparatory bench. The product is then moved to the dedicated assembly workbench where a clip is mounted to the product and a backplane card is mounted in the back housing and the back housing is then assembled with the profile housing. Further, the front foil is mounted on the front housing and then it is mounted on to the profile housing. Lastly, everything is screwed together.
During the assembly process, handheld screwdrivers with a pre-calibrated torque are used when assembling the product. In Table 9 the pre-calibrated torque of the screwdrivers needed to assemble each product is displayed.

<table>
<thead>
<tr>
<th>Product</th>
<th>M1 Nm</th>
<th>M2 Nm</th>
<th>M3 Nm</th>
<th>M4 Nm</th>
<th>M5 Nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viper</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RFR</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>RFI</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RFIR</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Wolverine</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9 Torque needed among products

4.5.1 Workplace design

The current workstation design has not been significantly updated in several years due to an increasing volume of products and the prioritizing from the company of updating other parts of the total manufacturing process that has been in more urgent need of change. Hence, the RedFox line has resorted to quick fixes when problems were encountered, this has resulted in cluttered and disorganized workspaces with no motivation for the operators to keep it organized. Most of the workstations are motorized with the ability to adjust the height of the table and the standardized measurements of the workstations are 220 cm wide and 85 cm in depth. With the current placement of fixtures, screwdrivers, and containers the actual space for assembly is quite small, roughly 50 %, and the operators’ struggle to fit more than one operator at each bench at the time.

Some efforts to implement 5S has been made, for example marking up the designated space for tools and fixtures but many objects located at the benches when the observation was made did not belong or did not have a space designated for it, some objects were not used anymore but were still located on the bench. When new material such as screws was needed at the assembly station the operators brought the whole package of screws and often overfilled the containers for it, if the contents did not fit the packed remained at the workstation until the rest could be fitted in the container, this caused some problems with mismatched material in containers next to the overfilled ones and thus led to the usage of wrong screws in the products. Further, some of the containers used for the screws were broken and ill-fitted for housing the screws needed in the assembly.

From a physical ergonomic perspective, the workbenches are sufficient since they are motorized enabling the operator to adjust the work height to his or her preference and the tools are close to the assembly area on the bench which causes the operator to remain in a good posture when assembling the products. However, reaching for the materials needed in the assembly which are located in a box at the back-end of the workbench can be difficult if the operator is shorter than average. Furthermore, parts needed could also be placed on other workbenches to free space on the workbench where the assembly was conducted. During observations, no operator changed the height of the workstations, despite the obvious difference in the height of the operators. All benches are equipped with lights which are required to fulfill a cognitive ergonomics portion of the workstation, despite having lights at the assembly benches, which was always lit, it was too dark from an ergonomic standpoint. However, at the preparation benches state of the art lights are installed but was never used due to lack of knowledge of its existence or due to lack of perceived proximity from the operators. The overall color scheme of the workbenches is darker shades of grey and the mats used for relief when standing are black. The dark color scheme added to the feeling of insufficient lighting.
Since each of the workstations is designed for a specific product family there are some differences between them such as differing torque on the screwdrivers, the assembly fixtures, and miscellaneous material but from a production process perspective, all workstations are similar in the material flow, tool layout, and fixture positions.

In the assembly process, computer screens are used to provide the operators with the necessary information required for assembling the products. During observations, the authors noticed the monitors were placed in locations that made it difficult for the operators to see the screen properly while performing their tasks. Additionally, during a majority of the observations, the monitor was turned off and no instructions were used during the assembly of the products. When asked why the monitors weren’t on and no instructions were used the operators insisted on “knowing by heart” how the products were assembled and that the monitors were not properly placed making it difficult to see the instructions and added that the instructions provided often contained faults and wasn’t up to date. The operators continued to claim this caused a stress for them and hence not using it was considered the better option.

The fact that the assembly area was an EPA was poorly displayed due to old and worn equipment and non-ESD containers placed at the workbenches along with non-ESD tooling also present at the workbenches. The overall impression was that consideration of EPA was not being considered as great as the production development department at the company said. The presence of EPA is a matter of quality assurance for the company and being able to display a confidence installing EPA is, according to production development, important for the case study company.

4.3 Interviews

In this chapter, the semi-structured interviews conducted with select people from the production management and the unstructured interview conducted with suppliers of complete workstations are presented. Complete workstations are defined as the workbench, lighting, storage solutions at the workbench, and add-ons to workbenches such as articulated arms for displays.

4.3.1 Interviews with Case Study Company

Four semi-structured interviews have been conducted with four employees at the company. Each of the four interviewed have a relevant position regarding the observed assembly line. There were five main themes which the interviewed got to elaborate about. For the full questions see appendices 8.1.

What do you consider to be the most important in a production environment?
The most prominent answer was the safety of the operators and suitable ergonomics at the workstations. Most answers circulated around making it possible for the workers to perform their work to the best possible extent and also making sure there was an ease of traceability in terms of finding what went right and what went wrong in order to fix the problem at its root. The central theme from the respondents is presented in Table 10.

