Investigating the barriers to increase levels of automation

A case study in pre assembly of tap changer assembly line
This exam work has been carried out at the School of Engineering in Jönköping in the subject area of Production Systems with a specialization in Production development and management. The work is a part of the Master of Science programme. The authors take full responsibility for opinions, conclusions and findings presented.

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Abstract

ABSTRACT

The overarching goal of this thesis is to investigate and explore the barriers that a company would face while increasing the Levels of Automation (LoA), in the preassembly production unit. To achieve the primary goal of investigating the barriers this study takes a threefold approach.

Firstly, the current LoA was measured for the preassembly workstations. This measurement was conducted by incorporating an existing methodology adapted from the literature review known as DYNAMO++ methodology. This method is incorporated such that, the current LoA of the preassembly workstations could be measured and analysed.

The current LoA of the preassembly workstations are analysed to investigate the potential workstations where LoA could be increased, in line with the company’s triggers for implementing automation. For this, experiences of the personnel’s belonging to the operational level of preassembly workstations were incorporated, to find the scope of improvements for increasing the LoA. Additionally, the company’s triggers for implementing automation was investigated from the managerial level.

The research questions were answered by adapting an explorative, single case study method. Additionally, four types of data collection techniques were used, such as – interviews, focus groups, observations, and document analysis. Subsequently, source triangulation was adapted to analyse the data collected; to develop a comprehensive understanding of the barriers identified.

Finally, the barriers faced by the company to increase LoA are identified by considering the implications that the improvement opportunities would impose upon the production systems environment.

The identified barriers were then categorised further based on factors that exist internal as well as external to the production systems environment.

The barriers identified in this study highlights various factors that the management must consider beforehand while initiating automation decisions in future automation projects in the preassembly area. Regardless of the barriers faced by the company, there are more opportunities to improve manufacturing processes through automation technologies. This thesis contributes to the knowledge of the factors that restrain the implementation of automation technologies and how companies could deal with it.
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List of Abbreviations

Cobot - Collaborative robot
COG- Cognitive
CTA- Cognitive Task Analysis
DYNAMO Project - Dynamic Levels of Automation for Robust Manufacturing Systems Project
EOQ- Economic Order Quantity
ERP- Enterprise Resource Planning systems
ETO- Engineering To Order
HTA- Hierarchical Task Analysis
LoA- Level(s) Of Automation
(LoAmin)- minimum Level of Automation
(LoAmax)- maximum Level of Automation
MABA- MABA- man are best at and machine are best at
MTO- Made To Order
Mech- Mechanical
NCR- Non-conformity report; NCR logs- Non-conformity report
PPC- Production Planning and Control
PLC- Programmable Logic Controller.
SOP’s- Standard Operating Procedures
SoPI- Square of Possible Improvements
SPM- Special Purpose Machine
1 Introduction.

1.1 Background

Technological advancements in the field of manufacturing operations and processes have led to automation in industries. Automation can be defined as the work or functions done by machines or robots usually supported by computers systems; which were earlier carried out by human beings (Parasuraman R., Sheridan, Fellow, IEEE, & Wickens, 2000).

Throughout history, automation has proven to be an efficient way to achieve cost-effective production in various industries (Satchell, 1998). Apart from eradicating repetitive, tedious and hazardous tasks; automation could also contribute towards improving production quality, productivity and reducing production costs simultaneously (Chinniah & Bourbonniere, 2006). Due to competitive global markets from low wage and labour-intensive countries, industrial markets with high wages are facing intense pressure to reduce production cost (Flegel, Heinrich, 2006). During such conditions, shorter product lifecycles are propelling manufacturing industries in developed countries to move towards automation (Hitomi, 1994). In recent times industries facing higher demands corresponding to increased product variety and shorter life cycles, automation has aided manufacturing companies to adopt greater flexibility by providing faster time to market along with high levels of customisation (Sharma, 2011).

Appropriate implementation of automation in manufacturing systems could be successfully achieved when the physical and cognitive workload on the labour is replaced by machines (Groover, 2001; Sheridan, 2002, as cited in Säfsten, Winroth, & Stahre, 2007). Such that, implementation of automation leverages the skills of operators in line with their physical and cognitive capabilities (Chung, 1996).

To optimise the full potential of humans and machines in a manufacturing system the interaction between them must be well understood, this requires a more human-centred ideology that deals with effects of technology in the context of human issues (Säfsten, Winroth, & Stahre, 2007, as cited in Chung, 1996). To strike a right balance in the task allocations between humans and machines the concept of Levels of Automation (LoA) should be well understood because, lower levels of automation will lead to ‘under-automation’ whereas, on the other hand, higher level of automation will lead to ‘over automation’ (Säfsten, Winroth, & Stahre, 2007).

According to (Satchell, 1998) the level of automation can be defined as “Distribution of task allocations between humans and machines with different degrees of human involvement” (Satchell, 1998). The concept of levels of automation within the context of task allocation between humans and machines was more accurately defined by (Frohm, Stahre, & Winroth, 2008) as “the allocation of physical and cognitive tasks between humans and technology, described as a continuum ranging from totally manual to totally automatic” (Frohm, Stahre, & Winroth, 2008).” Low levels of automation may lead to less utilisation of the manufacturing systems resources; whereas high levels of automation would interfere with the upcoming demands on the production systems (short lead times, high customisation) which will eventually lead to increased cognitive requirement on the operator to manage such high levels of information (Fasth, 2012). Pointing to the conclusion that the measurement of the levels of automation must be carried out systematically with the use of correct methods and tools that comply with the strategic goals of the industry.
The ‘DYNAMO’ project (Dynamic Levels of Automation for Robust Manufacturing Systems); therefore, the acronym ‘DYNAMO’ - financed by the Swedish Foundation of Strategic Research (Lindström & Winroth, 2010). Further research in the DYNAMO project led to the development of a systematic method called DYNAMO++ to measure and assess the levels of automation that could be applied in an industrial context (Garnell, Frohm, Bruch, & Dencker, 2007). The researchers in this thesis have adopted the modified DYNAMO++ method developed by (Garnell, Frohm, Bruch, & Dencker, 2007) within the context of the ‘preassembly part production’ area of the focal company; with an aim of measuring the current levels of automation; and thereby assess the possibilities to improve the level of automation in the preassembly part production area of the focal company. Once the suggestions for increasing the levels of automation was formulated by incorporating experiences of the production personnel’s; the researchers in this thesis, has thereby taken a qualitative approach applying these suggestions for improvement in the manufacturing systems context; to eventually investigate the barriers that the focal company would face in the effort to increase the levels of automation.

1.2 Problem description.

It has led to a pre-disposed notion amongst managers to invest in automation with a view of reducing labour cost and improving productivity along with all other benefits of automation mentioned above (Majchrzak, 1988). However, this is not always the case; implementing automation does not necessarily live up to the expectations and instead cause more disturbances, eventually causing the automation efforts to fail, which places the decision regarding automation in a grey area among managers (Fasth, Stahre, & Dencker, 2008). Which stems from the fact that the evaluations/assessment regarding the factors backing up such automation decisions is based on informal and unstructured interpretations, rather than facts (Fasth & Stahre, 2008; Säfsten & Aresu, 2000; Bellgran & Säfsten, 2005, as cited in Åsa & J.Stahre, 2013).

The focal company appointed the researchers to conduct a study in their preassembly areas, to systematically investigate the ‘barriers’ that the industry might face, if they decide to improve levels of automation in their preassembly production area. Therefore, before initiating the efforts to increase the level of automation, as a prestudy, the focal company needed to first assess their current levels of automation. Then, based on the assessment of the current levels of automation, various suggestions could be developed to increase the level of automation. Eventually, to achieve the primary goal of this study which is- to perceive the barriers that the focal company would face while increasing the level of automation, quantitative as well as qualitative approach must be taken to introduce the suggestions of improvement in the context of part preassembly area, to figure out the constraints that such improvement opportunities would impose on the other production-related factors of the manufacturing systems environment.
1.3 Purpose and research questions

The purpose of this study is to investigate the barriers faced by the production unit while improving LoA. To investigate the barriers to improve LoA, this study answers three research questions-

- **RQ1- What are the current levels of automation in the preassembly part production?**

  This research question aims to measure the current Levels of Automation in the preassembly part of production areas. This measured Level of Automation would then act as a foundation above which, the level of automation could be increased/improved.

- **RQ2- What could be the desired Level of Automation in the preassembly part production according to the focal industry’s triggers for implementing automation?**

  This research question aims to analyse and develop the level of an extent that would be feasible for the focal industry to advance while making decisions regarding automation, such that the automation efforts would be justifiable corresponding to the preassembly systems capabilities.

- **RQ3- What are the foreseeable barriers that the focal company would face to increase the Level of Automation in the preassembly part production areas?**

  This research question aims to qualitatively asses the barriers that increasing the Level of Automation would impose on the manufacturing environment of preassembly part production. This research question would be answered by source triangulation techniques that- qualitatively investigate the implications, increasing the levels of automation would have on other characteristics of the production unit from a production systems perspective.

1.4 Delimitations

This study was conducted within the preassembly workstations that belonged to the UC assembly line. Additionally, the types of components assembled at the preassembly station belonged to a niche category of electrical components that are subjected to extremely high levels of variations (due to customisation) and comparatively low production volumes. Therefore, the results of this study could only be generalised for similar pre-assemblies that produce- intricate preassembly components with a wide variety, low volumes.

This study makes conceptual suggestions in its analysis phase, regarding how current levels of automation could be improved in preassembly workstations. These conceptual suggestions were developed only to gauge the implications it would impose on other aspects of the production systems; and not with the intention of an actual implementation. Therefore, this study also does not consider economic/financial elements such as- investment costs, operating costs, Returns on investment (ROI); breakeven analysis, design aspects for automation such as DFA, prototype, simulations etc.
The DYNAMO++ methodology used to measure current LoA suggests videography as well as time and motion studies to study the operations while measuring LoA. However, owing to the ethical restrictions imposed in this research, the researchers were not permitted to take videos while conducting the studies. Alternatively, the use of an essential internal document known as Standard Operating Procedures (SOP’s) was used instead to carry out the measurements, which led to estimates being made while judging time parameters for assembly tasks. Additionally, certain (rare) products were not studied as the order cycles for these products was extremely long, which made it very rare to produce within the timespan of this thesis; which could have a considerable impact regarding the findings of this study.
1.5 Outline

**Chapter 1:** The chapter consists of the background of the study, a description of the problem, the purpose of the study, formulated research questions and the scope, along with the delimitations of the study.

**Chapter 2:** This chapter contains the various theories related to the content of the thesis report; it consists of the theoretical explanation of multiple terms and suggestions as seen in the report for example production systems, automation, levels of automation etc.

**Chapter 3:** This chapter contains information about the various methods chosen for the study and how it was implemented. The section also consists of information about the different types of data that was collected during the work and ends with a discussion about validity and reliability.

**Chapter 4:** This chapter focuses on analysing and presenting the findings obtained through empirical studies carried out.

**Chapter 5:** This chapter focuses on discussions of the methods used in this research and on the empirical findings by answering each research question.
2 Theoretical background

2.1 Production systems.

The term production refers to an output of industrial work done, and this is also the definition according to The International Academy of Production Engineering (CIRP) as, any result or output from a collection of industrial work in various fields is called production (Chisholm, 1990). A production system is defined as a set of people, machines and procedures assembled to carry out manufacturing operations or a series of operations for an organisation (Groover M. P., 2008). Some other authors have also defined the production system as a combination of the human workforce and mechanical or technological equipment used to produce an output through a series of industrial procedures (Rösiö, 2012). According to (Groover M. P., 2008) A production system is divided into two subsystems consisting of manufacturing support systems and production facilities where the manufacturing support system consists of set of procedures used by the organization to manage production purposes and to get support for production-related activities (technical and logistic issues), a facility generally refers to the workspace and the equipment used for production purposes. He also links the human perspective into production systems which are responsible for operating both the facilities and the manufacturing support system. (Hubka & Eder, 1984) have also defined and divided production systems into various subsystems consisting of human, technical, information and management systems.

2.1.1 Types of production system layouts

According to (Slack, Chambers, & Johnston, 2010) any production system would have a design and the primary purpose of it would be to determine the flow of information and raw materials throughout the plant form inbound till outbound. Any production layout would comprise of equipment’s or machines and operators to work with it. An excellent production layout would lead to shorter throughput times which would eventually lead to less work in processes, thus reducing the capital associated with it (Ohlager, 2007). He has further added that the primary purpose of a layout is to utilise high capacity and to have high flexibility. (Slack, Chambers, & Johnston, 2010) has classified layout into 4 different types depending on how the materials and information is transferred:

**Fixed Layout:** Fixed layout is used for producing products that are generally very heavy or large to produce like ships and aircraft, which are very hard to move at initial stages. Usually, in this layout, the equipment and tools are generally moved or transported to the product along with the operators (Ohlager, 2007). Generally, the skill level of the operator is typically high, and the demand for the products made in the fixed layout is very low (Slack, Chambers, & Johnston, 2010).

**Functional Layout:** Functional layout consists of machines or equipment that has the same function, and the same processes are carried out on a product. This layout creates a very flexible production operation sequence and is more suitable for producing products with a wide variety. One more feature of this layout is it can be used to make products that have very high or varying operating times. The operators working in this layout are generally considered to be highly skilled and can be flexible with their skills related to Production Planning and Control (PPC) (Slack, Chambers, & Johnston, 2010).

**Product Layout:** In process layout, the production processes are more product-oriented and structured in a way where each product variant/type has its own flow, and a set or sequence of operations carried out on it. This layout is usually designed for a single product type or single product group where demand is generally high. It is also suitable for products with limited variants (Ohlager, 2007). This layout has very less
Theoretical background

flexibility: if a different product is to be produced then, the entire machine or equipment setup must be changed to suit the process according to the component produced. Generally, this layout has an advantage of reducing the throughput times and work in process (Slack, Chambers, & Johnston, 2010).

Continuous Layout: In a continuous layout, the products are made or delivered in a continuous flow manner without any intrusion. The production steps in this process are generally interconnected, and this layout is preferred for products made in very high volume and where the product variety is very limited or where there is no variety at all. Industries which prefer these kinds of layouts are paper industry, breweries and gasoline production companies (Ohlager, 2007).

2.1.2 Make-To-Order (MTO)

In the recent time, there is an increase in customizability of the products as well as there is a demand for a wide variety of products which has eventually lead the industries to opt for Made-To-Order MTO production policy to satisfy the customers and to maintain an acceptable level in inventory (Altendorfer, 2014). The focal company’s preassembly area follows a Make to Order MTO setup where the production volume is generally medium or high along with very high inventory. The labours skill and flexibility is low as their work methods are generally routine. (Rahman Abdul Rahim & Shariff Nabi Baksh, 2003).

According to (Bellgran & Säfsten, 2010) any production system is built up in a hierarchical perspective where the production system is a subsystem to a manufacturing system. They have also explained the difference between these systems. A manufacturing system consists of a list of operation starting form planning the raw materials to choosing production processes till managing and marketing the finished products; whereas a production system focuses only on making and designing the products. Further, the production system is classified into two subsystems consisting of an assembly system and part production system(see Figure 1 below).

Figure 1 A Perspective on the Production System (Bellgran & Säfsten, 2010)

2.2 Automation.

The way in which automation is perceived among manufacturing industries would continuously alter with time (Parasuraman & Riley, 1997). Therefore, it is challenging to define automation in A generic sense, due to the wide range of contexts and applications in which automation is evolving today. According to (Osborn, 1953),
**Theoretical background**

Automation involves three main functions, Automatic operations; automatic processes; and automated handling of materials and information. The meaning of ‘automation’ also resonates with ‘mechanisation’. Mechanisation could be defined as the replacement of physical work functions of humans by machines (Groover M. P., 2019). According to him, the interrelations between the terms ‘mechanisation’ and ‘automation’ could be defined as follows-

“The application of machines to tasks once performed by human beings or, increasingly, to tasks that would otherwise be impossible; although the term mechanisation is often used to refer to the simple replacement of human labour by machines, automation generally implies the integration of machines into a self-governing system. (Groover M. P., 2008)”

From the above definition, it could be observed that automation is a function of mechanisation combined with an amalgamation of the ability to sense the environmental factors by using artificial sensors (Frohm, Stahre, & Winroth, 2008); (Parasuraman & Sheridan, 2005).

Historically, automation has not only relieved humans from repetitive, tedious, hazardous, and time-consuming tasks (Parasuraman & Mouloua, 1996). Throughout its evolution, automation has also proved to be an efficient tool for achieving a cost-effective production process in manufacturing units (Satchell, 1998).

According to (Frohm, Stahre, & Winroth, 2008) The development of achieving cost-effective production could be attributed to that fact that, today automation has not just freed the human in terms of physical/labour capabilities, but has also relived humans in terms of imparting of cognitive capabilities such as decision making, visualisation and interpretation of information (Frohm, Stahre, & Winroth, 2008). Therefore, in today’s frame of reference, design of automated systems should be focussed on both the mechanisation aspects as well as cognitive aspects, this requires a human-centred ideology which allows the design of automated systems within manufacturing to optimise between the task allocation between humans and machines.

### 2.2.1 Automated production systems.

(Groover M. P., 2008) has presented three main types of automation, namely fixed automation, programmable automation and flexible automation. According to the same author –

Fixed automation is also denoted as hard automation since this type utilises the equipment to do a specific operation. The operation may be a simple rotatory motion, and the main drawback is the making changes in the design of the product made in these machines. But when it comes to programmable automation and flexible automation, both of these have high flexibility when it comes to the design of the products. Both of these automation types accommodate the configuration of different types or a variety of products, but the only drawback is the production rate is low compared to fixed automation. These types of automation are suitable for batch production, where the investment cost is generally high in these types of automation.

Flexible automation consists of CNC machines and a programmable automation consist of industrial robots.

There is one more type of automation, namely integrated automation apart from the types explained by Groover (2008). In an integrated automation process, the entire manufacturing system is entirely controlled by computers and the transfer of information is completely digital. This system would use a combination of fixed automation and flexible automation where it consists of both robots and special
purpose machines in the production line along with this it also consists of automated storage and retrieval system (Power Electronic-EE IIT, 2010).
### Theoretical background

#### 2.2.2 Triggers for automation technologies in preassembly part production systems.

**Table 1. Depicts the common triggers for automation.**

<table>
<thead>
<tr>
<th>Triggers</th>
<th>Authors.</th>
</tr>
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<tbody>
<tr>
<td>• Reduction in operating costs.</td>
<td>(Groover M. P., 2008); (Tangen, Axelsson, Dencker, &amp; Gröndahl, 2008);</td>
</tr>
<tr>
<td>• Reduction in repetitive tasks.</td>
<td>(Ariss, Raghunathan, &amp; Kunnathar, 2000)</td>
</tr>
<tr>
<td>• Improved operator safety.</td>
<td></td>
</tr>
<tr>
<td>• Competitive advantage.</td>
<td>(Ohlager, 2007);</td>
</tr>
<tr>
<td>• Quality.</td>
<td>(Tangen, Axelsson, Dencker, &amp; Gröndahl, 2008) (Ariss, Raghunathan, &amp;</td>
</tr>
<tr>
<td>• Costs.</td>
<td>Kunnathar, 2000)</td>
</tr>
<tr>
<td>• Deliverability.</td>
<td></td>
</tr>
<tr>
<td>• Flexibility.</td>
<td></td>
</tr>
<tr>
<td>• Technological feasibility.</td>
<td>(Wickens, Hollands, Banbury, &amp; Parasuraman, 2013);</td>
</tr>
<tr>
<td>• Reduction in unpleasant/hazardous tasks.</td>
<td></td>
</tr>
<tr>
<td>• Faster production ramp-ups.</td>
<td>(Meredith, 1987).</td>
</tr>
<tr>
<td>• Improved productivity.</td>
<td>(Zairi, 1993) ; y (Ariss, Raghunathan, &amp; Kunnathar, 2000).</td>
</tr>
</tbody>
</table>

A company would have various triggers for automating their production systems; (depicted in Table 1 above). According to (Wickens, Lee, Liu, & Gordon-Becker, 2004) automation may felicitate by assisting the humans with difficult or unpleasant task and may also help in performing hazardous tasks, further automation increases human capability and facilitates in technological feasibility. (Groover M. P., 2008) has also argued how automation can help in reducing labour cost, manufacturing time and repetitive tasks, while at the same time increasing the quality, labour safety and productivity. In addition to these, one more main factor that would trigger a company for automating is for the competitive factors which would help in reaching the company's goals (Ohlager, 2007). Some researchers have said that a company's automation strategies will be directly connected to its competitive factors, (Tangen, Axelson, Dencker, & Gröndahl, 2008) have broken down companies competitive factors that trigger automation in terms of properties like cost, quality, delivery capability and flexibility.

The common factors, as discussed by most of the authors for a company to automate its production systems, are-

**Increased Productivity:** Adaptation of automation by companies has an enormous impact on their production systems, automation technology generally aims at improving the productivity of the company. This statement has also been argued by (Zairi, 1993) stating that implementing automation directly improves the overall effectiveness and efficiency of the production system in a company. Apart from this
some other researched have also found that automation technologies might help in reducing the lead time and work breakdown at the same time improving productivity and safety (Ariss, Raghunathan, & Kunnathar, 2000).

**Quality Improvement:** In the recent trend’s, customers’ demands have driven industries to increase the quality of the products; which forces the company to implement automation technologies as one main task done by these technologies is identifying errors or flaws in the products (Ariss, Raghunathan, & Kunnathar, 2000). The identification is generally made in the design phase itself thus, reducing the unwanted capital in reworks; this statement is also argued by (Zairi, 1993) who says quality has become the main criteria for the companies to implement automation in their production systems. (Kandray, 2010) has pointed out some areas like inventory, production planning and scheduling where automation may improve the quality of the product.

**Product Design:** Many researchers have found out that implementing automation at the design phase may help in reducing the errors or flaws in products and as well as help in modification or redesigning of the products at a very early stage (Ariss, Raghunathan, & Kunnathar, 2000). According to (Meredith, 1987) time taken during the product’s design phase is generally reduced by using automation technology by testing for structural and engineering aspects of the prototype before its even made. It has been noted that manufacturability of the products, as well as aftermarket maintenance, have found to be enhanced by using automation technologies in earlier phases of product design.

2.2.3 Why to automate?
According to (Frohm, Stahre, & Winroth, 2008) the reasons for why to automate could be broadly viewed from two perspectives, i.e., Industrial perspective and Production systems perspective, wherein the latter consists of a human-centred approach. Because, even though a company implements high-tech automated systems in their production units, there must be a balanced allocation of tasks between humans and automation. Otherwise, just improving the Level of Automation could also mean increased cognitive workload on the operator. Therefore, the main issue of consideration while designing automation within manufacturing systems is not just how to design the best automated production system, but also how to optimise the Task Allocation (TA) between human and automation.

2.3 Task Allocation.
The term task allocation has been defined and explained by various authors over the decades. Initially, the primary strategy of task allocation was determined by (Fitts, 1951) stating that, it is a way to allocate tasks between humans and machines while considering both as a resource of the production system. He also further added that both human and machines are better in each and went on to state that machine is better at doing repetitive tasks, whereas men are better at improvising the existing task (MABA-MABA). Later on, some more researches added to Fitts definition like (Sheridan T., 1995) incorporated the concept of automation into it and stated that humans should be allocated with the task best suited for them and automation should be allocated with tasks best suited for it. But this definition by Sheridan was counter-argued by (Endsley & Kiris, 1995) stating that if tasks in which machines are better being automated then a human is still needed to monitor it with full situation awareness which in some cases might increase the cognitive workload of the human leading to disturbances in the production system. (Prince, 1985) stated that some activities or set of tasks could be done by both humans and machines working together and further added on saying that both human and machine should be complementing
Theoritical background

each other in doing the tasks rather than splitting each task. (Sheridan T., 2000) Also supported (Prince, 1985) statement saying, there should be an equal split of tasks between human and machines rather than focusing on one resource alone. In the recent year’s researchers like (Parasuraman & Wickens, 2008) have said that designers are modifying the subsystems to improve the productivity and economic feasibility but overlook the fact that this will lead to overloading/suboptimisation of the valueable human capabilities in the system.

2.3.1 Types of Task Allocation:
Generally, A task carried out in A production system consists mainly of the mechanical or physical task along with cognitive tasks; various authors have split these tasks into multiple levels in terms of mechanical handling and cognitive handing. (Bright, 1958), in his book has allocated the task in 17 different levels in terms of a mechanical scale, where he decides the levels depending on the mechanical task done by the human. In his scale, if the human initiates the control to the system, then it lies between 1-4; if the control is shared between machine and human it lies between 5-8; and if the decision control is fully automated then it lies above level 9. Some other researchers like (Marsh & Mannari, 1981) have used a mechanical scale as well and have divided it into 6 levels where each level goes from a task done manually by a human to the fully automated task done by the computer system. In terms of information scale researches like (Sheridan T. B., 1980 ) have split it into 10 stages where each level denotes how much information is shared by the system to the human. (Parasuraman, Sheridan, & Wickens, 2000) Have also scaled the task in term of information shared by the systems and denoted that information shared must be a changeable factor. A task allocation can also be denoted with a combination of both mechanical and cognitive scales, (Frohm J., 2008) mentioned that- allocation of tasks between humans and machines varies from being completely manual to completely automatic, so he further split these mechanical and cognitive tasks into 7 levels each and formed a matrix which would give a total of 49 possibilities.

To do this first all, the task and sub-task carried out by the human in a system must be studied according to the Hierarchical Task Analysis(HTA) by (Stanton, et al., 2013), the tasks should be broken down until where the human to machine is responsible on how cognitive and what mechanical activity is need to do the task. Then with this, a cumulative mechanical LoA and cognitive LoA are noted, and a Square of Possible Improvements(SoPI) matrix is formed (Fast-Berglund & Stahre, 2010 ).
2.4 Levels of Automation.

Historically, (Sheridan & Verplank, 1978) provided a detailed explanation regarding the co-operation between humans and computers, concerning the shifting of roles of humans from manual to supervisory control. They introduced a model which encompassed 10 stages in the levels of automation; wherein, they provided an understanding of the variety of co-operative choices depending upon, who can be in control of the operation between humans and computers. These choices were listed down in a model varying from completely manual to completely automatic, giving an analytical description about who can be in control at every stage.

According to (Groover M. P., 2008), Level of Automation from a manufacturing perspective could be defined as the amount of level of engagement of humans, with the focus around machines, which could be either manually operated; semi-automated; or fully automated.

Later on, (Frohm, Stahre, & Winroth, 2008) in line with (Chiantella, 1982) and (Williams & Li, 1999) recognised that tasks related to automation in manufacturing operations could be categorised into two different classes, i.e. Mechanization (physical tasks) and Computerized (cognitive tasks). Wherein, mechanisation tasks are represented by human physical tasks which are involved in mission fulfilment such as the use of human muscle power or the tasks related to material and energy transformation (see Figure 2, below) (Williams & Li, 1999) and (Frohm, Lindström, & Bellgran, 2005). And, computerisation tasks are represented by information control tasks such as mental activities related to the human sensory thought process (Williams & Li, 1999).

(Frohm, Stahre, & Winroth, 2008) suggested that, changes in the levels of automation of tasks involved in manufacturing operations can be done to both, physical as well as cognitive tasks. Increasing the level of automation in physical tasks implies mechanised support; whereas increasing the level of automation in cognitive tasks, implies either the provision of decision support to the operator or to increase the
efficiency of the flow of information; that would eventually support the operator to have better supervisory control over the mechanised tasks.

*Table 2 LoA scales for computerised and mechanised tasks within manufacturing (Frohm, Stahre, & Winroth, 2008).*

<table>
<thead>
<tr>
<th>LoA</th>
<th>Mechanical and Equipment</th>
<th>Information and Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Totally manual - Totally manual work, no tools are used, only the users own muscle power. Eg. The users own muscle power</td>
<td>Totally manual - The user creates his/her own understanding for the situation, and develops his/her course of action based on his/her earlier experience and knowledge. Eg. The users earlier experience and knowledge</td>
</tr>
<tr>
<td>2</td>
<td>Static hand tool - Manual work with support of static tool. Eg. Screwdriver</td>
<td>Decision giving - The user gets information on what to do, or proposal on how the task can be achieved. Eg. Work order</td>
</tr>
<tr>
<td>3</td>
<td>Flexible hand tool - Manual work with support of flexible tool. Eg. Adjustable spanner</td>
<td>Teaching - The user gets instruction on how the task can be achieved. Eg. Checklists, manuals</td>
</tr>
<tr>
<td>4</td>
<td>Automated hand tool - Manual work with support of automated tool. Eg. Hydraulic bolt driver</td>
<td>Questioning - The technology question the execution, if the execution deviate from what the technology consider being suitable. Eg. Verification before action</td>
</tr>
<tr>
<td>5</td>
<td>Static machine/workstation - Automatic work by machine that is designed for a specific task. Eg. Lathe</td>
<td>Supervision - The technology calls for the users' attention, and direct it to the present task. Eg. Alarms</td>
</tr>
<tr>
<td>6</td>
<td>Flexible machine/workstation - Automatic work by machine that can be reconfigured for different tasks. Eg. CNC-machine</td>
<td>Intervene - The technology takes over and corrects the action, if the executions deviate from what the technology consider being suitable. Eg. Thermostat</td>
</tr>
<tr>
<td>7</td>
<td>Totally automatic - Totally automatic work, the machine solve all deviations or problems that occur by it self. Eg. Autonomous systems</td>
<td>Totally automatic - All information and control is handled by the technology. The user is never involved. Eg. Autonomous systems</td>
</tr>
</tbody>
</table>

(Frohm, Stahre, & Winroth, 2008) further identified two independent continuums, one of which comprised of mechanical and equipment (physical tasks); and the other consisted of information and control tasks (cognitive tasks); they also provided a model to assess the two-level of automation (LoA) continuums into two seven-step reference scales, each reference scale indicated levels of automation from totally manual to automatic. (see Table 2 above.) and finally concluded that, by assessing the (a) Relevant minimum levels of automation (LoAmin) (b) Relevant maximum level of automation (LoA max) and (c) Current levels of automation (LoA cur); on both the respective reference scales for each work tasks carried out by humans, machines or both humans and machines; the potential for increasing or reducing the level of automation for work tasks could be gauged in line with the requirements of the study.

The results of such assessments could be applied for improving the levels of automation of manufacturing systems.
2.5 Dynamo method

The ‘DYNAMO’ project (Dynamic Levels of Automation for Robust Manufacturing Systems) therefore, the acronym ‘DYNAMO’ was financed by the Swedish Foundation of Strategic Research (Lindström & Winroth, 2010). Further research in the DYNAMO project in conjunction with the researchers from the project ProAct, led to the development of a systematic method to measure and assess the levels of automation that could be applied in an industrial context (Garnell, Frohm, Bruch, & Dencker, 2007).

The purpose for validation and assessment of the measurement of levels of automation (LoA) was to seek the appropriate levels of automation for balancing the manufacturing systems, with an approach of achieving high effectiveness in improving the levels of automation of manufacturing systems (Garnell, Frohm, Bruch, & Dencker, 2007).

The development, implementation and validation of the DYNAMO methodology presented by (Garnell, Frohm, Bruch, & Dencker, 2007), was based on six case studies conducted from the years 2004 to 2007 wherein, single case studies were adapted sequentially; and was mainly focussed to improving reliability of the existing dynamo methodology, to enhance its applicability over a wide range of industries.

Further research on the DYNAMO methodology led to modifications to the original method, and the revised methodology was known as DYNAMO++; which was developed during the years 2007-2009; and was validated further by assimilating useful information from additional five case studies that was conducted within Swedish manufacturing industries (Fasth, Stahre, & Dencker, 2008) (Garnell, Frohm, Bruch, & Dencker, 2007).

The main modifications included- conducting a value stream analysis (VSA), which was done to gain information regarding the flow of materials and information as well as to gather information regarding time parameters to be studied during the flow. Additionally, video documentation was included to enhance the analysis carried out at the assembly area (Fasth, Stahre, & Dencker, 2008) (Garnell, Frohm, Bruch, & Dencker, 2007).
Theoretical background

Table 3 DYNAMO++ four phases with twelve steps. (Garnell, Frohm, Bruch, & Dencker, 2007); (Frohm J., 2008).

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
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<tbody>
<tr>
<td>1.</td>
<td>Choose a system</td>
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<tr>
<td>2.</td>
<td>Walk the process</td>
</tr>
<tr>
<td>3.</td>
<td>Identify flow and time parameters (VSA)</td>
</tr>
</tbody>
</table>

**Phase I - Pre-Study**

- 1. Choose a system
- 2. Walk the process
- 3. Identify flow and time parameters (VSA)

**Phase II - Measurement**

- 4. Identify main operations (HTA)
- 5. Measure LoA (mechanical and cognitive)
- 6. Document the results

- 7. Decide the minimum and maximum levels for the identified operations (Workshop)
- 8. Design the Square of Possible Improvements (SoPI) based on results from the workshop
- 9. Analysis of the SoPI

**Phase III - Analysis**

- 10. Visualize suggestions of improvements
- 11. Implementation of the suggested improvements
- 12. Follow-up on the implementation

**Phase IV - Implementation**

The DYNAMO++ methodology according to (Fasth, Stahre, & Dencker, 2008) (Fasth & Stahre, 2008) (Fasth, 2012) consists of the following.
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The DYNAMO++ methodology comprises of 12 steps which are supposed to be carried out in succession; and these 12 steps are further categorised into 4 phases, with 3 steps in each phase. (see above, Table 3 & Table 4)

The first two phases are executed to know the present status of the system to get a clear idea about- current levels of automation, current material flows, current information flows, current production flows/layouts, as well as current resource flows. (see figure 3 below)

Level of automation (LoA) is measured of each task carried out in the area under study with the help of a seven-step reference scale that measures level of automation (LoA) related to- mechanical and equipment (physical) tasks, as well as current levels of automation (LoA) of the information and control (cognitive) tasks.