<table>
<thead>
<tr>
<th>Person</th>
<th>Safety &amp; Ergonomics</th>
<th>Production Flow</th>
<th>Visual Management</th>
<th>Flexibility</th>
<th>Standardized work</th>
<th>Clean and Orderly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interviewee 1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interviewee 2</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interviewee 3</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Interviewee 4</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 10 Respondent central themes
What do you think is important to show during an audit from a customer?

The general perception of what was desired to show to auditors was the quality of the assembly line which would imbue the auditors with trust in the company’s capability to deliver the required quality. To mediate quality of the production the respondents pointed out the need for a process which could be easily explained and show to the auditors. Furthermore, it would be necessary for the workplace to be clean and orderly structured. Each respondent’s opinions are shown in Table 11.

<table>
<thead>
<tr>
<th>Person</th>
<th>What do you want to show?</th>
<th>How would you show it?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interviewee 1</td>
<td>Showcase a great product and a process that can guarantee the quality and delivery of that product.</td>
<td>Through knowing the process and being able to easily explain and visually show the process. The process should be understood at first sight.</td>
</tr>
<tr>
<td>Interviewee 2</td>
<td>Being able to show clear and quality assuring production flow with a workbench which is kept clean and orderly. It is very important how we are perceived by customers.</td>
<td>Through clear processes, an orderly environment, and an understandable flow.</td>
</tr>
<tr>
<td>Interviewee 3</td>
<td>An organized workplace where it is clear to Observer how we work and thus mediate quality through that.</td>
<td>Through having an understandable process and keeping the workplace organized and clean.</td>
</tr>
<tr>
<td>Interviewee 4</td>
<td>We want to show visitors quality, as it is the essence of our company.</td>
<td>A structured line, clear flow and orderly and clean workstations. Furthermore, the ability to show standardized work and poka-yoke.</td>
</tr>
</tbody>
</table>

Table 11 What each respondent wanted to show during an audit

When you visit a supplier for an audit, what do you especially notice?

What was to be noticed if the respondents themselves did audits at suppliers showed an interest in knowing whether the supplier’s process was assuring the respondents of the supplier ability to deliver according to quality and delivery demands. Additionally, some of the respondents claimed the treatment of the operators they interacted with during their visit. As it could be a glimpse into the company culture and an indication of how well the company is functioning. Each respondent’s personal answers are shown in Table 12.

<table>
<thead>
<tr>
<th>Person</th>
<th>What do you notice?</th>
<th>Key phrases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interviewee 1</td>
<td>Is it a good flow, are there any large stocks anywhere between processes. Is it structured and clean? Is it easy doing the right thing, is it easy for operators and production control to access information regarding the status of the production?</td>
<td>Flow, clean, organized, visual.</td>
</tr>
<tr>
<td>Interviewee 2</td>
<td>Basically, the same as what I want to show. The treatment you get from the employees you meet of the firm. The feeling it imbues is important.</td>
<td>The feel, operator acting, company culture, flow, clear process</td>
</tr>
<tr>
<td>Interviewee 3</td>
<td>Nice, clean and organized workbenches, the same as I would want to show. How the operators act when you interact with them</td>
<td>Operator acting, clean and organized</td>
</tr>
<tr>
<td>Interviewee 4</td>
<td>The ability to see and understand the flow. Clean and orderly. The presence of 5S. The same as we want to show</td>
<td>5S, clean and orderly, flow</td>
</tr>
</tbody>
</table>

Table 12 Respondents focuses while visiting a supplier
What is a modern assembly line to you?
This question was asked to gain insight into what the respondents considered central characteristics of a modern assembly line. The respondents all agreed on the need for a thoroughly thought through process. Meaning that everything placed in or around the line, every function and every supportive function should have a purpose to it. Nothing should just happen. Further, it was added that it should be built for its purpose and enable the operators working in it. Each respondent’s personal answers are shown in Table 13.

<table>
<thead>
<tr>
<th>Person</th>
<th>What are the characteristics of a modern assembly line</th>
<th>Key phrases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interviewee 1</td>
<td>Not an abundance of material or tools, well-thought-out layout, and placement of processes. The material needed should be close at hand or batched out with precision by dedicated material handlers. Everything should be thought through.</td>
<td>Structured and thought through.</td>
</tr>
<tr>
<td>Interviewee 2</td>
<td>Much of what has been discussed in the previous questions. A Clear flow that is easy to understand paired with good instructions and an easy way to access the information needed.</td>
<td>Clear flow, good cognitive ergonomics</td>
</tr>
<tr>
<td>Interviewee 3</td>
<td>A clear flow, automation/fixture based workstations which reduce the potential for making mistakes.</td>
<td>Clear flow, poka-yoke</td>
</tr>
<tr>
<td>Interviewee 4</td>
<td>Ease of access to all information needed such as instructions, work orders etc. through for example touch screens. The assembly should be customized to handle the product range in the best possible way. Which to a large extent means flexible. Standardized work? Logistics and material supply should function well. Feedback to know why we are doing as we are doing. A thought behind everything. All above to ensure quality.</td>
<td>Quality ensuring, standardized work, functional for products, well-functioning logistics, feedback, ergonomic</td>
</tr>
</tbody>
</table>

Table 13 Modern assembly line as presented by respondents

Do you believe that aesthetics of a workstation can affect productivity and quality?
The respondents unanimously thought that a suitable workplace design can affect productivity and quality. Mostly through its ability to motivate the operators in continuing keeping it clean and the feeling of care from management through investing in their workplace. Respondents further argued that visually displaying quality could also be valuable. Individual answers are presented in Table 14 below.