The last two phases - phase 3 and phase 4; are used to develop the levels of automation for the future stage. (see Figure 3 below)

The output analysis carried out from the first two phases; acts as an input for the subsequent two phases, i.e., phase 3 and phase 4.

The first phase, PHASE 1, is called as the ‘prestudy phase’. The second phase, PHASE 2, is known as the ‘measurement phase’. The third phase, PHASE 3, is known as the ‘analysis phase’. And lastly, the fourth phase PHASE 4 is known as the ‘implementation phase’.

---

2.5.1 PHASE 1 – PRESTUDY.

The main objective of the pre-study phase is to get an overview and initial understanding of the characteristics of the production system under study.

This phase helps the researchers to decide upon the ‘goal functions’ that the study seeks to accomplish; it also helps to get a clear understanding about the ‘triggers for change’; and helps to get a better understanding about the logistical flow of the production system under study (Fasth, 2012).

Step 1 - Choose the system.

This step could be performed outside of the system under study, and involves establishing the goals and purpose of measurement and thereby, helps the researchers...
to perceive the delimitations of the production flow such that, the system boundaries could be set for the measurement (Frohm J., 2008). For example, ‘The goal of the LoA measurement is to investigate the current levels of automation in the preassembly part production system, and thereby gauge the possibilities to increase the level of automation in the preassembly part production system’.

The presudy could also involve chalking out a pre-LoA measurement plan to get an idea about the protocols of the measurement; this would also help the researchers to approximately gauge the timeframe required for the study as well as understand the underlying goals of the measurement; during this time other vital information regarding the production flow can also be identified and evaluated such as- the demographics regarding the type of organisation prevalent in the area under study, information regarding the types of machines, and the other vital information regarding the system under study (Frohm J., 2008).

**Step 2- Walk the process.**
According to (Frohm J., 2008), This step is supposed to be conducted on-site. This step involves identification and documentation of the parameters pertaining to the production flow from a company perspective; this step helps the researchers to denote the start and end of the production flow in line with the scope of the study (Frohm J., 2008).

This step also involves the industry representatives, as it is necessary to run through the measurement steps so that the people in the industry that are directly or indirectly involved in the measurement are well informed about the procedures, objectives as well as the intentions regarding the study conducted. Informing the people is necessary such that they are comfortable to participate in the process, and it also avoids probable biases/Hawthorne effect as the behaviour of the workforce may tend to be different than normal during the study. Once the people involved in the study are well informed, the initial data collection in the industry may commence.

Some of the vital data points for collecting data at this step could be regarding- variants as well as volumes of the products produced, demographics regarding the work organisation, and most importantly the tasks carried out by the machines as well as the tasks carried out by humans (Frohm J., 2008).

**Step 3- Identify and visualise the flow and time parameters (VSA)**
Value stream analysis is done in order to collect information related to flow and time parameters such as – a) information flows b) material flows; VSA is carried out to get a visual overview of the different types of flows as well as, to identify the buffers between the production operations (Fasth, Stahre, & Dencker, 2008). The output achieved from conducting the value stream mapping, also helps the researchers to identify the value-added and non-value-added tasks performed in the production systems (Fasth, Stahre, & Dencker, 2010).

2.5.2 PHASE 2 – MEASUREMENT.

The main aim of the measurement phase is to identify-measure, and thereby document the current status of the production systems, in terms of current Levels of Automation, on both cognitive as well as mechanical reference scales stated above (Fasth, 2012). The output achieved at the end of this phase, helps the researchers to document the current levels of automation (LoA) prevalent in the production system under study.
Step 4- Identify the main operations using Hierarchical Task Analysis (HTA).

According to (Shepherd, 1985) as cited in (Schaafstal & Schraagen, 1992); (Annett, 2003), hierarchical task analysis could be defined as- a method to re-describe the overarching goal of the task, into a set of subordinate goals; supported by a procedural plan, that indicate 'how' and 'in what order', the subordinate goals must be executed; to achieve the overarching goal of the task.

According to (Fasth, Stahre, & Dencker, 2010) In the context of measuring the levels of automation (LoA); Hierarchical task analysis is carried out by decomposing the value-adding assembly operations into tasks and subtasks to the point it reaches a level where, either ‘human’ or ‘technology’ is accountable regarding- HOW? (cognitive/information and control); and with WHAT? (physical/mechanical and equipment); the task is performed (see Figure 4 below). The HTA is done to comprehend the overall structure of the operations performed, and thereby reasonably differentiate between why the task is performed? And why is the task performed in that specific order?

To decipher the main task as well as the sub-tasks accurately, the use of video recordings was suggested (Garnell, Frohm, Bruch, & Dencker, 2007). It may, however, be a case where, due to ethical/security reasons, the use of video recordings is not possible, the researchers can document repeated observations of the task, supported by documents that contain the standard operating procedures.

![Figure 4 Identification of subtasks in the production flow of HTA.](image)

Step 5- Measure Level of Automation (LoA); (mechanical and cognitive).

Once the main tasks, as well as the subtasks, have been disintegrated and documented from step 4, the current levels of automation (LoA), for individual task could be judged by attributing each task to the two 7-step reference scales i.e. 'Mechanical and Equipment' LoA; and 'Information and Control' LoA (Frohm J., 2008); (see Figure 4, above) The ‘judging’ of the LoA for each task could be based on two essential criteria’s, i.e. by questioning- ‘how the task was conducted?’ and ‘what type of interaction between human and machine was involved in the task fulfilment?’; the latter would be more appropriate to be matched with the two reference scales (Frohm J., 2008).
The judged levels of automation (LoA) on each respective scale could be documented, which would denote the current levels of automation indicated by (LoA\textsubscript{current}) for each individual task. By the end of this step, the researchers would be able to obtain the current levels of automation corresponding to the ‘mechanical and equipment’ LoA reference scale as well as ‘information and control’ reference scale respectively.

**Step 6- Documenting the results.**
The results obtained from the previous step could be documented and represented through a matrix that encompasses the two reference scales- LoA\textsubscript{cognitive} on X-axis; and LoA\textsubscript{mechanical} on Y-axis respectively, thereby forming a 7-by-7 matrix scale containing 49 types of possible solutions for task allocation (Fast-Berglund & Stahre, 2013). The matrix provides a good representation of the current LoA and acts as a benchmark for discussing the further scope of possible improvements (SoPI) that would help improve the level of automation (Fast-Berglund & Stahre, 2013).

2.5.3 PHASE 3- ANALYSIS.

This phase involves analysing and discussing the current levels of automation, with the operators and production engineering personnel’s onsite, with the aim of estimating the relevant minimum levels of automation as well as relevant maximum levels of automation for each of the observed tasks (Frohm J., 2008). Thereby predicting the conceptual (future) possible solutions that could be implemented to increase the automation potentials of the observed tasks based on the goals of the measurement.

The evaluations carried out in this phase gives an overview regarding *when? And how?* to change the current levels of automation; and thereby perceiving which people and what factors related to the production system would be affected by the changes (Fasth, 2012).

**Step 7- Decide the minimum levels of automation (LoA\textsubscript{min}); and maximum levels of automation (LoA\textsubscript{max}); for the identified operations (workshop).**
The results documented in step 6 regarding the current levels of automation are discussed in detail with the production operators and the production engineering team. Such discussions aim to estimate the relevant minimum LoA as well as relevant maximum LoA that could be possible, for each of the work tasks measured.

The respondents for the discussions must be carefully selected, as they act as vital inputs in this stage. For example, the production operators and the production engineers are chosen as the respondents for the discussion, as they have a better knowledge about the tasks being observed and conducted.

(Frohm J., 2008) suggests that it would be beneficial to translate the assessed LoA values, in terms of hypothetical on-site tasks that the respondents could practically relate to.

**Step 8- Design the Square of Possible Improvements (SoPI) based on the results of the workshop.**

This step involves compiling the analysed data regarding current levels of automation (step6), along with the relevant min and relevant max values (step 7); thereby obtaining the Square of Possible Improvements (SoPI).

The Square of Possible Improvements (SoPI), provides a visual representation of the current LoA, relevant min LoA, (LoA\textsubscript{min}) and relevant max LoA, (LoA\textsubscript{max});. Thereby visualising the boundaries that denote the current status of the production systems
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LoA, as well as the extent to which the current LoA could be increased or decreased according to the goals of the study (Fasth & Stahre, 2008).

For example, a given task in a particular process, see Figure 5 below shows the current level of automation LoA curr (shaded in dark green) on the LoA matrix. And the light green box represents the Square of Possible Improvements that could be done on that task. The light green box encompasses the boundaries depicted by relevant minimum LoA and relevant maximum LoA (shaded in light green).

The orange blocks in Figure 7 depicts ‘operation optimisation’. Operation optimisation provides a common base for improving all the tasks performed in a given operation. As to what extent all the tasks of that particular operation could be improved on common grounds; such that all tasks would still be categorised to fit in within the same operation but with an improved LoA.

Step 9 - Analysis of the SoPI.
According to (Fasth & Stahre, 2008), the square of possible improvements SoPI, could be analysed for two different types of optimisation - A) Task optimisation; B) Operation optimisation.

A. Task optimisation- Refers to optimising only specific selected tasks carried out in a given operation.
B. Operation optimisation- Refers to optimising for one operation along with the included tasks on common grounds.

For example, Figure 6 shows that only one selected task (dark green) could be optimised along the measured boundaries; i.e., 12 possible solutions for task optimisation.
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Example- Figure 7 shows, operation optimisation, i.e., six possible solutions if the entire operation and it’s including tasks, must be optimised.

2.5.4 Phase 4- IMPLEMENTATION.
Once the analysis of the SoPI has been done in the previous phase, the implementation phase starts with the development of an action plan for implementation of the selected improvement solutions; and ends with a thorough follow-up evaluation of the implementation. The follow up towards the end of this phase also supports to analyse the effects of such implementation, on the production systems environment. And finally helps to evaluate- whether the effects of such changes are in line with the goal of the study/automation triggers.

Step 10- Visualise suggestions for improvements.
This step helps the research team to simulate the effects that the change seeks to achieve. The simulation could be on vital factors such as economic feasibility, safety, production performance, ergonomics etc. This step ends by chalking out a thorough project plan, that includes other vital details required for the implementation of the project.

**Step 11-** Implementation of the suggested improvements.
This step involves carrying out the implementation of the suggested improvements according to the project plan.

**Step 12-** Follow-up on the implementation.
This step involves checking up for the effects of the implemented changes on other vital aspects of the production systems.
And towards the end, evaluate whether the goal of the development projects was met as per plan (Fasth, 2012).

2.5.5 Barriers faced in increasing levels of automation.

The implementation or adaptation of automation may have positive or negative impacts directly on companies, customers and suppliers. The major barriers faced while implementing automation have been classified into three main categories namely organisational barriers, external barriers and technical or internal barriers where the organisational barriers consist of technical expertise of the operator, human perception and stakeholders (Del Aguila-Obra & Padilla-Meléndez, 2006). Furthermore (Saliba, Zammit, & Azzopardi, 2017) have classified internal barriers into subcategories like low volume in production, high variety of products in production, high demand fluctuations and product life cycle. These factors can also be classified into product and production aspects as well, for example, volume, variety and demand fluctuations are based on challenges faced in terms of production and factors like standardisation and life cycle depends on product perspective. In terms of external barriers (El-Gohary, 2012) has classified them in terms of customers and suppliers.

2.5.5.1 Internal Barriers

**Low volume:**
According to (Löfving, Almström, Jarebrant, Wadman, & Wedfeldt, 2018), it has been a challenge to implement automation into companies which produce products in low volume since it may affect the entire production system. Generally, if a company had a very high variation in production volume, it would eventually lead to low utilisation of machinery and thus directly affecting the workforce. (Löfving, Almström, Jarebrant, Wadman, & Wedfeldt, 2018).

**High variety:**
The degree of automation in Swedish manufacturing industries is meagre, less than 1% due to the fact that most the industries produce products that are high in variety and low in volume where industrial automation is generally developed of low variety products that are typically made high in volumes (Thomassen, Sjøbakk, & Alfnes, 2014). (Frohm J., Lindström, Winroth, & Stahre, 2006) Argues that implementing automation strategy for a company which has high variety may not be successful and lead to significant complication in the production systems.
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**Product life cycle:**
A product’s life cycle also plays a major part in a company to adopt automation, (Frohm J., Lindström, Winroth, & Stahre, 2006) suggests that implementation of automation strategies for products with shorter life cycles are not beneficial. Also (Vogel-Heuser, et al., 2014) argues that if a product is made up of many components, then the shorter life cycle of these components may be a challenge to the plant automation.

**2.5.5.2 External barriers**

**Customers:**
Adaption of automation in a company may lead to an improvement in operator productivity and may improve the overall quality of the component made, but a decision to implement the automation decisions can be successful only if the company has a good relationship with its customer base (Helper, 1995). This statement is also supported by (Hall & Khan, 2003) stating that, a strong and stable customer base is needed for a company to sustain its automation implementation decision. The factors like just in time and quality are essential key characteristics of the industry that the customer would prefer in a company, and these factors justify the implementation of automation in a company. Which in turn, compels the industry to justify the use of appropriate automation strategies/ethics within the industry.

**Supplier integration:**
According to (Rosenberg, 1972) Since suppliers are one of the significant sources of input for raw materials, they have a critical role in influencing the production aspects of the focal company; he also states that appropriate collaboration/integration of suppliers allows the focal company gain a technological advantage which eventually supports automation decisions. The same statement has also been argued by (Hall & Khan, 2003) stating that, automation adaption rate will increase if the suppliers are interested in supplying parts or components that can be incorporated in automated systems.

**2.5.5.3 Organizational barriers**

**Technological expertise of the operator:**
The employees who work in the shop floor or the operator acts as an essential factor for a company to implement automation, as their education level or skills should be considered. (Ariss, Raghunathan, & Kunnathar, 2000), also supported this statement by stating that the operator spends more time working with these automation technologies so the company’s management should consider their competence level during automation implementation decisions. The training that needs to be given to the operators must also be considered as the money spent on it would directly affect the adaptation of automation by a company (Ramchandran, 1986). (Chao & Kozlowski, 1986) also concluded this statement by stating that the employees with higher skill tend to accept automation easily than employees with lower skill and training.

**Human perception:**
It is crucial to know how the company’s employees perceive the implementation of automation strategies, (Parasuraman & Mouloua, 1996) have also denoted this saying that implementing automation may have adverse effects like employees being overloaded with information. (Endsley M., 1995) Has also indicated in his article that implementation of automation may create issues like distrust in automation or over-dependence on automation leading to skill degradation or even lead to a change of roles for the operator. Operator’s trust in automation may not be the same throughout, it
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may vary time to time as in (Muir, 1987) article, he has argued that an operators trust in automation is similar to trust between individuals, i.e., if the operator is let down once he/she tends to lose confidence in automation. Whereas in (Lee & Moray, 1992) they have suggested that operators may blindly trust automation even it fails to notify error and continue working unless they notice the same failure repeated. The Ironies of automation according to (Bainbridge, 1982) states that a highly automated system will leave the operator bored where’s a semi-automated system will challenge the operator’s cognitive skill more. These ironies were further argued by (Wickens, Hollands, Banbury, & Parasuraman, 2013) saying that increase in the level of automation in a system will tend to increase the cognitive load of the operator thereby, raising the possibility for catastrophic failures.
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3.1 Structural approach.

3.1.1 Connections between the research questions and research method.

The purpose of this study was threefold. Firstly, to assess the current levels of automation (LoA) in the preassembly part production area.

Secondly, to identify the potential workstations where increasing the LoA was suitable. The first two steps in this research, gave the researchers a clear picture of which operations are the most appropriate for the industry, to improve in terms of automation.

The third and the final scope of this research was to identify the barriers faced, internal as well as external to the firm. The identification of barriers was done by considering the implications of increasing the LoA; within the context of the production systems environment.

To fulfil the three-dimensional purpose of this research, a structured approach to this study was developed. The structure consists of six steps which were essential for answering the research questions. (see Figure 8 below).

3.1.2 Six-Step Structure for Answering Research Question

![Six step structure for answering the research question.](image-url)
3.1.2.1 Literature review.

Scientific research literature, as well as academic research articles, was collected from various sources. The search strategies used during this literature review was relevant to understand as well as evaluate the levels of automation (LoA) of the preassembly part production. A similar pattern of the literature review was conducted parallelly, focussing on the barriers that prevent the use of automation technologies in related as well as different types of production systems. The literature review helped the researchers to gain a deeper understanding of the background, problems and its context. The literature review carried out in the topic of interest also shed light upon the methodological preference accepted by other researchers in the field, which indirectly influenced the choice of the method chosen in this study.

3.1.2.2 Identification of the production characteristics of the Preassembly part production.

Due to the limited scope of this research, it was decided by the management, to confine the boundaries of this research within the preassembly part production area. Respecting the limitations of this research, the researchers began with an initial pre-study, to understand the characteristics of the preassembly part production area on the grounds of the following-
   a) The logistical flow of materials and information.
   b) Identification of the main tasks performed at each workstation of the preassembly part production area.
   c) Demographics of the work organisation in the preassembly part production area.
   d) Product variety and volumes.

The research techniques used in this step were as follows-
   i. Unstructured/exploratory interviews with the production engineering team.
   ii. Unstructured/exploratory interviews with the production operators at each workstation, belonging to the preassembly part production area.
   iii. Participant observations were conducted to understand the production characteristics of the preassembly part production area.

3.1.2.3 Evaluation of the current levels of automation (LoA).

After scrutinising the current as well as relevant literature pertaining to this field, the researchers chose to apply the DYNAMO++ methodology, in the preassembly part production area, to assess the current levels of automation (LoA). The evaluation of the current levels of automation (LoA), was done by using DYNAMO++ methodology which consisted of the following-
   i. Document analysis.
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ii. Hierarchical Task Analysis (HTA) and Cognitive Task Analysis (CTA); of each operation carried out in the preassembly part production area.

3.1.2.4 Analysis of the current LoA to generate possible solutions for increasing automation levels in the preassembly part production area.

The current LoA was analysed with the assistance of the production floor operators as well as the production engineering team, with the aim of discussing the possible solutions that could be developed for increasing the LoA. Observations, as well as discussions, were brainstormed in focus groups to generate the solutions for increasing the LoA.

3.1.2.5 Analysis of suggestions and improvement to show what effect it has on other characteristics of the production systems environment.

Identification of the barriers faced by the industry was made by visualising the suggestions for improvements, within the context of the production systems environment.
To investigate the barriers faced by the firm in the effort to increase the LoA, firstly, the suggestions for improvements were visualised in the context of the preassembly part production.
Such visualisation aided the researchers to investigate the implications that such suggestions could have on other aspects of the ‘production systems environment.’
The investigation of the barriers faced by the industry was done by discussing the suggestions for improvement, by conducting semi-structured interviews with personnel belonging to other functions of the production systems such as production manager, design team, as well as quality assurance team.

3.1.2.6 Classification of barriers faced by the industry.

The barriers identified by discussions from the semi-structured exploratory interviews, with personnel’s belonging to different areas of the production system; were then classified based on the factors that are prevalent; internal as well as external to the production systems environment.
The classified barriers were reconfirmed with the literature review, thereby confirming and conceptualising the barriers faced by the firm.
3.2 Research method

3.2.1 Research philosophy.
Understanding of the research philosophies is essential because it constitutes the assumptions based on which researchers perceive the world (in this case, the dynamics of the production system) and how it affects the build-up of knowledge.

(Saunders, Lewis, & Thornhill, 2016) defines research philosophy as-
“An overarching term related to a system of beliefs and assumptions about the nature of knowledge and the nature of that knowledge in relation to research.”

Research philosophy helps to guide the research approach towards the concept under investigation, thereby it aids to integrate research effectively into industrial/professional practices.

According to (Saunders, Lewis, & Thornhill, 2016) research philosophy could be classified into 4 types- positivism, interpretivism, critical realism and pragmatism. Primarily, research philosophy could be broadly split into two dichotomous categories- positivist and interpretivist.
(Williamson, 2002) Suggests that, the positivist approach is mainly related to the quantitative methods in research, with a deductive style of reasoning based on hypothesis testing. Whereas the interpretivist approach is majorly associated with a qualitative approach, with an inductive style of reasoning which is inclined towards hypothesis generation. She further explains that the positivist approach seeks to link cause and effect. Positivist approach apprehends that new knowledge can only be found upon what could be objectively experienced/observed, and thereby measured.

‘Interpretative approach’ as the name suggests is of an exploratory nature and thereby aids to create a vibrant and in-depth understanding about the research phenomena in its natural context (Saunders, Lewis, & Thornhill, 2016).
Interpretivist approach acknowledges the fact that humans interpret a phenomenon differently, they consider that the researchers exploring a phenomena deals with multiple realities that are constructed socially as well as individually, and therefore attempts to focus upon the meanings made by people as they interpret the research phenomena (Williamson, 2002). This idea of interpretivism was also in line with (Savin- Baden & Claire Howell, 2013) as they mention that, from an interpretivist perspective, the social reality in its entirety is characterised by intersubjectivity and shared understandings, which needs to be interpreted and acknowledged. They further explain that the key features of an interpretivist approach in research involve a thorough understanding of a phenomenon, interpreting the data and lastly applying self-evaluations and reflections to analyse the data.

In this research owing to the presence of ‘human factors in engineering,’ related factor that affect the use of automated technologies in the production area; the data collection also considered the aspects such as- a) Common perceptions of the operators towards the use of automated technologies. b) Reluctance to change. d) Competencies of the personnel’s to quickly adapt to advanced manufacturing systems etc. which required an interpretation of human perceptions in this study; therefore, the use of an interpretive approach was suitable for this study.

3.2.2 Research purpose.
A research project may have various purposes. The four common research purposes categorised by (Saunders, Lewis, & Thornhill, 2016) are as follows -
 a) Exploratory.
 b) Descriptive.
c) Explanatory.  
d) Evaluative.  
e) Combined.  

According to (Saunders, Lewis, & Thornhill, 2016) adoption of exploratory research could be useful for researchers as they make use of open-ended questions to investigate about a particular phenomenon, to obtain a better insight about the topic of interest. In the process of exploring or understanding a problem/phenomenon, exploratory research often makes use of ‘what?’, ‘how?’ type of questions. Typical exploratory research begins with an extensive literature review, followed by-in-depth interviews with the people who have an expertise in the topic under investigation, or the people who are dealing with the phenomenon frequently as they could have enriched information about the problem/phenomenon. (Saunders, Lewis, & Thornhill, 2016) Further mention that, the use of unstructured interaction between the researchers and the subject paves the way for the acquisition of new contributions/insightful data, this aspect also makes the design more flexible. As a consequence, exploratory research makes a funnelling approach, which begins with a broad focus that converges gradually into a narrower approach as the research investigation progresses.

The purpose of this study was to explore the barriers faced by the industry while increasing the LoA within the context of the preassembly production area; the approach towards answering research questions was exploratory. Consecutively, to gain a better understanding of the production flow as well as the various tasks carried out in the production system, from the perspectives of the operators; a qualitative approach was suitable. The idea of combining exploratory research with qualitative data collection approach was also in line with (Williamson, 2002), as she mentions that, qualitative research methods are often used in conjunction to exploratory research, especially when the research is in the theory-building stage. (Shanks, Arnott, & Rouse, 1993) as cited in (Williamson, 2002).

3.2.3 Research approach.  
The research approach is synonymous to reasoning styles. The reasoning is a method of arriving at conclusions based upon a logical argument (Walliman & Bousmaha, 2001). Research approach deals with how we know about something empirically (Thomas, 2017). To know something ‘empirically’ means developing the knowledge of science via experience (Williamson, 2002). To build trustworthy and reliable knowledge using experience, we need to impart analysis to infer causal links between the ‘experience’ and how that experience leads to ‘Knowledge’. A study done to a set of data may differ from one individual in a particular context to another. As discussed earlier, everyone has their own ways of analogy or psychological approach of analysing given data and building upon new knowledge based on the choice of research philosophy, research methodology and research approach. Therefore, to justify the build-up of knowledge, corresponding to what was experienced in the field, the psychological approach to research should be based upon a specific style of reasoning. By mentioning the reasoning style, the researchers aim to present the research approach used. The two contrasting approaches to research or approaches to the development of theory could be classified as follows-

a) Deductive.  
b) Inductive.


A. Deductive reasoning

Deductive reasoning occurs when logical derivation of conclusion occurs from a set of premises, and if the observed premises are true, then the conclusion is believed to be true (Ketoviki & Mantere, 2010) as cited in (Saunders, Lewis, & Thornhill, 2016). Premises could be defined as the initial set of assumptions that the researcher believes to be true, which could be approved or disapproved by the conclusive results of the study.

According to (Williamson, 2002) deductive reasoning starts with generalisation and then moves towards inferences about particular instances. Deductive style of reasoning mainly encompasses the hypothesis testing approach. Hypothesis testing judges the ‘value of the data collected’ as well as the ‘value of the results obtained’, in conjunction to the ‘methods used to obtain the results’, to justify/validate the relevance of the conclusions made (Leedy & Ormrod, 2019).

(Williamson, 2002) defines variables as an element or factor under investigation. Deductive style of reasoning is widely used in scientific experiments where different variables can be controlled. Due to which, deductive reasoning is extremely important in areas such as hypothesis generation, theory testing, which are critical factors in various disciplines such as- mathematics, chemistry and physics.

However, in industrial applications, especially involving a human factor, it becomes complicated as well as challenging for researchers to control the variables. This research was not undertaken to prove or disapprove a theory; instead, it was carried out to explore the barriers faced by the firm in the effort to increase the LoA. Therefore this study takes an approach that leads to the development of a hypothesis that is capable of capturing the various decision categorises (triggers) in terms of barriers faced by the firm. Additionally, since the process of qualitative data collection and analysis; related to barriers faced by the firm was partly conducted using the perceptions of the subjects, therefore the use of deductive approach towards this research seemed improbable.

B. Inductive approach.

The inductive approach can be understood in contrast to deductive approach. In inductive approach, there is a gap in ‘reasoning argument’ that is used to link - the conclusions made and the premises observed (Ketoviki & Mantere, 2010), As cited in (Saunders, Lewis, & Thornhill, 2016).

According to (Leedy & Ormrod, 2019) unlike deductive approach, the inductive approach begins with an observed instance; these specific observed instances are then used as a reasoning argument to draw conclusions about the entire event; (i.e. observing the sample to draw conclusions regarding the population). Hence the inductive approach can also be termed as ‘hypothesis-generating approach to research’; hypothesis-generating approach leads to the development of new theories that could be tested. Therefore, we can say that the inductive approach allows the data to lead to the development of new theory.

Inductive style of reasoning is more prevalent in the interpretivist approach as it completely immerses the researcher in the field (Williamson, 2002). Once the researcher is wholly involved in the research environment, the data is collected and analysed; thereafter, the researchers understand the patterns in the data to develop an understanding of the relevant situation, concepts or insights (Reneker, 1993) as cited in (Williamson, 2002).
The use of inductive approach proved to be more suitable in this study because, the researcher’s main goal was to identify the potential barriers faced by the firm to increase the LoA of the preassembly production area; as a result to fulfil the main scope of this research, i.e. to identify the barriers to improve the LoA; (and to answer the research questions accurately), it was important for the researchers to understand the dynamics of the production systems, which involves aspects of decision making related to the use of automated technologies at the shop floor. The decision making criteria was explored and understood by using empirical data from the people belonging to the (operational level); at the shop floor as well as the people involved in making decisions regarding the use of automated technologies (managerial level).

Additionally, the literature review that was done in the initial phases of this research also pointed out certain qualitative aspects regarding the perceptions of the people towards the use of automated technologies. To get a clear understanding about the perception of the production operators about the use of automated technologies, and to develop a better understanding of the dynamics of the current production systems; an in-depth qualitative approach was needed that was flexible enough to improve upon the knowledge of the researchers as well as the production operators.

It’s also worth noting that, deductive approach is quite a rigid methodology, due to the control the researchers has on the contextual variables. However, in this study, the researchers wanted to understand the characteristics of the variables which could be translated into barriers in increasing LoA. The in-depth, as well as flexible data collection, necessitated the researchers to use a flexible reasoning style. Therefore, the use of the inductive approach proved to be suitable for this study.

3.2.4 Case study.

A case study in a broader perspective is a detailed investigation about a phenomenon within its real-life context (Saunders, Lewis, & Thornhill, 2016). The term ‘case’ in case studies can be viewed as- A phenomenon that lies within its context. In this study, the phenomenon is LoA, and the context where this phenomenon is studied is the preassembly part production area of the focal company. The boundaries in a case studies play a vital role in research, as it locates the phenomenon and the context within its boundaries.

According to (Yin, 1994) as cited in, (Williamson, 2002) case study method can be defined as follows-

“An empirical enquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomenon and context are not clearly evident”

Case study methods could be used in conjunction to different research philosophies, approaches and purposes; this flexibility offered by the case study research allows the researchers to design an in-depth study for a wide variety of applications, reasons and purposes (Saunders, Lewis, & Thornhill, 2016). Case studies could be used to describe a phenomenon, develop nuanced theories or to test an existing theory/hypothesis (Cavaye, 1996). Case study research is used to create an understanding of a phenomenon in its natural setting, especially when the existing knowledge about the phenomenon is limited (Williamson, 2002). As compared to other methods, case study method allows the use of multiple sources of data collection, this ensures that the phenomenon is not viewed through one lens but rather through multiple lenses, which enables the researcher to understand numerous facets of the phenomenon to be unveiled and understood; this eventually also helps to increase the validity and quality of the research (Baxter & Jack, 2010).
According to (Leedy & Ormrod, 2019), the most common research techniques used in a case study method are- observations, interviews, focus groups and document analysis. The data collection, interpretation, and analysis of case study data could also vary upon the research undertaken; for instance- The analysis of the case study data could involve thematic categorisation and interpretation of data. Another way of analysing the case study data could include a synthesis of the data collected to paint a revealing portrait of the researcher’s interpretations.

(Williamson, 2002) states that, while designing and developing the structure and scope for case studies, it is crucial to do an extensive literature review, as it facilitates the researchers to comprehend the existing body of research concerned with the area of interest. An initial literature review also directs the researcher to align the research according to its context; to precisely frame research questions within the area/topic of interest. Such that, the researcher is able to effectively determine the number of cases and unit of analysis.

3.2.4.1 Unit of analysis.
Essentially, Unit of analysis points out to the researchers regarding ’where to look for answers?’; ’what to observe?’; and ‘whom to ask?’ (Miles & Huberman, 1984). Unit of analysis also aids in deciding upon the generalisability of the research findings; (i.e., can the results obtained from this study be applied to others?); (Williamson, 2002).

Once the unit of analysis is understood, the researchers can gauge the extent of data collection required to conclude.

According to (Leedy & Ormrod, 2019), the unit of analysis of the case study determines the focus of research; depending on which, the study could encompass either a single case study design; as well as a multiple case study design.

(Yin, 1994), characterises case studies broadly into three types-

a) Descriptive case studies.
b) Explanatory case studies.
c) Exploratory case studies.

a. Exploratory case studies-

Exploratory case studies, as the name suggests, involves undertaking exploratory fieldwork, and data collection before defining the research questions and the scope of the thesis. Such exploration is crucial when the researchers do not have prior knowledge in the field, such type of exploratory studies enables the researchers to assess and determine the availability and accessibility to the relevant data.

During the literature review, it was found that the concept of LoA was insufficient in the context of preassembly production. Additionally, the researchers seldom found frameworks that linked the concept of LoA to the barriers faced during its adaptation/implementation.

By linking the concept of LoA and its measurement techniques within the context of preassembly part production unit; the researchers wanted to explore and develop an understanding about various barriers that were prevalent in the focal industry. Which eventually emphasised the selection of a research method that permitted an in-depth study of the LoA concept, specifically within the boundaries of the preassembly area of the focal industry. As a result, an explorative type of single case study was chosen.

In this study, to answer the research questions, multiple sources of evidence were captured using various data collection techniques such as- observations, interviews and focus groups; to understand the barriers faced by the firm. Additionally, to justify the scope for a commendable level of reliability and validity, the researchers chose to
adapt source triangulation in their data collection; as mentioned by (Williamson, 2002). Therefore, it was necessary to use a case study method as it can encompass qualitative data collection using different research techniques required for source triangulation this study.

3.3 Data collection techniques.

3.3.1 Literature reviews.
Literature reviews are considered as a primary source of data collection. Literature reviews help the researcher to develop a strong foundation for the research by evaluating the previous contribution by other researchers in the field. Thereby, the literature review also helps the researchers to identify gaps in previous research that could open new ventures of topics for the researchers.

Scientific research literature, as well as academic research articles, were collected from various sources. The search strategies used during this literature review was relevant to understand as well as evaluate the levels of automation (LoA) of the preassembly part production. A similar pattern of the literature review was conducted parallelly, focussing on the barriers that prevent the use of automation technologies in similar as well as different types of production systems. The literature review helped the researchers to gain a deeper understanding of the background, problems and its context.

The literature review carried out within the topic of interest also shed light upon the methodological preference accepted by other researchers in the field, which indirectly influenced the choice of the method chosen in this study.

3.3.2 Interviews.
Interviews are a type of research technique used to collect information and vital data pertaining to the topic of interest, from the participants by means of asking questions. Interview research technique is most commonly used for the collection of first-hand qualitative data, wherein the respondent's knowledge, opinions and explanations about a 'phenomenon' in a given 'context' is required (Williamson, 2002).

Qualitative interviews can be described as- a developmental site of knowledge, which involves two or more individuals to discuss upon a theme of mutual interest (Kvale, 1996); (Kvale & Brinkmann, 2009), As cited in (Marshall & Rossman, 2016).