<table>
<thead>
<tr>
<th>Person</th>
<th>Yes or No</th>
<th>Why and how?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interviewee 1</td>
<td>Yes</td>
<td>Structure makes a difference in productivity and furthermore ease of working at a given station. It can emit quality to persons seeing it.</td>
</tr>
<tr>
<td>Interviewee 2</td>
<td>Yes</td>
<td>It can emit quality. It is largely about the soft side of meeting operator requests and the ability in providing them with a good work environment.</td>
</tr>
<tr>
<td>Interviewee 3</td>
<td>Yes</td>
<td>If designed for its purpose it can look good and emit quality. Furthermore, a good-looking could boast operator’s morale.</td>
</tr>
<tr>
<td>Interviewee 4</td>
<td>Yes</td>
<td>A nice-looking workstation motivates to keeping it clean and in order. Good equipment goes hand in hand with productivity and quality</td>
</tr>
</tbody>
</table>

Table 14 Individual answers regarding if workplace aesthetics can affect productivity and quality
4.3.2 Interview with Suppliers of Workstations

Meetings with two possible suppliers complete workstation solutions including workbenches, lighting, storage solution and other add-ons to workbenches were arranged to take part of their knowledge of the design of workstations and their insight into what was important to consider when constructing a layout for an assembly line as well as getting an understanding of the economic investment needed. In the following parts are summaries of the discussion had with the suppliers. The suppliers will be named supplier 1 and supplier 2.

Supplier 1:

Primarily talked about the ergonomics as part of what was important to consider. Supplier 1 noted that although the physical ergonomics such as the work height of the benches, securing the operators from making heavy lifts in bad positions and repetitive work could be considered as workplace hazards the knowledge of physical ergonomics was quite extensive amongst most of the companies he had met. Further, he noted that most suppliers of workstation solutions had similar options when it came to the workbenches, such as the possibility of getting height adjustable tables. Supplier 1 also highlighted the need for proper cognitive ergonomics such as providing the right type of lighting for the operators, especially when conducting precision work. Furthermore, Supplier 1 emphasized the importance of having adjustable lighting and subsequently an adjustable cognitive environment. Supplier 1 announced that the importance of being able to adapt things such as the strength of the light or the size of the text on the instructions is equally important as being able to adjust the height of a workbench. Seeing as each operator is a different person with different traits and that is not limited to the height of the operator, rather it includes a lot more parameters.

A good workplace design and a good look at the production is important to both motivate the current staff and attract people who see the production. For example having a person stand in a dark environment, which Supplier 1 said often could be the case, surrounded by equipment that is old and in a cluttered workspace it will affect the operator negatively. Whilst on the other hand if the colors are lighter, the equipment updated and the workplace is organized the operator will immediately feel that the workplace is better for them. Amongst the younger workforce today the industry has to fight for attention in a way it hasn’t had to do before. Supplier 1 proclaims that earlier the industry was a more obvious occupational choice and didn’t have to compete for the attention of workers the same way it has to today. Further, saying that the industry today is more pressured in providing not only a productive and ergonomically sound workplace but also an attractive one. It may also be of interest for visiting customers to see a workplace that is organized and provides an edge through being easily accessible just by the looks and feeling up to date.

Further when designing a new workplace what is important to think about is how it is going to fit into the current production. Especially the material supply is amongst the hardest to get a working solution for as well as a very easy to overlook. There are a lot of technical solutions available for material supply and material storage both for supplying the line with material as well as storing material in the line.

Lastly, Supplier 1 announced the importance of having all this in mind whilst designing the production line and not just focus on getting new equipment. Supplier 1 urged the authors to think “why” the company should invest in this solution and “how” can this solution help the company improve its production.
Supplier 2:
Supplier 2 stated the importance of having an ergonomically sound workplace where it is possible for people with greatly varying physical conditions to safely and efficiently being able to perform their work. The ability to quickly adjust the workplace when a new operator arrives is of great importance as this could be seen as a kind of set-up time in order for the operator to perform at his or her best. The wide variety of possible customization available for today’s workbenches makes it possible for companies to get exactly what they want in terms of customized workplaces especially suited for their needs. Supplier 2 further claims the importance of being able to make adjustments on existing workbenches in terms of being able to buy new gadgets and attach them easily without the need for specialized personal making said adjustments or larger investments. This was especially important to facilitate the concept of continuous improvement according to Supplier 2 and the feeling for the operators that they can truly affect their working environment.

The importance of having a proper workplace design is imperative according to Supplier 2. Not only does it mean to provide the operators with the best possible conditions to perform their job but it is also a way of guiding the production towards its purpose. Designing the production to produce your product in the best possible way is, of course, the reason behind making conscious choices in the production design.