(Williamson, 2002) Points out that, an important aspect to be considered while designing an interview is the structure of the interview discussions. The interview structure describes to what extent the interview must be structured. It refers to the degree of freedom given to the respondent to answer and reflect upon the questions openly. The interview structure is dependent upon the type of information researchers wish to obtain from the interview. For instance, a rigid structure of interviews can be used in conjunction with closed questions asked in a predetermined order, where precise answers to precisely defined questions are required; such structures of interviews are majorly incorporated in a positivist's approach, where quantitative and statistical analysis is applied. On the other hand, a free/unstructured interview can be used in conjunction with unstructured and open-ended questions, where exploration of unpredicted information is required.

According to (Williamson, 2002), A semi-structured interview precisely lies between structured and unstructured interviews. In semi-structured interviews, the interviewer
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does have a set of predetermined questions or topics for discussions but; at the same time, the interviewer also has the freedom/flexibility to ask impromptu follow-up questions (outside the predefined structure) based on the response provided by the interviewee.

The use of semi-structured interview was preferred for exploratory research like this study because it allows the interviewer to gain a better understanding/clarification about the response by asking follow-up questions. The high degree of freedom imparted to the interviewer and the interviewee could also open novel leads of investigation that are critical to the study. This idea was also found in line with (Galletta, 2013); As cited in (Marshall & Rossman, 2016) as they state that semi-structured interview designs allow the researchers to gather systematic data iteratively, wherein the arrangements of the question as per protocol aids to acquire rich data. As a result, the efficiency of data analysis could also improve

Use of open-ended questions also allows the interviewee to ascertain whether the interviewee has interpreted the question correctly as per the intentions of the researcher. Additionally, the questions developed during the semi-structured interviews were intended to capture the attitude of the personnel’s regarding the use of automated technologies at the shop floor, which required the instrumentation of semi-structured interviews, since the researchers had little prior knowledge about its presence, which permitted the researchers to apprehend the prevalent attitudes of the workforce regarding the use of automated technologies.

The purpose of conducting the interviews in this study was twofold; Firstly, exploratory interviews were instrumented to get a general understanding of the focal company’s production processes. And to assimilate information related to decision criteria/ triggers as well as barriers related to the use of automated technologies. Secondly, explanatory interviews were instrumented to comprehend and collect data pertaining to the operations/tasks performed at the preassembly production area’s workstations.

3.3.2.1 Exploratory interviews

Exploratory interviews are used when the researcher’s intention from the interview is to seek new knowledge or to determine reasons for certain behaviours (Wisker, 2019). Exploratory interviews generally answer What? Why? How? and, in what effect? Types of questions.

The intentions of the researchers behind conducting the exploratory interview was firstly, to comprehend the production process of the focal company. By conducting initial exploratory interviews with the preassembly production staff, the researchers were able to understand the dynamics of the production system related to- the logistical flow of materials, demographics of the work organisation and interdependencies between different production units. Secondly, in the latter phases of this study, as the knowledge of the researchers in the field was developing, the researchers planned to use exploratory interviews with production as well as management staff to understand the various decision criteria’s that are considered currently, regarding the use of automated technologies. In the final stages of this study, exploratory interviews were conducted with the managerial employees, which focussed upon various barriers that restricted the use of automated technologies in their experience.

The procedure of asking the intended questions was categorised by using a funnelling approach, where the initial questions of the interview were generic and broad, and as the discussions progressed further, the focus was narrowed down. The funnelling
approach aided the enhance the quality of the interview data by giving a logical thread to the interview questions, which governed the interviewee's response within the topic of interest.

In semi-structured exploratory interviews conducted in this study, the researchers developed a questionnaire design as leads to guide the discussion corresponding to its intent. The interview questionnaire could be found in Appendix 1. interviews.

Before commencing the interview, the interviewers had sent an invitation via email to the respondents at least 15 days in advance. The invitation email contained a presentation of the topic and the purpose of conducting interviews. The intention of providing the interview details in the invitation mail was to mentally prepare the respondents to discuss within the context of the topic effectively. Sending the details in advance also gave the respondents time to reflect upon previous experiences pertaining to the topic. Before starting the interview, the respondents were given time to clarify their doubts. The interview lasted for approximately 90 mins; conducted in the meeting room situated near the production unit office.

While conducting the initial set of interviews, the positions of the respondents in the focal company, were as follows-

- Preassembly team leader.
- Workshop technicians at preassembly.
- Production supervisor.
- Maintenance engineer.
- Production manager.
- Production ergonomics supervisor.
- Quality engineer.
- Product design engineer.

3.3.2.2 Explanatory interviews.

Explanatory interviews are used when the researcher’s intentions from the interview are to seek explanations for events and actions. As the name suggests, explanatory interviews seek to investigate cause and effect relationships between two or more occurring phenomena.

Throughout this study, explanatory interviews were used to collect data relevant to the operations and tasks performed in the preassembly area. Explanatory interviews were also used to complement the exploratory studies conducted in the initial phases of this study. Eventually, explanatory interviews were also used to make causal links to the barriers identified in the latter part of the study.

The objective of conducting explanatory interviews was to collect qualitative as well as quantitative data from key personnel directly or indirectly involved in the preassembly production processes. Sometimes impromptu explanatory interviews were also conducted with the staff belonging to the subsequent section of the preassembly
material flow to decipher the interdependencies between the preassembly production and the production units that the preassembly area caters to.

The structural characteristics of the explanatory interviews varied from one interview to another. Thus, the interview questions were both, open as well as close-ended; depending upon the context, objectives, and the type of information sought.

The positions of the interviewees for explanatory interviews are stated below.

- Preassembly team leader.
- Workshop technicians at preassembly.
- Material handling personnel.
- Production supervisor.
- Maintenance engineer.
- Production manager.
- Workshop technicians at diverter switch assembly.
- Workshop technicians at diverter switch housing/tap selector assembly.
- Workshop technicians at testing/final assembly.

### 3.3.3 Focus groups.

(Kreuger, 1994) defines focus groups as-

"focus group is a carefully planned discussion, designed to obtain perceptions on a defined area of interest in a permissive, non-threatening environment."

According to (Savin-Baden & Claire Howell, 2013) Focus group is an assemblage of a few people, who through discussion with each other, provide resourceful, first-hand information about an issue or a subject. Such that, it is capable of being a productive, active and efficient qualitative method to provide immediate information about the perceptions and opinions of the members. Focus groups are also resourceful in research contexts, where the development of broad perspectives is required through in-depth conversations. Especially when ideas are novel, focus groups also helps to understand group consensus. Therefore, focus group techniques could prove best for researchers who seek to study perspectives and interactions of the people about a phenomenon in group dynamics.

(Creswell, 1998), pointed out that, the main objective of the focus group is for researchers to obtain information about the reality of ideas about a phenomenon in group dynamics. Additionally, it also helps the researchers to assimilate a wide variety of ideas opinion or perceptions about a group mainly, to shed light upon the inconsistencies of attitudes amongst the different members of the group within their domain of expertise.

The main objective of focus groups was to incorporate first-hand experiences from the people directly involved in the preassembly production processes, into the findings of the study that was conducted to measure current LoA; with the aim of brainstorming and generating suggestions regarding the ways in which LoA could be improved from current levels.

The participants of the focus group were limited to employees with vital knowledge regarding the preassembly production processes and the ones who were a part of previous projects that were undertaken to implement automation in the preassembly unit. The list of participants of the project group are as follows-

1. Preassembly team leader.
2. Production supervisor.
3. Production engineer.
4. Preassembly production personnel.

Invitations for the focus groups were sent to the participants by email one month in advance. A total of 11 people was invited to participate in the focus groups, out of which 4 accepted the invitation. The total time for the focus group schedule was decided to be 120 mins, which was divided into two sessions with a 15-minute break in between. For a detailed schedule of focus groups (see Appendix 2 Focus group schedule.)

Before staring the focus groups, researchers presented the aim, observations as well as the results obtained from the study that measured the current LoA; to the participants of the focus groups. Following which, participants doubts and queries about the study was clarified, which ensured that the participants had a clear understanding of the objectives behind this study.

After the initial presentations, the focus groups discussed upon improvement opportunities at workstations by focussing upon the study’s results related to each workstation one at a time and thereby suggested innovative ways in which the study results can be worked upon for its practical implementation.

While the participants were brainstorming upon the improvement opportunities, there were also counter discussions within the participants that were related to the factors that hindered the use of automation technologies at the shop floor. The moderators of the focus group built upon such discussions on an impromptu basis as they were surfacing, creating new leading questions that were required to explore various barriers perceived by the participants as a result of their experiences at the preassembly area.

Apart from the primary goal of discussing upon the improvement opportunities that could be implemented at the shop floor; the researchers also had an underlying intention to focus upon the perceptions of the participants related to the use of automation technologies at the preassembly area. For which, the researchers also, prepared topics and questions for discussions well in advance. The questions and topics of discussions were designed to have a broad focus, reflective, and debatable; to enhance participant engagement (see Appendix 2- Focus Groups)

During the entire span of the duration of the focus group, one researcher withheld the role of a moderator while the other took notes. The discussions from the focus groups, not only generated innovative applications for enhancing LoA; but also aided the researchers to understand the common perspectives and challenges related to the use of automated technologies in the preassembly area.

3.3.4 Observations.

According to (Marshall & Rossman, 1995), observation involves a systematic description of events, behaviours and procedures within the natural setting chosen for the study. Therefore, Observations can be viewed as a data collection method that highlights the complete picture within the context of the study.

According to (Mulhall, 2002), observations help the researchers to assimilate information related to the social setting in which people function; which is done by recording the context in which they work. It can also be useful for pointing out contradictory information between, what was being said about a phenomenon; and what actually happens in that phenomenon. Therefore, it could be noted that observations can either be used to complement other techniques and findings by providing evidence for an event or be used to improve and develop upon the knowledge of the researchers in the field. To explain this, she uses an interesting analogy of jigsaw puzzles, where each piece of the jigsaw can be related to individual observations; and
how these different building blocks help to build distinct pieces of evidence to paint a clear picture about an entire context or phenomena.

The idea of using observations to paint a clear picture of a context or a phenomena also resonates with (DeWalt & DeWalt, 2002) as they mention that, observations is a method used to create a complete understanding of the phenomena under study; which could be instrumented to- a) answer descriptive questions, b) develop new theory c) generate hypothesis, d) test hypothesis. They further state that the observation technique could be applied to a wide area of research pertaining to qualitative as well as quantitative research.

According to (Saunders, Lewis, & Thornhill, 2016), observations could be classified into two types depending upon the type of research they are used for (qualitative or quantitative); which are as follows-
  a) Participant observations.
  b) Structured observations.

3.3.4.1 Participant observations.

According to (Saunders, Lewis, & Thornhill, 2016), Participant observation is a qualitative data collection technique which stems from the field of social anthropology, that emphasises on the meanings made by people as they understand the phenomena within its context. They further clarify that Participant observations, allows the researchers to deeply understand the meanings constructed by the people, as they align themselves to the research environment; and how they respond, relate and make changes to their social environment respectively. Participant observation requires the researcher to enter the environmental context of those being observed (participants) and thereby attempts to study the phenomena by immersing himself/herself into the research environment by becoming the member of the workgroup/organisation. They further state that the extent to which researches participates in the field depends upon the study and could range from ‘pure observation’ to ‘full participation.

3.3.4.2 Structured observations.

According to (Saunders, Lewis, & Thornhill, 2016), contrary to participant observations; structured observations as the name suggests takes a highly predetermined and a structured approach to observe selectively. Therefore, it can be viewed as a technique more inclined towards quantitative research. Structured observations usually describe the ‘How?’ aspects rather than ‘why?’ aspects. A classic example of structured observations could be the time and motion studies, that is used to describe the procedures for various tasks with respect to time.

(Saunders, Lewis, & Thornhill, 2016), also mention that structured observations are more than just mere surveillance or fact-finding; because the logic behind the predefined structure of such observations also has a clue regarding how that data would be analysed; such that- the analysis could be transformed into valuable research findings.

(Williamson, 2002), classified observations differently based on four types of observation styles these observation styles seems to be based on the sampling methods,
which describes ‘which phenomena to watch’ as well as ‘when to watch it’. The four observation styles are presented below-

a) **Ad libitum.** - *Ad libitum* observations style as its name suggests – ‘as often as necessary’. Which means that ad libitum observations do not have any systematic constraints upon - ‘what is being recorded’ and ‘when it’s being recorded’. Therefore, we can say that the decisions regarding what and when to record in ad libitum style of observations, is entirely dependent upon the researcher/observer according to what he/she feels relevant. Due to the unsystematic nature of recording observations, ad libitum style comes with an inevitable disadvantage that all relevant events cannot be recorded. But, such methods of observations are useful to assimilate different types of information, especially when the researchers are new to the field.

b) **Focal**- In *Focal observation style*- In focal observation styles, the observer selectively chooses an individual or a group, and thereby records- physical characteristics, events, and behaviour over a predetermined time span (*Kellehear, 1993*).

c) **Scan**- In *scan observation style*, a group of subjects is rapidly scanned, at regular intervals of time, and their behaviour/observations at that particular time are recorded. Such types of observations are mainly instrumented to record behavioural states, i.e., the presence or absence of a phenomenon at a given point of time.

d) **Behaviour**- In *Behaviour observation styles*, a particular behaviour is chosen selectively in advance, parameters such as who? when? And why? Aspects of the phenomena are recorded by describing the contextual characteristics of the phenomena. Such observation styles are instrumented when the researchers are only interested in recording specific behaviour patterns, then the entire event.

For this study, the researchers incorporated all the observation styles stated above for different types of empirical data collection. The justification of the style/type of observation chosen is presented below-

The researchers chose the *ad libitum style* of data collection throughout the study, but mainly during the initial phases to gain an in-depth understanding of the material and
information flows. Additionally, it was also used to understand the essential processes that are necessary to be undertaken to manufacture tap changers.

*Scan style* of observations was undertaken to understand and collect information related to the main tasks performed at each workstation within the production unit.

*Focal style* of observations was undertaken to collect empirical data regarding the standard operating /assembly procedures for each component, assembled across all the workstations in the preassembly production unit.

*Behaviour style* of observations was chosen to understand the decision-making criteria’s, contexts and parameters; related to the choice of sequence in which various components were assembled in the preassembly area.

The use of structured observations was incorporated in the study conducted to measure current LoA. As per the methodology by (Fasth, Stahre, & Dencker, 2008) (Fasth & Stahre, 2008) (Fasth, 2012) (See section 2.5; table 3 and table 4, Dynamo++ methodology). The use of a structured method of data collection allowed the researchers to selectively focus on each main activity conducted at each workstation, and thereby measure the current LoA in the preassembly workstations.

Similarly, the use of unstructured observations was incorporated in the initial phases of the research to, understand various production characteristics of the preassembly area.

### 3.3.5 Analysis of internal documents.

Analysis of internal documents was an important source used for quantitative data collection, data categorisation and data analysis. Critical complementary data was collected through the organisations Enterprise Resource Planning (ERP) system. Historical data saved in the ERP system from 3rd January 2018 to 7th May 2019 was collected and analysed. The analysis of internal documents helped the researchers in this study in the following ways.

#### 3.3.6 Preassembly data.

The preassembly data collected from the ERP systems at the preassembly area allowed the researchers to–

- Procure a list of all the components assembled at preassembly area, along with their Economic Order Quantity (EOQ) per batch.
- Categorise the main component list according to their respective workstations.
- Categorise the main component list according to their respective product segments.
- Arrange the complete component list according to their respective volumes manufactured in 1 year; (arranged in descending order).
- A scheduled plan of all the components manufactured in the year 2019, along with their scheduled as well as actual- start and end times.

The ERP system also had a provision made for non-conformity report logs, known as NCR logs. The operators updated NCR logs at every workstation within the manufacturing unit; whenever the takted assembly line was stopped/delayed. This list also contained a record that described the cause as well as the duration of the delay, which allowed the researchers to point out towards critical buffers and frequently
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erooneous workstations/components, within the manufacturing unit of UC tap changers.
Findings and analysis

4 Findings and analysis

The findings and analysis of this study are described in this chapter. The findings and analysis are arranged according to the six-step structure for answering research questions. (see section 3.1.2; figure 8).

4.1 Description of the UC type tap changers manufacturing unit.

This section describes the general findings related to the description of the manufacturing unit, as it helps to understand the interdependencies between the various production units with respect to the preassembly area.

The complete UC tap changers manufacturing unit comprises of 7 individual production units (see Figure 9 above). Wherein each production unit is a takted assembly line. The takt time for all the assemblies is 48 mins except the preassembly production unit and resistance assembly production unit. The preassembly and the resistance assembly production units are not takted. The product flows through the respective production unit’s assembly lines, in a defined order. The categorisation of the production units according to the order of the flow is as follows-

a) UC preassembly, (Non-takted).
b) Resistance assembly, (Non-takted).
c) Diverter switch assembly, (takted).
d) Diverter switch housing assembly, (takted).
e) Tap selector assembly, (takted).
f) Final assembly and testing, (takted).
g) Packaging.

4.1.1 Resistance assembly.
The resistance winding assembly is a vital component of the diverter switch assembly. It comprises of the wires wounded around a plate according to the specified resistance.
The resistance winding components are assembled in the resistance assembly unit. The resistance winding assembly is Engineering To Order (ETO) component workstation; which means that- winding specifications of component resistance assembly, for each tap changer is customised according to individual customer requirements. It was found from the explanatory interviews that, due to different customer specifications, each resistance assembly has a unique winding specification.