Supplier 2 also claimed the importance of having a high-level executive’s involved and driving in the process of production design implementation. Whilst a lot of jobs can be done during the actual design phases of a production by people who are not necessarily executives they should be continuously updated on the progress as they are the ones later responsible for the implementation. The part of the implementation needs to be supported by the high-level executives.
5. **ANALYSIS**

The empirical data and the information gathered from the literature review will be analyzed in the perspective of the research question presented. Based on the analysis, a new concept layout for the case study company’s final assembly line was generated and will be presented at the end of this chapter.

5.1. **How can Industrial Look and Feel be defined?**

During the interviews with the case study company, the participants were asked what they wanted to mediate during company audits and the opinions of the participants coincided with each other. All of the participants wanted to showcase the company’s competitive edges and be able to reassure the auditors of their ability to deliver a product which meets the quality requested by the customers. The participants unanimously thought that the ability to show a production process which strengthen their arguments of the company’s capabilities was imperative and what they wanted to show for the auditors was summarized by the quote from the Specialist Consultant.

> “Showcase a great product and a process that can guarantee the quality and delivery of that product”

*Interviewee 1*

When the participants were asked about what they considered to be the most important in a production environment the unanimous answer was workplace safety and good ergonomic conditions. However, the authors found that when ergonomics was brought up it was primarily the physical part of ergonomics. Further, one of the participants mentioned the cognitive aspect of ergonomics and the suppliers mainly focused on the lighting at the workstations in relation to the cognitive ergonomics. As stated by Berlin & Adams (2017) and Dul & Neumann (2009) ergonomics should be considered to provide a safe work environment and at the same time enable the operators to perform at their best. Aligning with the ability to deliver a product that conforms to quality aspects as well as the ability to deliver on time as the interviewees pointed out as important to mediate to auditors. Whilst ergonomics is said to be promoting both worker safety and system performance it often becomes a biased focus towards either work safety or system performance (Winkel, et al., 2017). Ergonomics have data regarding the stress originating from the cognitive load from work tasks and the stress related to achieving production goals, which can in the worst case lead to sick leaves within the workforce. Further, it is recorded that the lack of proper equipment is a source of stress, however, it does not actually mention the workplace from a perspective of aesthetics and the perception of it with regard to the aesthetic part of workplace design (Berlin & Adams, 2017; Winkel, et al., 2017). The workers’ health can, from an ergonomic perspective, be divided into either physical or psychological health. Whilst the research on stress as a product of the work performed are plentiful as stated by Westgaard & Winkel (2011), data on stress originating from workplace design is scarce since it is often overlooked when studies are conducted on ergonomics (Schell, et al., 2012).

One possible reason for this may be that it is difficult to quantify the psychosocial and cognitive factors related to employee health and during the interviews the authors discovered that this was the case, the interviewees often stated that it was important to mediate the feeling of quality but failed to mention how this could be done in practice. The only remotely related to workplace aesthetics was the use of an organized workplace related to 5S, however, during the observations, the authors found that some efforts had been made towards 5S but not sufficient enough to mediate the feeling of quality.
The interviewees proclaimed a focus on ensuring the quality through the use of different lean principles such as poka-yoke and standardized work to minimizing the room for error in assembly phase, which was said during the interviews and the need vocalized during the unstructured interviews with the operators closely reassembles the need associated with cognitive ergonomics. Ergonomics is, as previously mentioned, concerned with the well-being of workers and the system performance in production. The cognitive aspects in ergonomics mainly focus on not to burden the operator with too many important decisions which could compromise overall product quality as well as not overloading the mental capacity of the operator and thus reducing overall psychological strain (Berlin & Adams, 2017; Arbetsmiljöverket, 2018). The workplace design can further contribute to preventing the psychological strain if the workplace is designed to facilitate lean production, since one of the leading reasons for stress amongst workers is the implementation of lean or rationalization of production (Westgaard & Winkel, 2011; Lowe, et al., 2003). Whilst having various causes one of the most prominent is an ill-adapted workplace causing stress for the operators as it is not clear to them how to work according to the new production principles within the existing production environment (Westgaard & Winkel, 2011; Schell, et al., 2012). Cognitive ergonomics also relates to the subject through pointing out the importance of having clearly defined processes as well as poka-yoke system and standardized work to reduce the cognitive load on the operator (Berlin & Adams, 2017).

One of the interviewees highlighted the importance of company culture both when visiting a supplier and within their company. The company culture sets the tone both towards visitors in the form of how interactive the operator is when meeting with auditors and also internally in making sure the operators conduct their work. According to the interviewee, one of the best ways to make sure the operators had faith in the production management is that the production management show they care through investing time, effort and money in their workstation, thus making sure the operators have the best possible conditions to perform their jobs. Since lean needs to be treated as a company philosophy to be successful, as suggested by Liker (2004) the employees have a great responsibly in accepting and spreading it within the company. The lean principle of 5S is no exception and without rooting it simply becomes a one-time thing and won’t have any impact over time (Chapman, 2005). Lowe et al. (2003) state that workplace design is closely related to perceived work satisfaction, where a well-designed and aesthetically pleasing workplace have higher rates of perceived satisfaction. Chapman (2005) regarded this as work-pride and it is closely interlinked with the implementation of the final two S’s which ensures the success of 5S over time, therefore, the morale and well-being of the workers is of utmost importance to spread the philosophy within the company (Schell, et al., 2012; Lowe, et al., 2003). If the employees enjoy working at their stations it is much more likely to become second nature with the lean philosophy and thus brings forth the importance of workplace aesthetics. The lean philosophy is centered around the thought of empowering the workers and having them contribute to improving the production (Liker, 2004).

The observations and unstructured interviews with the operators proved a large turn-over rate on the personal. Making the need for providing a proper workplace setting to facilitate unexperienced workers as well as providing current workers with a workplace that will encourage them to remain within the company. By considering the ergonomic and aesthetic needs of the employees, many of the stress related issues to large organizational change can be countered according to Schell (2012) and thus improve the overall worker well-being within the company (Lowe, et al., 2003). Further, the interviewees also emphasized the need for a clean workplace as well as a visual flow. The importance of a visual flow and a clean and orderly workplace are highlighted by Raghavan et al. (2014) and Modig & Åhlström (2016) both claiming that flow efficiency is an important part of the lean concept and much needed for any organization wanting to increase productivity. Qi & Miller (2011) highlights the importance of being able to meditate this kind of
quality assuring feeling to auditors visiting the plant and the auditor should be able to understand without an explanation what is happening in the production to further get the feeling of confidence in the manufacturers ability to deliver (Smallwood, et al., 2014).

Workplace aesthetics is a central part in the industrial look and feel as mentioned earlier and closely connected to all parts within production performance, however, it is often overlooked due to the fact that soft values are difficult to quantify. The ability to showcase certain values and mediate feelings is important, even in a production environment and the need to do so is highlighted during the interviews with the production management of the case study company.

Through the analysis of the empirical data, the concepts included into industrial look and feel are the production performance, mainly in the form of utilizing lean principles, ergonomics, physical as well as cognitive, and workplace aesthetics. Furthermore, it’s the simultaneous presence and utilization of the three key concepts that make up the industrial look and feel.

5.2 How does Industrial Look and Feel contribute to increased performance of a production line?

Using the analysis above the authors defines industrial look and feel as the consideration and utilization of production performance, ergonomics and workplace aesthetics. The three concepts that are included in industrial look and feel are each individually contributing to performance or the perceived performance of a production line. However, separately implementing any of the concepts without consideration of the others could potentially lead to sub optimizations, as mentioned by Winkel et al. (2017). The most prominent way in which industrial look and feel can contribute to increased production performance is through the holistic approach it provides in seeing all the three key concepts concurrently while designing or improving a production line. Each of the concepts is important to consider and can also endorse each other.

An aesthetically well-designed workstation has the ability to reinforce production performance through encouraging the employees to keep an orderly and organized workstation. The principles of keeping an organized workplace are closely related to the 5S methodology (Chapman, 2005).

As mentioned ergonomics plays a major part in industrial look and feel and can have a positive impact on workplace safety as well as on the productivity when designing manufacturing processes (Falck & Rosenqvist, 2014). Therefore, considering ergonomics in the process design can be beneficial to the overall system performance as well as improving the workers’ overall health. Although when doing ergonomic improvements or production rationalization it is common for the project manager to have tunnel-vision, solely focusing on one of the aspects and thus sub-optimizing the system towards either ergonomics or production performance leaving the other largely neglected (Winkel, et al., 2017). The IEA (2018) concludes in their definition that ergonomics should be workplace-health and system performance, thus Winkel et al. (2017) suggests that a holistic approach is required to achieve the goal of simultaneously improving ergonomics and the overall system performance.

With industrial look and feel incorporates and actualizes workplace aesthetics it has the ability to address the soft values such as perceived workplace satisfaction and thus improving the employee well-being (Lowe, et al., 2003). This also infuses the employees with work-pride as Chapman (2005) describes the workplace satisfaction and thus enabling the company culture to thrive.

Through the incorporation and highlighting interconnection of the three key concepts, the industrial look and feel have the ability to affect the production performance positively.
5.3. What is important to consider when designing a production line considering industrial look and feel in an HMLV environment?

The study has indicated that focus when developing a production line should lie on providing an understandable and good production flow, and to provide the operators with a work situation that enables them to perform their job with minimal risk of injury or mental exhaustion whilst also providing them with processes that minimize the risk of error. Concurrently the workplace should be appealing to both auditors and operators alike, inducing them with confidence in the ability of the company. The overall system performance was considered the linchpin of the entire production by the interviewees and the ergonomics and aesthetics of the workplace was mainly considered as enablers of system performance and a way of mediating it to both operators and external observers.

The authors found five things especially important to consider when wanting to achieve the mentioned goals found, while also considering industrial look and feel.

Ergonomics

During interviews with production management, the suppliers, and the more unstructured interviews with the operators the authors discovered how important all the participants believed ergonomics were. As stated earlier, neither the production management nor the operators had the proper knowledge to implement ergonomic solutions thus relying solely on external suppliers for earlier implementation. However, during interviews with the production management, all participants agreed on that having the ergonomic aspect in consideration at an early development stage were important. Therefore, when designing an assembly line and its workstations the aspects of ergonomics become highly important, considering both the employee health and the overall system performance. From a physical ergonomics perspective, the repetitive work should be kept at a minimum and the posture of the workers required to perform the task should be within the regulations prescribed by Arbetsmiljöverket (2018) in regard to height and ergonomic zones. Furthermore, from a perspective of cognitive ergonomics, the design principles of Boghard (2009) should be utilized to create an environment where the operators’ mental workload is kept at a manageable level.