The resistance assembly comprises an automated wiring machine that can wind the resistances according to the customer requirements. The assembled resistances are then kitted with different accessories as per the type of tap changers and are placed in the diverter switch assembly inventory. The resistance assembly is eventually assembled inside the diverter switch assembly; in the diverter switch production units.

4.1.2 Diverter switch assembly.
The diverter switch is an integrated internal part for the tap changer. The diverter switch of an On load tap changer (OLTC) is responsible for the switch-over applications between the different taps in the tap changer (ABB, 2018).

The diverter switch assembly line comprises of U-formation takted assembly line, which contains six workstations. Each of the six workstations is further divided into two halves. In the first half, diverter switch for ‘conventional-type’ tap changers are assembled; and in the second half, diverter switches for ‘vacuum-type’ tap changers are assembled. All the assembly procedures on all six workstations are performed manually.

The main tasks identified at each one of the six workstations of the diverter switch assembly are as follows-

I. **Diverter switch assembly Workstation 1** - The main task identified for workstation 1 is to assemble the spring device used for diverter switches.

II. **Diverter switch assembly workstation 2** - The main task of this workstation is to assemble the moving contacts system.

III. **Diverter switch assembly workstation 3** - The main task of this workstation, is to assemble the vacuum bottles on the vacuum type tap changers.

IV. **Diverter switch workstation 4** – The main task for this workstation is to assemble resistors in the diverter switch assembly. (The resistance assembly required for this step are supplied by the resistor assembly production unit in the form of kits).

V. **Diverter switch workstation 5** - The main task for this workstation is to assemble lifting plates on the diverter switch assembly.

VI. **Diverter switch testing workstation 6** - The main task for this workstation is to test the diverter switches.

The diverter switch assembly unit comprises a storage area which represents a supermarket inventory storage. The diverter switch assembly unit pulls specific components used to assemble diverter switch, from the preassembly production unit. All other raw material parts are procured from the central raw material inventory storage.

During the observations and the explanatory interviews, it was found that owing to irregular data in the Enterprise Resource Planning systems (ERP); the operators had to often physically go to the supermarket inventory of diverter switch assembly, in order to check the parts that are required. Based on which, operators at preassembly production area, had to prioritise production of parts that are required on the diverter switch assembly line. This, in turn, hampered the ERP data even more.
4.1.3 Diverter switch housing assembly.
In all tap changers, diverter switch is placed inside the diverter switch housing. The diverter switch housing can be classified into a set of 3 different parts.

a) **Top section** - Top section contains a flange used for mounting the tap changer on the transformer. It also encompasses the motor drive and a gearbox that is used to drive the operating shaft (ABB, 2018).

b) **Middle section** – It comprises of a cylinder made up of glass fibre reinforced epoxy (ABB, 2018). This cylinder is assembled in the preassembly production unit and then delivered to the diverter switch housing assembly in the form of inventory kitting.

c) **Bottom section** - Bottom section of the diverter switch housing is made of cast aluminium. It contains locating holes for the diverter switch bearings. It also includes brackets used for mounting tap selectors and current terminals of the diverter switch (ABB, 2018).

The diverter switch housing production unit comprises of 3 workstations, each having a takt time of 48 mins. The main tasks identified in the three workstations of the diverter switch housing assembly are as follows-

I. **Diverter switch housing assembly workstation 1** - The main task of this workstation is to assemble the top part of the diverter switch housing.

II. **Diverter switch housing assembly workstation 2** - The main task of this workstation is to assemble the bottom part of the diverter switch housing.

III. **Diverter switch housing assembly workstation 3** - The main task of this workstation is to mount the top and bottom sections of the diverter switch on the middle section (cylinder).

4.1.4 Tap selector assembly production unit.
Tap selectors are assembled on this production unit. It consists of three workstations. The main tasks of the three workstations are as follows-

I. **Tap selector assembly workstation 1** - The main task of this workstation is to mount the component containing fixed contacts.

II. **Tap selector assembly workstation 2** - The main task of this workstation is to mount the components containing moving contacts.

III. **Tap selector assembly workstation 3** - The main task of this workstation is to mount the components containing fixed and moving contacts. This workstation is only used for size F tap changers.

The tap selector assembly unit comprises a storage area which represents a supermarket inventory storage. The tap selector assembly unit pulls specific components used to assemble tap selectors such as fixed and moving contacts cylinders, from the preassembly production unit. All other raw material parts are delivered from the central raw material inventory storage.

4.1.5 Final assembly and testing unit.
The final assembly and testing unit comprises of three stages which are presented below-

a) Preparatory stage.

b) Final assembly and testing stage.

c) Completion stage.

**Preparatory stage**-
The inventory storage of the preparatory stage contains- assembled diverter switch, diverter switch housing and assembled tap selectors; which are moved after completion from their respective workstations.
In the preparatory stage, firstly, the diverter switch is lowered and inserted inside the diverter switch housing. After which, arc quenching oil is filled inside the diverter switch housing. After this stage, the oil-filled diverter switch housing is moved to the testbeds.

**Final assembly and testing stage**
Final assembly and testing of tap changers take place in the same workstation. This stage pulls the fully assembled oil-filled diverter switch, along with its housing from the preparatory stage. The next step in the final assembly is to mount the selector switches below the oil-filled diverter switch housing. After which, the moving contacts are connected via the current collectors, to the diverter switch using paper insulated copper conductors. This marks the end of the final assembly.

**Testing stage**
The subsequent step after final assembly is to test the completed tap changers on the testbeds. There are a total of 10 testing workstations, where the assembled tap changers are prepared for testing. Once all the connections are made for testing the tap changers, the testing process starts. The testing process involves driving the motor drive to check whether all the contacts are switching correctly as per requirements. During this stage, visual inspections are also conducted to check whether the tap changers are assembled according to the specifications. After the testing is completed, the oil from the diverter switch housing is drained out. In the next step, the tap changers are dismantled in two parts which are diverter switch housing assembly and selector switch assembly. The two disassembled parts of the UC tap changers are then sent to the packaging section.

**Packing stage.**
In the packing stage, the disassembled diverter switch housing assembly and selector switch assembly; are placed inside wooden containers. Further, important documents such as user manual, maintenance manuals and other details regarding operating instructions are placed inside the wooden box. An order sheet is then attached to the wooden box and is sent to the final product dispatch.

### 4.1.6 UC Preassembly production unit.
The UC preassembly production unit supplies preassembled tap changer component parts to various sections in the UC manufacturing layout (presented above). The layout of the preassembly production unit is based on process layout, which is also known as the functional layout. The preassembly production unit comprises of 8 workstations. Each workstation produces preassembly parts for different production units on the UC assembly line. Such that, each workstation caters to a specific production unit of the takted UC assembly line. The different workstations in the preassembly production unit can be classified as follows:

- **a) Workstation 1-a (Tap selector preassembly)**- This workstation preassembles parts required for the tap selector assembly.
- **b) Workstation 1-b (Tap selector preassembly)**- This workstation also preassembles parts for the tap selector assembly unit.
- **c) Workstation 2 (Diverter switch housing preassembly)**- This workstation preassembles parts required for diverter switch housing assembly unit.
- **d) Workstation 3 (Diverter switch preassembly)**- This workstation preassembles parts required for diverter switch assembly unit.
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**e) Workstation 4 (Cylinder preassembly)** - This workstation assembles the cylinders required for diverter switch housing as well as tap selector assembly units.

**f) Workstation 5 (Shaft preassembly)** - This workstation assembles shafts required for the tap selector assembly unit.

**g) Workstation 6 (Vacuum diverter switch preassembly)** - This workstation assembles components required for vacuum-type diverter switch assembly.

**h) Kitting station** - The main task of the kitting section is to create kits by organising the cylinders, shafts as well as guard rings, required for each tap changer manufactured. The parts included in each kit are the cylinders, and tap selectors required for the diverter switch housing and tap selector assembly units.

Each workstation has an inventory buffer which consists of inventory parts required for the respective workstations; these inventories are replenished from the central storage using Kanban cards.

### 4.2 Production characteristics of preassembly production.

This section describes the findings and analysis related to the production characteristics of the preassembly production area. The findings and analysis are structured according to each one of the six respective workstations present in the preassembly area. (Refer figure 10 for illustration of the workstations).

#### Findings related to Production characteristics of Workstation 1-a (Tap selector preassembly); and Workstation 1-b (Tap selector preassembly).

The main types of machinery used in these workstations comprise of the following- One drilling station; one hydraulic press station; and one riveting stations. Apart from these significant machineries, the tap selector preassembly unit also comprises of different tools and specially designed fixtures used to preassemble various components.

The variety of components assembled at this station was found to be high with a total of 144 variants of tap selector pre-assemblies; additionally, due to low production volumes of tap changers, the Economic Order Quantity (EOQ) of the products manufactured was found to be low with an average batch size of approx - 4 components per batch.

During the observations and explanatory interviews, it was found that the planned sequence in which the components manufactured were decided by the production planner depending upon the daily order, the logic behind the planning sequence wasn’t done to reduce the number of steps in preassembly.

#### Findings related to Production characteristics of Workstation 2 diverter switch housing preassembly.

The main types of machinery used in workstation 2 comprised of 1 drilling machine; 1 hydraulic press station, along with different tools and specially designed fixtures used to preassemble various components.

Most of the components assembled at this station require at least 2-6 fixture/ tool changes from pressing to drilling operations because the assembly procedure involves pressing and drilling operations done alternatively on a single component.
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The variety of components assembled at this station was found to be high with a total of 63 variants of diverter switch housing pre-assemblies; additionally, due to low production volumes of tap changers, the economic order quantity (EOQ) of the products manufactured was found to be low with an average batch size of approx. 3 components per batch.

Findings related to Production characteristics of- workstation 3 diverter switch preassembly.
The main types of machinery used in workstation comprised of 1 drilling machine; along with different tools and specially designed fixtures used to preassemble various components. Most of the component assembled at this workstation comprised of- insertion of a circlip, which was inserted by using hand pliers that were found to be at low (LoA level 2) on both mechanical as well as cognitive continuum scales. Additionally, insertion of circlips was found to have an unsafe working method, because the step where circlip is inserted inside the component has a low level of operator safety due to improper use of fixtures.

The variety of components assembled at this station was found to be high with a total of 38 variants of tap selector pre-assemblies; additionally, due to low production volumes of tap changers, the economic order quantity of the products manufactured was found to be comparatively high with an average batch size of approx.- 14 components per batch.

Findings related to Production characteristics of- workstation 4-cylinder preassembly.
Workstation 4-cylinder assembly comprises of one pressing station, that is used to press-fit contacts on the cylinder. This workstation highlights a high automation potential due to low variety of operations performed at this workstation. The variety of operations at this workstation is low with two primary varieties of cylinders. But a high level of repetitive and cognitively- demanding tasks was observed at this station.

Findings related to fixture changes; and non-value adding workpiece interpolations in workstations 1-6.
The results of work-study measurement done in the preassembly, it was found that the assembly procedures for most of the components assembled in this station had drilling and pressing operations on the different axis on the component and these operations were not combined in one sequence. Due to which the operators often had to switch the fixtures from drilling to press and then back to drilling. Such fixture changing operations were found to be non-value adding at the workstations.

Findings related to repetitive tasks in workstations 1-6.
All the workstations in the preassembly section; a common trigger for the use of automated technologies was found to be related to the high number of repetitive tasks performed on operations with low mechanical LoA as well as cognitive LoA.

4.2.1 Demographics of the work organisation:
The preassembly area produce parts for diverter switch assembly, diverter switch housing assembly and tap selector assembly, the ERP system in the preassembly areas lacks data, so the operators working on the preassembly area had to go manually to diverter switch assembly, diverter switch housing and tap selector assembly and look for the components or parts in the supermarkets of each area that are needed and come back to the preassembly area to assemble the prioritised parts first.
4.2.2 High product Variety ad Low Volumes:
Preassembly area consists workstations for tap selector, diverter switch, diverter switch housing, vacuum diverter switch, cylinder, shaft and a kitting area. In each of these stations, there is a high variety of product made. For example, in the diverter switch housing station alone, a totally of 63 components were made. This high variety of products in each station involves various assembly procedures thus making the implementation of automation very complicated. Apart from that, the volumes of these components made in diverter switch housing is very low with an average of 2 to 3 components made in a single batch which is very low, through exploratory interviews it was found that due to the low volumes per batch it was not advisable for the company in adopting automation as a business case. The overall product variety is very high in all the preassembly stations, and the volume of each product made is comparatively very low. Though observations the total number of components made in each station and the average volumes of each component assembled in that station are listed below in Table 5

<table>
<thead>
<tr>
<th>Station</th>
<th>No.of Components/variety</th>
<th>Avg. Volume/Batch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diverter Switch Housing</td>
<td>63</td>
<td>3</td>
</tr>
<tr>
<td>Diverter Switch Assembly</td>
<td>76</td>
<td>14</td>
</tr>
<tr>
<td>Diverter Switch Vacuum Assembly</td>
<td>23</td>
<td>8</td>
</tr>
<tr>
<td>Tap Selector</td>
<td>144</td>
<td>4</td>
</tr>
</tbody>
</table>
4.3 Evaluation of the current levels of automation (LoA).

This section describes the findings and analysis related to the current Levels of Automation; measured at the preassembly area. This section aims to answer RQ 1 “what is the current LoA in the preassembly area?”. The findings and analysis are structured according to each of the six respective workstations present in the preassembly area. (Refer figure 10 for illustration of the workstations).

The measurement of current Levels of Automation also incorporates phase 2 of the dynamo methodology discussed in section 2.5 (See section 2.5; table 3 and table 4, Dynamo++ methodology).

The current levels of automation were evaluated in each station starting from station 1 to 6 which is described in figure 10 below.

**Workstation 1:**

The level of automation is evaluated by comparing the steps from hierarchical task analysis as well as cognitive task analysis; to the physical and cognitive level of automation. For each workstation in preassembly, the current level of automation was noted down with respect to physical skill and cognitive skill required to accomplish the task. The hierarchical task analysis was done for each component through observation at each station, and the steps were noted down. In the tap selector station, plus-minusribba component was made, through HTA all the tasks involved in assembling it was noted down as follows-
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Table 6 Physical and cognitive LoA of plus-minus ribba

<table>
<thead>
<tr>
<th>Steps</th>
<th>Task</th>
<th>Physical LoA</th>
<th>Cognitive LoA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Valjare3 Formontge- Plusminus ribba</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Preassembly.</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Place the ribba on the fixture; place the rivets in the holes and hammer the rivets using a hammer.</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Flip the rib and mount contacts and faste.</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Place the contacts and faste assembly on the fixture and press.</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>Add one more rib on another side.</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Attach brass and black secure ring washers.</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Place the ribs on fixtures and hollow press to expand the rivet (Pressing the sandwich).</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>Place half of the middle skärmring on the rivet</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>mount 2 skärmring on each end</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**Workstation 2:**
In the Diverter Switch Housing area, Förmontage gaffelarm was made, and through HTA and CTA all the tasks involved were observed, and their respective current physical and cognitive LoA were noted down.