Group Technology

The interviews with production management and the interviews with operators indicated that a clear production flow was desired and a critical part of achieving better production performance. Observations showed that the grouping of the products into families already done by the company had yielded a more manageable number of product families and had been used to dedicate special workstations to special product families. However, when desiring to implement a clear production flow the production line layout is beneficial and also allows for the principles of lean to be easier to implement, as stated by Raghavan et al. (2014). Using the GT approach to further group together families with similar traits could be a beneficial approach when desiring to utilize a production line layout and reap to benefits associated with a line flow whilst dealing with a wide variety of products as associated with HMLV (Irani, 2011; Bohnen, et al., 2011; Weber, 2016).

Production rationalization (Lean)

Something made clear in the interviews with production management and the interviews with operators was the vocalized need for production rationalization in order to gain better production
performance. The interviews with production management also indicated that the production performance was the main focus and that the need for it was not to be neglected. The authors discovered, during observations, that production rationalization efforts only had been loosely implemented and that not enough persistence from the production management had been put into the efforts and thus rendered most of the efforts ineffective. The importance of Lean principles such as 5S in production was made clear due to providing organization needed to manufacture inconsistent quality and knowing the process. Further, implementing lean principles such as standardized work eases the burden on the operators as well as making continuous improvements possible (Shook, 2007). Focus on the productivity and quality is a linchpin in any production.

Workplace aesthetics

Interviews with the production management showed that workplace aesthetics is something that is often neglected when designing a new production or assembly line and none of the participants had thought about workplace aesthetics as a tool to improve the employee well-being. However, all participants agreed that the aesthetics of a workstation could have the benefit of improved production performance through improved worker morale, motivating the use of 5S, and improving quality. Another major benefit if the workbenches were designed with industrial look and feel in mind, is the feeling of confidence it induces in auditors, which was considered important for the participants of the interviews. Currently, the workplace design did not allow auditors to easily gain an understanding of the overall flow of materials in the line according to the interviewees. While redesigning an assembly line there is an importance to focus on the well-being of the operator since major layout changes can have a negative impact on their stress-level, especially since management usually tend to focus on the key performance indexes (Lowe, et al., 2003). Schell et al. (2012) state that there is a need to focus on the perceived feeling emitted by the new layout as it also does affect the operators’ perceived stress. Also, workplace design will become increasingly more important as studies suggest younger people are more sensitive to the workplace aesthetics and with a coming shortage of workers available the importance of the ability to offer good workplace aesthetics will rise (Berlin & Adams, 2017; Berlin, 2014).

Holistic approach

Industrial look and feel are mainly concerned with the concurrent consideration of ergonomics production performance and workplace aesthetics to both have a production that yields result and look the part. The benefits of considering all parts are to reduce the chance of sub-optimization towards one aspect whilst forgetting the others.

5.4. Assembly line concept based on industrial look and feel

A concept for a new assembly line was generated by the authors. The components of the benches was created using SolidWorks where they were assembled. With each bench created in SolidWorks they were imported to Visual Components 4.0 where they were put together in a 3D representation of the actual factory.

When designing a production line each separate part on workstation level must be considered to look and function properly, at the same time the whole line must be considered so that each of the workstations fit together to function on a larger scale. With regards to the data gathered in the empirics and the theory gathered in the literature review, a major remodeling of the current assembly line is necessary to achieve an improved working-environment, production performance, and aesthetic appeal. The current layout makes it difficult to understand the material flow and assembly process at first glance. With the current state being based on a cellular
production layout where the utilization of the different cells is severely unbalanced with one cell accounting for approximately 80% of the production volume with the other three share the remaining 20%. The cells limited workspace inhibits multiple operators to smoothly work together in one cell. The current cell-layout is based on the concept of GT, which is beneficial for HMLV production. However, Weber (2016) states the importance of focusing on the similarities between products rather than differences to achieve best possible groupings using GT. Through the current state analysis of the assembly steps of the different product families, the authors found many similarities in the sequences and tools used.

Utilizing a line based production layout to ensure the visibility of the production, as well as the potential to easily detect and eliminate non-value adding action to make for a more effective and efficient production, was considered fundamental. Using a line based layout in an HMLV environment was made possible due to the use of GT to make even bigger groups of products.

<table>
<thead>
<tr>
<th>Line</th>
<th>Product families to be made at each line</th>
<th>Torques required (Nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viper Dedicated Line</td>
<td>Viper</td>
<td>M2; M4; M5</td>
</tr>
<tr>
<td>Mixed Product Line</td>
<td>Viper, RFR, RFI, RFIR, Wolverine</td>
<td>M1, M2, M3, M4</td>
</tr>
</tbody>
</table>

Table 15 Required torque at each line

The new groupings ensured using two production lines could be possible. In figure 10 an overview of the new production line is presented. Using two lines also meant increased room for the operators to conduct their work tasks, which from an ergonomic standpoint is beneficial. With the Viper family accounting for 80% of the production volume to utilize the equipment and space of the production line as well as increasing the production capacity there is a need to be able to assemble Viper units in both lines.
The Viper dedicated line is made only to assemble products of the Viper family, that includes the more specialized versions of the Vipers made for specific customers. The Mixed Product line is equipped to assemble all of the different product families, however it is not equipped to assemble the specialized Vipers due to more specialized equipment necessary and that the specialized Vipers does not make up a significant amount of the total production volume making it only necessary to be able to produce them in one line.

The representation of the workbenches, shown in Figure 11, uses a color-coding which is matched to the assembly process steps of the different products displayed in Figure 12, Figure 13, Figure 14, and Figure 15. For example, the preparatory work of the Viper is performed at the bench marked in red.

The Viper assembly process shown in Figure 12 differs from the current process of assembling the viper due to the changes in Layout and re-organization of the workstations. In the new layout, the preparatory work is conducted at the first bench. Further, the pressing of front-foil onto the front housing and internal assembly processes are conducted on the second bench and lastly, the applying of cooling paste and final assembly of the front and back housing are conducted at the third bench.

The first four assembly steps for the RFI are conducted at the first bench with the mounting of DIN-clip and mounting of the backplane in the back housing is carried out at the second bench. Lastly, the front and back housing is assembled together with the profile at the third bench.
RFR has the first four steps of preparatory work conducted at the first workstation. At the second workbench the internal mounting is conducted and at the third workstation, the front and back housing is assembled with the main housing.

Wolverine has the preparatory work conducted at the first workstation and the internal mounting is conducted at the second workstation before the assembly of the front and back housing together with the main housing at the third workstation.
The RFIR’s process remains exactly the same as the process only being conducted on the last two workbenches only. This is due to its need for screwdrivers throughout the entirety of its assembly process.

The workbench design was based on the current design with specialized torque screwdrivers and fixtures for the placement of the work-pieces. The removal of unnecessary and obsolete items at the benches was made to further encourage a production environment dominated by the principles of lean production and workplace organization. Providing a more accessible placement of the instructions display and making it flexible adheres to the need for proper information in an HMLV environment.

Further, the cognitive and physical aspects of ergonomics were taken into account when remodeling the workstation to make sure it was accessible to operators with varying physical attributes and with varying experience of the assembly process. Ensuring good work posture through the use of height-adjustable tables and shallow workbenches resulting in the operator being able to access the tools and materials required in the assembly process without having to overextend or work outside of the preferred area. To ensure a healthy work environment the aesthetics and the perceived feeling of the work area was taken into account when designing the new workplace. Taking ESD into account limited the availability of different workplace design alternatives. ESD equipment has a limited number of suppliers as well as a very limited range of different looks severely limiting the number of design options. In the choice of colors, the authors opted for light colors due to increasing the perception of space. A healthy work environment was considered in terms of making the process steps obvious and provide the operator with space and equipment necessary to do perform the tasks as requested. Furthermore, the orderliness and dividing the workbenches by the process steps make it understandable for observers such as company visitors and auditors that will be assessing the company production. Making it possible to mediate the values and strength of the production solely through visual observation.
Figure 18 New Viper line

Figure 19 New mixed product line
Furthermore, the orderliness and dividing the workbenches by the process steps make it understandable for observers such as company visitors and auditors that will be assessing the company production. Making it possible to mediate the values and strength of the production solely through visual observation.
The proximity of the materials and tools needed for the different products was made possible through exploiting the storage space available at the workbenches, where smaller components needed for the production such as screws and front-foil could be stored whilst the larger housings storage should remain where it is currently at. PCB cards should also remain where they are currently at due to the PCB storage being too large to facilitate at the workbenches. Housing and PCB cards should be kitted before each job and the material then delivered to the line as the products are to be produced.
How the operators can be utilized and the use of a dedicated material handler and how that can ensure the right materials are supplied at the right time. The new layout also possesses the ability to be useful in future production development projects such as the introduction of a one-piece flow or automation solutions. The current layout does not allow for these types of improvements due to the inherent restriction of its confined cell layout.
As stated in the analysis, the key concepts of the industrial look and feel are production performance, ergonomics and workplace aesthetics. However, the most important idea of industrial look and feel is the combination of the three concepts and the simultaneous utilization of them to harness the benefits of the concept. The authors found that the usage of production rationalization principles and, to some degree, ergonomics were thoroughly investigated areas in terms of using them to gain competitive advantage in production. Further, some authors claimed the importance of simultaneously considering production rationalization and ergonomics to avoid sub-optimization. The concept of industrial look and feel adds workplace aesthetics due to its focus of mediating the excellence of the production to external observers but also due to it actualizing the need to consider how the operators within the production perceives the workplace. By considering the operators and external observers perception of the workplace alongside the usage of production rationalization principles and considering ergonomics a better performing workplace as well as a more attractive workplace is possible to achieve.