Table 7 Physical and Cognitive LOA of gaffelarm

<table>
<thead>
<tr>
<th>Steps</th>
<th>Tasks</th>
<th>Physical LoA</th>
<th>Cognitive LoA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Förmontage gaffelarm-21844419-B</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Place the bolts on the bearing.</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Hammer the bolts and the bearing assembly on the 2 arms of the Gaffelarm.</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Clamp the arm using a special fixture. ( near the drill table).</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Drill 2 holes through the bolts using a 2 mm drill</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Punch 2 FRP in the drilled hole.</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Grind the sharp edges of the borehole</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Fixture change (press).</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>Press the cylinder in the arm, using 25,9 spacers.</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td>Fixture change (Drill).</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>Bore through the arm and the cylinder pin with 5 mm bore.</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>Punch 1 FRP in the drilled hole.</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>Fixture change (press).</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
<td>Press.</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>14</td>
<td>Fixture change (Drill).</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>15</td>
<td>Punch.</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>16</td>
<td>Drill a hole through the punch using a 5mm drill.</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>17</td>
<td>Punch 1 FRP in the drilled hole.</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

**Workstation 3:**
In the diverter switch preassembly, the only component studied was Koppling. Through observations, it was noted that the LoA involved in each task of assembly was
Findings and analysis

very basic. The HTA of the components along with its current physical and cognitive LoA are described below;

Table 8 Physical and Cognitive LoA of Koppling

<table>
<thead>
<tr>
<th>Steps</th>
<th>Tasks</th>
<th>Physical LoA</th>
<th>Cognitive LoA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Koppling</td>
<td>Preassembly- Collections of tools, and inventory</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Put Jib in the rod and hammer</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Apply grease with a brush</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Hit the axel inside the koppling with a hammer</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Mount the grove ring on the underside of the shaft.</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>hammer a bearing with a dowel and a hammer</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Workstation 4:
In the cylinder preassembly station, the only component made was Grovväljarcylinder, and through observations, it was noticed that this station has some tasks already automated and had scope for more automation. The HTA for this component and the current physical and cognitive LoA are as follows;

Table 9 Physical and Cognitive LoA of Grovväljarcylinder

<table>
<thead>
<tr>
<th>Steps</th>
<th>Tasks</th>
<th>Physical LoA</th>
<th>Cognitive LoA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Väljare C Förmontage- Grovväljarcylinder</td>
<td>Preassembly, inspection</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Inserting skärmbricka on the copper Kontakt</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Inserting skärmbricka+copper kontakt from inside.</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Mounting skärmbricka from outside. (Convex side facing outdoors)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>(Pre-pressing operation) Insert black plug to hold the Kontakt in place</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>(Bulky Cylinder) Use hoist crane with transverse.</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Mounting appropriate rollers on the press.</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Mounting the cylinder on the rollers</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Mounting the correct pressing tools</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Engage head of the contact by sliding the cylinder using the lever</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Remove the plug and gently release it to rest.</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Start the press and set the pressure values for the respective cylinder 7,5 UCG; 4,5 UCL</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Lower the press tool on the cylinder contact to press.</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Activation of the press using two handles.</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Check if the correct pressing has been done, in case of damages, replace the Plug/Kontakt</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Use the adjustment levers to move the cylinder so that the axis of the next contact to be pressed can be aligned to the axis of the press action</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Mark up the cylinder protocols on the paper</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Workstation 5:
In the shaft preassembly, isoleraxel is the only product made, and through observation, it was found that the steps involved were elementary; therefore automating this station
was not advisable. The HTA of this product along with its current physical and cognitive LoA are as follows;

Table 10 Physical and Cognitive LoA of Isoleraxel

<table>
<thead>
<tr>
<th>Steps</th>
<th>Tasks</th>
<th>Physical LoA</th>
<th>Cognitive LoA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>setup</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>insert koppling in fibre rod</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>assemble nuts on axle</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>assemble nuts on axle</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

Workstation 6:
In the Vacuum Diverter Switch assembly station, most of the products had very less scope of automation. The HTA of the components made in this station along with their current physical and cognitive LoA are listed below:

Table 11 Physical and Cognitive LoA of Kort länk

<table>
<thead>
<tr>
<th>Steps</th>
<th>Tasks</th>
<th>Physical LoA</th>
<th>Cognitive LoA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Preassembly- Collections of tools, and inventory</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Insert a circlip.</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Drive the bearing with the bearing tool</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Insert a circlip.</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Drive the bearing with the bearing tool</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>
Findings and analysis

4.4 Analysis of the current LoA to generate possible solutions for increasing automation levels in the preassembly part production area.

This section describes the findings and analysis related to RQ2 “What could be the desired Level of Automation in the preassembly part production?”.

*In this section, the findings and analysis concerning the development of improvement opportunities are discussed in detail.*

This section mainly incorporates phase 3 of the dynamo methodology discussed in section 2.5 (See section 2.5; table 3 and table 4, Dynamo++ methodology).

4.4.1 Findings and analysis of Improvement opportunity at workstation 1 (tap selector assembly).

Findings and analysis related to Measurement at workstation 1 tap selector assembly.

From the discussions during exploratory interviews, it was found that- The focal company had already purchased a collaborative robot (Cobot), known as ‘YUMI’, for automating the operations of the motor drive assembly. But, the project of utilising YUMI for automation of the motor drive assembly was halted, as they learnt in the final stages that, it was unsafe to use tools on YUMI that weighed more than 0.5 KG. Due to which, the collaborative robot YUMI was not in use currently, and therefore was a depreciating asset in the production unit, since it wasn’t used.

4.4.1.1 Improvement opportunity1 (YUMI)

From the observations and work measurements conducted at workstation 1-a, it was found that-

During step 1 of plusminusribba assembly (preparatory step). (See Table 6 above; and Figure 11 below)

The study done to measure current LoA corresponded to the following-

- Current LoA<sub>mechanical</sub> = 1; *(totally manual)* and Current LoA<sub>cognitive</sub> = 3; *(teaching)*

![Figure 11: step 1 of plusminusribba assembly (preparatory step).](image)
operations of more than 0.5 KG. Therefore, upon analysis, it was proved that YUMI could be used for performing such tasks. Therefore, upon analysis, it was proved that YUMI could be used for performing such tasks. 

Thereby increasing the LoA to-
- Future $\text{LoA}_{\text{mechanical}} = 6$; (flexible machine/workstation) and future $\text{LoA}_{\text{cognitive}} = 7$; (totally automatic).

When researchers presented the idea of utilizing YUMI for preassembly operations at workstation 1, it was known that, due to low volumes and high variety of components made at this workstation (see table 5 above); the company was unable to make a valid and justified business case, that could project the benefits of using YUMI ‘only’ at workstation 1-a.

Although during the analysis on work measurement, it found that, there were another component pre-assemblies that could similarly utilise YUMI, but with different programming (see table 6; step 1 of valjare C); (see Figure 12 below). The study that was done to measure current LoA for valjare C also corresponded to the following-
- Current $\text{LoA}_{\text{mechanical}} = 2$; (Static hand tool) and Current $\text{LoA}_{\text{cognitive}} = 2$; (decision giving).

If Yumi was implemented for the preassembly of this task as well, the future LoA predicted in accordance with dynamo++ methodology are as follows-
- Future $\text{LoA}_{\text{mechanical}} = 6$; (flexible machine/workstation) and future $\text{LoA}_{\text{cognitive}} = 7$; (totally automatic).

**Table depicting Current LoA and Future LoA for pre-assemblies in plusminusribba and valjare C. (YUMI improvement)**

<table>
<thead>
<tr>
<th>Current</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{LoA}_{\text{mechanical}}$</td>
<td>1; (totally manual)</td>
</tr>
<tr>
<td>$\text{LoA}_{\text{cognitive}}$</td>
<td>3; (teaching)</td>
</tr>
</tbody>
</table>

Further analysis of work studies done across different preassembly sections shed light upon two more workstations namely workstation 5- shaft assembly and workstation 6- vacuum Diverter switch assembly that could also benefit similarly with YUMI, as they also involved assembly of specific lightweight components.
Findings and analysis

From the discussions, it was also concluded that such small, lightweight pre-assemblies even existed in different workstations outside the preassembly production unit. Therefore, if all such small assemblies are combined the researchers estimated that it could be possible to use a separate YUMI preassembly station; which would then be a strong business case to be justified for its implementation.

Researchers suggested that separate YUMI station could then have YUMI robot(s) with different schedules planned and allotted to all types of lightweight preparatory steps belonging to various production units. Such a facility would require having pre-programmed codes to be used in conjunction with different types of fixtures as per assembly requirements. And the programming for the YUMI for each unique preassembly operation could be initiated by using RFID dedicated to each type of preparatory preassembly procedures.

The interviews pointed out that due to lack of knowledge transfers between different production units within the industry, such efforts are not being surfaced. Additionally, due to the lack of data related to production processes performance, complete feasibility tests for such improvements were not possible, which were one of the significant production-related internal barriers.

Figure 13 YUMI Cobot.
4.4.1.2 Improvement opportunity 2 at workstation 1 (Press automation).

From the work measurements conducted at workstation 1a, for the component plusminus ribba; it was found that-

Riveting press operation carried out in step 7 (see Table 6 above); the operators had to attach contacts between the wooden ribs, and press the contacts by means of a pressing tool (see Figure 14 below); each press operation was then repeated in the same procedure for pressing other contacts, by means of sliding the fixture that holds the component manually.

Figure 14 Press operation for plusminusribba.

The press operations were found to be done at least 3-6 times for each plusminusribba assembled. The current LoA corresponding to this step was as follows-

- Current $\text{LoA}_{\text{mechanical}} = 5$;\textit{(static machine/workstation)} and Current $\text{LoA}_{\text{cognitive}} = 5$;\textit{(supervision)}

Analysis.

Analysis done by the researchers to the work-study conducted at this workstation found that the sliding interpolation of the fixture could be done automatically using a closed-loop servo motor connected to an optical scanner; capable of doing pressing as well as sliding operations sequentially (see below Figure 15; & Figure 16)

Figure 15 Visual representation of the suggested press. (Dongguan Fityou Robot Automation Co., Ltd.)
Findings and analysis

Figure 16 Visual representation of the suggested press.

Such improvements would enable an $\text{LoA}_{\text{cognitive}}$ improvement from the following:
- Future $\text{LoA}_{\text{mechanical}} = 6$; \textit{(flexible machine/workstation)} and Future $\text{LoA}_{\text{cognitive}} = 6$; \textit{(intervene)}.

Thereby improving $\text{LoA}_{\text{mechanical}}$ from Level 5 \textit{(Static machine/workstation)} to Level 6 \textit{(Flexible machine/workstation)}. Similarly, an improvement on $\text{LoA}_{\text{cognitive}}$ would increase from Level 5 \textit{(supervision)} to Level 6 \textit{(Intervene)}. (see Table 13 below)

Additionally, the improvement would also relieve the operator from such manual, unsafe and repetitive procedures.

Table depicting Current LoA and Future LoA for pre-assemblies in plusminusribba. \textit{(Fixtures with sliding interpolation improvement)}

<table>
<thead>
<tr>
<th>Current</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{LoA}_{\text{mechanical}}$</td>
<td>5; \textit{(Static machine/workstation)}</td>
</tr>
<tr>
<td>$\text{LoA}_{\text{cognitive}}$</td>
<td>5; \textit{(supervision)}</td>
</tr>
</tbody>
</table>
4.4.2 Findings and analysis related to Measurement at workstation 4 Cylinder preassembly.

Data procured from the NCR logs, collected from the ERP systems; highlighted frequent line stoppages that were related to the component assembled at this workstation. The problem description from the NCR logs highlighted quality inspection issue that was concerned with 2 major aspects that were related to cognitive LoA; which are as follows.

- Incorrect skärmbricka Placement.
- Incorrect press operation on contacts.

Findings related to incorrect skärmbricka placement.

In steps 2, 3 and 4 in cylinder assembly, (see Table 9 above); according to the present production process, the operator must insert two skärmbricka. One of the skärmbricka is placed on the copper contacts before insertion of the copper contact on the cylinder (steps 2 and 3), and the other skärmbricka is mounted from outside (step 4).

The study conducted to measure the current LoA in the workstation 4 pointed out that, the steps- 2, 3 and 4; demanded a high cognitive workload on the operator, since the skärmbricka had a convex and a concave side, and these must be facing in the right direction during assembly; otherwise the cylinder would be incorrectly assembled.

- Current LoA_{mechanical} = 1; (Totally manual) and Current LoA_{cognitive} = 1; (Totally manual).

Findings related to incorrect press operations on contact.

Steps 9 to 14 in the cylinder assembly comprises of a press operation (see Table 9 above). Once the press operation is completed, the operator must inspect each contact manually if it is pressed correctly. Such inspection methods required the operator to hold the contacts and inspect them individually to check for extra material removal or misaligned/crooked insertion of contacts. This caused a constant-high cognitive load on the operator for steps 9 to 14, irrespective of their LoA_{mechanical} differed.

- In the current state, the LoA_{cognitive} = 1 (Totally manual).

The study conducted to measure the current LoA in the workstation 4 pointed out that the manual inspection methods to inspect the pressing operation done on copper contacts, demanded a high cognitive workload on the operator; sometimes to the extent that the inspection was not done correctly; which resulted in a line stoppage due to quality issue on the NCR logs.

Findings related to repetitive tasks.

The study conducted to measure the current LoA in the workstation 4 pointed out that, the pressing operation, as well as the manual inspection of the pressing operation, had to be done individually for each contact pressed. Typically, the number of contacts on each cylinder ranges from 18-30 depending upon the size of the cylinder. Due to which, each cylinder had the same repetitive pressing and inspection stages at least 18-20 times for each cylinder assembled.

Analysis.

The analysis applied to work measurement study done to evaluate current LoA resulted in 2 main improvement opportunities at workstation 4 (Cylinder preassembly); these improvement opportunities are presented below.

Improvement opportunity 1 - Use of optical scanning device connected in a closed-loop with servomotor.

Table describing the advantages of implementing improvement opportunity 1
Findings and analysis

Table 14 advantages of implementing improvement opportunity 1

<table>
<thead>
<tr>
<th>Improvements to reduce repetitive physical/mechanical workload on the operator.</th>
<th>Improvements to reduce the cognitive workload on the operator.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of an optical scanning system fitted on the press head; which would also be connected in closed-loop with the servo motor attached to the testbed.</td>
<td>Poka-yoke, (mistake proofing); to avoid incorrect assembly operation orientation of copper contact/skörmbricka; with the help of an optical scanning system mounted on the press tool head.</td>
</tr>
</tbody>
</table>

A detailed explanation of the current assembly procedure at workstation 4-
The current state of cylinder preassembly area (workstation 4); comprises of a C-clamp hydraulic press, with a sliding fixture (that is used to hold the cylinder during the pressing operation).

Steps 1-5- Presently, the operators firstly place the contacts and skörmbricka upon the cylinder; and holds it in place mounted on the cylinder, with the use of a plastic stopper. (The plastic stopper is inserted between the contact and the skörmring, to prevent the contact from sliding down); (See below, Figure 17; Figure 18 & Figure 19)

Figure 17 Arranging skörmbricka on contacts.

Figure 18 mounting skörmbricka on the cylinder
Findings and analysis

**Steps 6-9** Once all the copper contacts are arranged with the skärmbricka on the cylinder- The operator then, lifts the cylinder with a hoist, and loads the cylinder horizontally on the press. After which, appropriate press tool is attached to the press tool holder (Press head). (See below, Figure 20; Figure 21 & Figure 22)

**Steps 10-13** - Engage head of the contact by sliding the cylinder using the lever. The next task for the operator is to align the press tool (mounted on the press head) with each contact on the cylinder manually, (See Figure 23 below). This is done by manually sliding the base plate of the press with the help of a lever (see Figure 24 below); such that, the press tool is aligned to the contact in the correct position. After which the pressing operations commence.
Steps 14-17 For the pressing operation, the operator activates the press machine by pressing the press button with both hands, to lower the press tool and begin the pressing process.

Once the pressing operation is completed, the operator then must again lift the press tool; and slide the base plate of the press (that holds the cylinder); onto the next contact, and the entire process (from step 10-17); is repeated, until all the contacts are pressed.

4.4.2.1 Improvement opportunity 1 at workstation 4- Use of optical scanning device connected in a closed-loop with servomotor.

The repetitive process of pressing and sliding the cylinder (mounted on the base plate as discussed above); could be automated and improved by the incorporation of an optical scanning device mounted on the press head; which would also be connected to control a servo motor that is attached to the slide of the press bed.

By implementing such automation improvements, the repetitive task of pressing and cylinder sliding operations could be automated as the optical scanner would automatically recognise the cylinder type, to locate the next contact to be pressed. Thereby, signalling the servomotor (attached to the base plate, that holds the cylinder); to traverse to a certain extent. Such that the servomotor slides the base plate in a way that the press tool automatically aligns to the next contact and initiate the press operation. Once the press operation is completed, the tool can interpolate to the following contact, and repeat the process until all the contacts on the cylinder are pressed.

After completion of each pressing operation, the optical scanner could also be programmed to inspect if the contacts are inserted correctly by using AI imaging. This would not only reduce the cognitive workload on the operator due to continuous vigilant inspection from LoA 1(Totally manual). To LoA 6; (Intervene) but will also reduce the physical workload on the operator due to repetitive tasks. Because, in the improved system, the operator would only be responsible for placing the contacts and skärmbricka; and loading the cylinder on the press; i.e, steps 1-9 (See above, Figure 17; Figure 18; Figure 19 & Figure 20). All the succeeding operations would be done with the help of the automation provided by the optical scanning system connected to the servo motor attached to the base plate. steps 10-17; (See above, Figure 22; Figure 23; & Figure 24)

Such automated systems could be incorporated in the present press available at the cylinder preassembly with some modifications such as- a) Programming accordingly for continuous interpolation of the tool from one contact to another and b) Attaching
the optical scanner connected in closed-loop with the servomotor and attaching the servomotor to the guide rails on the base plate. The current pressing machine could be programmed into the Programmable Logic Controller, PLC systems that are already present in the press. Such automation enhancements would then reduce the cognitive workload on the operator from the following:

- Current LoA\text{cognitive} = 1 (Totally manual). Future LoA\text{cognitive} = 6 (Intervene).

4.4.1.1 Improvement opportunity 2 at workstation 4- replacing the press operation by screwing operation.

The discussions from the focus groups led to an emergence of another innovative idea to reduce the abovementioned issues related to increased cognition and high repeatability of physical work tasks. The suggestion involved complete elimination of the pressing operation to mount the contacts on the cylinder. And instead of press, use of threaded screws/nuts to assemble the contact and skärmring on the cylinder. The use of threaded screws would reduce the inspection ability, as the operator would only have to check the torque on the screw belonging to each contact; and if the torque is within the specified range, then the contact could be safely assumed to be assembled correctly.