Having a great focus on the holistic approach when utilizing the concept of industrial look and feel is, as earlier stated, the most fundamental part of the concept. Whilst bringing workplace aesthetics up to the fore, the workplace aesthetics will only have an impact if the production rationalization principles and ergonomics parts are simultaneously utilized. However, as previously shown the workplace aesthetics and its impact in a production environment has been studied very limited and actualizing its importance in the context of production and incorporating it with the more established ergonomics and production rationalization principles will have a possibility of affecting the production performance of a company in a positive way. The possibility of a positive impact due to focusing on the workplace aesthetics will be largely due to the company actively considering what their production should mediate and how. When knowing what is desired to mediate steps can be taken towards achieving the desired state.

Whilst the definition of the concept industrial look and feel has been performed in a case study its relevance is not limited to any specific company setting or any specific industry branch. The benefits of a holistic approach when designing a production line is universal and should be something considered by companies regardless of which industry branch. The actualization of workplace aesthetics within the production setting could also be of interest due to it shedding light on the importance of how the production is perceived by both observers and operators. Further, the possible benefits in terms of employee health through the consideration of workplace aesthetics and the possible impact on such things as the company culture through giving the employees a workplace they can feel proud of. In a larger perspective the concept of industrial look and feel could be of importance to companies regardless of branch due to the holistic approach which adds focus on the way the production is perceived by stakeholders from a perspective that has been largely neglected by most of the manufacturing industry.
7. CONCLUSIONS AND RECOMMENDATIONS

In this chapter, the research questions will be answered to fulfill the aim of the thesis. Recommendations for future research will also be treated in this chapter.

RQ1: *How can Industrial Look and Feel be defined?*

Industrial look and feel is the synergy between ergonomics, production rationalization and workplace aesthetics where all of them needs to be included when designing a new production line to ensure the well-being of the employees as well as providing an increase in production volume or efficiency. The expression of industrial look and feel can differ between factories depending on what type of business a company is conducting, which includes all parts of the industrial look and feel and not only the aesthetic part. The authors have condensed the definition of “*Industrial Look and Feel*” into a sentence presented below.

> “The ability of the production to mediate its own excellence through solely being observed and the feeling of production excellence should install confidence in the observer of the productions capability”

RQ2: *How does Industrial Look and Feel contribute to increased performance of a production line?*

Industrial look and feel as defined by the authors contain the means to increase overall production performance.

Workplace aesthetics attracts potential employees as well as being beneficial to the operators working at the company and further ensuring healthy employees. Further, it allows for the workplace to become a medium to express and ensure the proclaimed quality when visited by auditors. The orderly and thoroughly planned workplace could contribute to the work pride of the operators which has the potential of encouraging a constructive company culture where the operator are a driving factor for further improvements.

RQ3: *What is important to consider when designing a production line considering industrial look and feel in an HMLV environment?*

To design a production line considering industrial look and feel is to employ a holistic approach during the entire design process, simultaneously considering the performance of the production line as well as the perception of it. Further, it is to not neglect the effect of having a production line that is easy to understand and where the operations are self-explanatory to give the observer the sense of confidence in the company displaying their production line.

It is important to be able to apply conventional production rationalization methods, even in an HMLV environment. The start for that is GT that reduces the number of different products into a more manageable number of product groups. Secondarily the design of the workstations should be done considering ergonomics and workplace aesthetics, as to complete industrial look and feel.
**Recommendations**

During the thesis, the authors noticed that research regarding the impact of workplace aesthetics on the health and motivation of operators in a production or operational environment was scarce. Most of the research conducted regarding workplace aesthetics impact was made in a service setting. Furthermore, the research regarding the operator health in production was mostly limited to the physical and cognitive constraints related to the character of the work rather than the setting surrounding the operator and the psychological impact it has. The authors hence recommend for the future researcher to investigate the impact of workplace aesthetics in a production environment.

The authors have proposed a definition the term of industrial look and feel and further theorized on the impact of having a design of production stations and layout that does mediate the capability of said product to be an argument in assuring both operators and visitors of the quality of said production. The theory should, therefore, be tested and for future research, the impact of designing production with the concept of an industrial look and feel in mind should be investigated.

Further, future research should also be concerned with investigating strategies how to make use of a holistic approach when designing new production layouts. As the literature concludes there are benefits of considering ergonomics and production rationalization simultaneously, however, this is seldom done in practice and with the authors’ introduction of the concept of industrial look and feel, a third variable in the form of workplace aesthetics is added to take into account when designing new production layouts and designs. The authors strongly encourage a holistic approach simultaneously considering production performance, ergonomics, and workplace aesthetics when designing new production layouts and stations.
8. REFERENCES


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Semi-structured interview questions

- Vad tycker du är viktigt i en produktionsmiljö?
  - Varför är just det viktigt?
  - Hur kan det uppnås?
  - Tycker du att ni uppfyller det idag? – varför?
- Vad tycker ni är viktigt att visa upp när en kund kommer på besök?
  - Hur förmedlar ni det?
- Om ni besöker en leverantör, vad är det ni lägger märke till då?
- Om det är någon skillnad, varför?
- Vad är en modern monteringslinia för dig?
- Tror du att utseende och design kan påverka produktiviteten? -Motivera
  - Tror du att utseende och design kan utstråla kvalitet?