Such a breakthrough change in the current production process will not only ensure reduced physical workload and more exceptional inspection ability; but also enhance the repairability of the UC cylinders and tap selector assembly. Because of the threaded contacts attached to the cylinders, the maintenance and service team of tap changers would only have to only replace the faulty contacts in case of repairs, instead of replacing the entire cylinder.

After visualising and analysing the incorporation of such improvements in the current production process highlighted the fact that, applying such radical changes in the production process would mean a complete design change in the tap changer cylinder design as well as relative part drawings. To successfully develop the confidence in such radical design changes; the newly designed component would have to go through various “type tests” to ensure safe compatibility of such new designs in the current production systems. Such type tests require high investment costs. And the remaining short lifecycle of the product does not give enough time to recompensate for high investment costs.

“To be able to successfully create a business case for the same; profits must be reaped as soon as possible for high investment costs involved with automation.”

In the interviews also pointed out that the high investments involved in such breakthrough production process changes were not able to justify a business case strong enough to obtain approval to make such changes.
4.4.3 Findings and analysis related to Measurement at workstation 2 (Diverter switch housing preassembly).

Findings related to high levels of fixture and tool changes at workstation 2

The work measurement studies conducted at workstation 2 (diverter switch housing preassembly); highlighted many non-value adding activities related to fixture changes, tool changes and workpiece changes. Most of the components assembled at this station require at least 2-6 fixture/tool changes from pressing to drilling operations because the assembly procedure involves pressing and drilling operations done alternatively on a single component. (See Table 15 below).

The table below presents a) name of the component, b) the total number of fixture/tool changes and c) the step numbers involved in the fixture/tool changes.

Table 15 Name of the components with no. of tool changes and steps involved in fixture changes

<table>
<thead>
<tr>
<th>Component name</th>
<th>Total number of fixture changes involved in assembling component</th>
<th>Step numbers that involve fixture changes.</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAV</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Arm 223XXXX-XX</td>
<td>6</td>
<td>3,5,8,10,13,15</td>
</tr>
<tr>
<td>Arm 2184xxx</td>
<td>2</td>
<td>2,6</td>
</tr>
<tr>
<td>Gaffelarm 1zddXXX</td>
<td>2</td>
<td>3,5</td>
</tr>
<tr>
<td>Gaffelarm 2184xxx</td>
<td>5</td>
<td>3,7,9,12,14</td>
</tr>
</tbody>
</table>

The total number of fixture and tool changes was also found to be quite high for other components assembled at this workstation.

The analysis done to measure current LoA, highlighted that the current LoA are low in this workstation due to the use of basic pressing and drilling machines. The average LoA in the current production processes are as follows-

- Current: LoA\textsubscript{mechanical} Level 5, (Static machine/workstation); Current: LoA\textsubscript{cognitive} Level 4, (questioning).

Analysis

4.4.3.1 Improvement opportunity 1 at workstation 2 (Diverter switch housing preassembly)

To save the non-value adding times wasted in fixture and tool changes; the discussions with the personnel’s belonging to preassembly area, led to the development of a new concept, that involved- implementing Special Purpose Machines (SPM). (SPM’s could also be related to reconfigurable manufacturing systems)

Such SPMs would then be equipped with the following-

a) Automatic tool changers, (With tool magazines shared between press and drill machines). (see Figure 25 below)

b) Automated fixture changers- (shared between press and drill machines). (see Figure 25 below)
c) Automated pallet changers- (shared between press and drill machines). (see Figure 25)

Special Purpose Machining operations.

Figure 25 Basic visual representation of SPM improvement for Workstation 2

The tool changers, fixture changers as well as the pallet changers were planned to be shared between the pressing and drilling machines as the size of the fixtures, tools and components assembled at this station were found to be compatible, with universal types of fixture changers, pallet changers as well as tool changers.

Further analysis of using such SPM machines in the current preassembly area, showed an increase in LoA as follows:

- Future - LoA_{mechanical} Level 6, (Flexible machine/workstation); Future- LoA_{cognitive} Level 6, (Intervening).

Additionally, due to the implementation of automation this workstation, would also allow the operator to perform machining operations on both drilling as well as pressing machines simultaneously. Thereby increasing the overall productivity and enhancing the machine utilisation.

It was also noted that the current preassembly area did not have enough space to accommodate the use of SPM, due to which the workstation would either have to be moved or might involve a change in the production layout.
Findings and analysis

4.4.4 Findings related to Measurement and analysis at workstation 3 and workstation 6 Diverter switch housing preassembly

Findings pertaining to the circlip insertion step.
The observations carried out to measure current LoA pointed out that several components assembled at this workstation involve a circlip insertion step. In this step, a circlip is inserted on both sides of the bearing, to hold a bearing in place inside a component. (see Figure 26 below)

Figure 26 circlip insertion

4.4.4.1 Analysis of improvement opportunities at workstation 2 (diverter switch housing preassembly).
The process of inserting the circlip was currently done with the use of a hand plier (see Figure 26 above). The LoA corresponding to this step was found to be –
- LoA\textsubscript{mechanical} − Level 2, (Static hand tool).
- LoA\textsubscript{cognitive} − Level 2 (Decision giving).

Analysis.
The procedure to use the pliers to insert the circlip could be termed as an unsafe working method, as there was a chance the circlip slipping out of the plier when compressed, this could cause minor injuries to the operator.
The analysis conducted by the researchers to improve upon the current LoA suggested the use of a fixture to insert the circlip. An illustrative model for the same could be found in- Figure 27 & Figure 28.

Figure 27 Exploded view of circlip insertion fixture.
Incorporating the use of such fixtures in the production process was found to have an enhancement from their current LoA. The LoA of the system after incorporating such fixtures were as follows:

- $\text{LoA}_{\text{mechanical}}$ – Level 4, (Automated hand tool).
- $\text{LoA}_{\text{cognitive}}$ – Level 4 (Questioning).

Additionally, such fixtures could also enable the operator to insert two circlips on both sides of the bearing at the same time. They are thereby reducing the time required for this operation by half.
4.5 The barriers faced by the industry was identified by visualising the suggestions for improvements in the production area, to see what effect it has on other aspects of the production systems environment.

Once the researchers identified the potential improvements for a few component assemblies, it was found that the improvement suggestions might also have some barriers experienced during its practical implementation. To investigate the obstacles faced in the implementation phase, this study also involved an amalgamation of the company’s current innovativeness and firsthand practical experiences of the people involved in the production development process.

Table 16 The barriers faced by the industry was identified by visualising the suggestions for improvements in the production area to see what effect it has on other aspects of the production systems environment

<table>
<thead>
<tr>
<th>Workstation</th>
<th>Components</th>
<th>Improvements</th>
<th>Barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station 1</td>
<td>Plusminusribba</td>
<td>1. Utilization of Yumi Co-Bots</td>
<td>1. Space consideration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Riveting press automation</td>
<td>2. Knowledge Transfer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Station 2</td>
<td>Gaffel Arm</td>
<td>1. Use of Special Purpose Machine (SPM)</td>
<td>1. Space consideration</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. Maintenance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. Operator competence and training</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4. Production flexibility</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5. Safety</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6. Trust in automation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7. Product high variety</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Replacing press automation with screwing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>operations</td>
<td></td>
</tr>
<tr>
<td>Station 4</td>
<td>Cylinder</td>
<td>1. Using an Optical Scanning system connected</td>
<td>1. Supplier integration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>with servo motor</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Replacing press automation with screwing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>operations</td>
<td></td>
</tr>
</tbody>
</table>
Findings and analysis

| Station 3 and Station 6 | 1. Koppling  
2. Mellanlank  
3. Mellanlank UCG  
4. Kort lank | 1. Lock ring insertion fixture | 1. Product variety  
2. Space consideration  
3. Component dimensions |

In station 1 the barriers associated with the component plusminusribba can be seen in Table 16 the first improvement suggested was using of Yumi co-bots, but the barriers associated with it were firstly the space consideration if Yumi co-bots are implemented in the present production layout, then there will be a complete change over which would require to remove the existing machinery in station 1. That would directly lead to increase in cost expenditure for implementing automation; which may not be justified since the company makes very few parts per batch.

The second significant barrier associated with this improvement was the lack of knowledge transfer. Knowledge transfer between various units within the manufacturing system is very less. If the developments made, are and not shared with other stations; then it won’t be a business case for the company.

The second improvement associated in this component workstation was using riveting press automation, and the barriers associated with it was complex product architecture and high component variety. The distance between the contacts for riveting operations was found to be varying since there were various sizes of the same component, which made it hard for implementing automation.

Space consideration was also identified as a production-related internal barrier; since the riveting improvement will need more space for a new machine in the existing layout.
Additionally, since the machine might have some moving parts, operator safety should also be considered, and the workstation must be modified accordingly.

High maintenance cost was also considered as a barrier as this would increase the overall investment for implementing automation in this station alone. Currently, the maintenance of the machines at the preassembly area is outsourced, that, in turn, prohibits knowledge transfer. Therefore in house maintenance could be seen as a must for implementing such improvements.

Inconsistent batch size would also be a barrier since the improvement suggested would produce parts continuously, but the company doesn’t need such a high volume of parts made per batch. Finally, the last barrier that identified was the operator’s competency level for operating these automated machines, and the company would have to train the existing workforce to handle these types of automated systems.

In station 2 the barriers associated with the component gaffel arm can be seen in table 16 the improvement suggested for this component was using a special-purpose machine for automated fixture/tool/workpiece changing devices; but again, the researchers noticed that there was insufficient space to accommodate such machines. Since this special purpose machine would be a new addition to the workstation 2. In the existing layout, production flexibility will also be a barrier; as currently, the operators don’t follow the ERP system and they walk around the assembly area to prioritise the production schedules according to the inventory requirements. And if SPM machines are used for a specific component alone, it will reduce the existing flexibility that is actually desired at the workstations.
Findings and analysis

The current production system makes products with high variety and low volume which was also considered a barrier for implementing an automated machine because an SPM machine is more suitable for low variety and high volume production which would not support the output the company is trying to achieve by implementing automation.

If an SPM machine is implemented, then there is a barrier associated with the operators that, their trust in automation may fail; so the company should train them more. The other restrictions the researchers found were very similar to the component in station 1 like increase in maintenance cost, improving the safety for the operators working in that station and the operator’s competence level for operating these machines.

In station 3 the barriers associated with the component cylinder can be seen in table 16 the first improvement suggested was using an optical scanning system connected with a servo motor but it was noticed that one of the significant barriers is the supplier integration, there was an uncertainty form the supplier side which has always made it hard for the company to implement automation. If the optical scanning machine had to be introduced then there were to be significant design changes in the contacts placed in the cylinder and these contacts were outsourced from the suppliers, so they had to make design changes in their production processes to adapt to the newly designed contacts.

The second improvement that was suggested was replacing press operation with screwing operations, but for this improvement a design change was needed for placing the screws, and this design change would require all the stakeholders that are- the maintenance team, design team, quality team and the testing team to approve this design which would be a significant barrier. Secondly, to convince the feasibility to all the stakeholders A ‘type test’ must be done which would prove very expensive for the company and wouldn’t make a proper business case.

In station 3 and station 6 various components were selected for the same improvement, the components chosen were Koppling, Mellanlank, Mellanlank UCG and Kort lank. The suggested development in circlip insertion fixture also pointed out significant barriers related to complex product architecture and high variety.

### 4.5  4.6 Classification of the barriers faced by the industry.

The barriers identified in the previous findings and analysis were categorised according to the literature on the barriers related to automation found during the literature review. Such categorisation of barriers would help the company to understand and visualise in a better way to see what aspects related to the implementation of automation are affected by which barrier (see Table 17 below). This would also help the company to create a logical course of action in their future projects to try and eliminate the barriers in the best possible way that they can.
Findings and analysis

Table 17 Classification of barriers faced by the industry.

<table>
<thead>
<tr>
<th>Internal Factors</th>
<th>Production</th>
<th>Organizational</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product</strong></td>
<td><strong>Production</strong></td>
<td><strong>Organizational</strong></td>
</tr>
<tr>
<td>1. High variety; low standardisation.</td>
<td>1. Production flexibility</td>
<td>1. The technological expertise of the operator. (skill/training)</td>
</tr>
<tr>
<td>2. Increased Complexity.</td>
<td>2. Component weight and dimensions.</td>
<td></td>
</tr>
<tr>
<td>(intricate assembly).</td>
<td>(fixture interpolation)</td>
<td></td>
</tr>
<tr>
<td>3. Tradeoffs with quality.</td>
<td>3. Complex/intricate assemblies.</td>
<td></td>
</tr>
<tr>
<td>4. High demand fluctuations</td>
<td>Requires Complex and high cost automation.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Space considerations.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(layout change).</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. High maintenance costs of automation.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. Safety (moving parts)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Inconsistent batch size</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>External factors</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Cost competition.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Supplier integration.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Unions/regulations.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Stakeholders.</td>
<td></td>
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</tr>
</tbody>
</table>


5 Discussion and conclusions

5.1 Discussion of method

The purpose of this thesis was: To investigate the barriers, that a company would face in the future if it decides to increase the levels of automation in their UC preassembly section.

To eventually investigate barriers for increasing the LoA, researchers had to firstly ‘measure’ the current LoA in the preassembly area; only then would the researchers know about what to improve? And how to improve? Which brings us to the second point, that is to analyse the current state of automation, to seek what could be improved in the preassembly area. Only once we know about how things could be improved, can we project/visualise the ideas for improvement in the future to explore the implications such plans would impose at the preassembly production area.

Therefore, the purpose of this study structured was threefold, and is presented below-

❖ **Objective 1**- The first objective of this study comprised of measuring “what are the current levels of automation, of the workstations belonging to the preassembly area?”

❖ **Objective 2**- The second objective was to analyse the previous findings related to the current measured levels of automation; to seek “how can the levels of automation be improved from their current levels, in the preassembly area?”.

❖ **Objective 3**- The third and the final, conclusive aim of this study was to “identify the barriers to increase the levels of automation”. These barriers were identified by combining the results/experiences of the researchers from the first two objectives, to visualise what implications the new improvement opportunities would impose in the dynamics of the production systems. Such that, the company would be able to predict and visualise the challenges that they might have to face if they decided to increase the levels of automation in the preassembly area.

The crux of the data collection methods used for measuring and analysing the current LoA (objectives 1 and 2), was more inclined towards structured and quantitative data collection methods (Saunders, Lewis, & Thornhill, 2016).

On the other hand, the objective 3, of investigating the barriers to increase LoA, was explored by incorporating first-hand experiences as well as perceptions of the people belonging to both operational level as well as the managerial level (Bottom-up approach). Such type of data collection methods considered intersubjectivity and shared understandings of the people directly or indirectly belonging to the preassembly area, about how they perceive, interpret and construct their reality, within the context- use of automated technologies in the preassembly area (Savin-Baden & Claire Howell, 2013) (Williamson, 2002). Therefore, we can say that the data collection methods used for investigating as well as analysing objective 3, was more inclined towards qualitative data collection methods.

Since the scope of this study was only restricted to the preassembly area, due to ethical and safety-related restraints, researchers had in the industry. The researchers chose to focus their research in-depth pertaining only to the preassembly section. Additionally, the industry where this study was conducted; as well as the types of products assembled in the preassembly area, belonged to a niche category; that was subjected to high specialisation, high customizability, low volumes, and high variations. Therefore, conducting a study in such an environment required the researchers to do in-depth research thereby leveraging the validity of the findings. The results of this study could only be generalised for similar pre-assemblies that produce- intricate preassembly components with a wide variety, low volumes.
Discussion and conclusions

As the researchers wanted to use a research methodology flexible enough to incorporate in-depth, qualitative as well as quantitative data collection methods focussing upon a single case company; therefore use of single exploratory case study method was chosen to be the most appropriate research method for this research (Yin, 1994).

The use of semi-structured interviews allowed the researchers to reap the benefits of both structured as well as unstructured interviews. Which greatly enhanced the quality of the discussions; as the interview questions were not restrictive and nor were, they too broad, thereby allowing the respondent to answer freely, but at the same time, it ensured that the conversation stayed within its context. The instrumentation of such data collection techniques also aided the interviewer to clarify doubts by asking leading questions during the interview on an impromptu basis, which an essential peculiarity of semi-structured interviews also mentioned by (Williamson, 2002). Asking such impromptu questions further enhanced the quality and validity of the respondent’s response as such data collection methods were both systematic and iterative (Galletta, 2013); As cited in (Marshall & Rossman, 2016).

The exploratory interviews allowed the researchers to seek new knowledge. Additionally, explanatory interviews were instrumented to complement the findings from the exploratory studies to generate concrete evidence for the new knowledge assimilated. Therefore, it could be said that the use of exploratory and explanatory interviews in conjunction with each other also helped to increase the validity and quality of the data collected by providing concrete evidence.

The choice of respondents for interviews as well as focus groups could have adversely affected the data collected, as there was a chance of neglecting certain respondents who might have had an impact on the findings of this study. To overcome this issue, a master list was created that contained broad questions related to different topics about this research. The questions of this master list were discussed with the industry supervisor who was a production engineer in the production unit of tap changers. The different questions were then categorised according to the relevant positions in the field by the supervisor, as he had better knowledge due to prior experience in the industry and knew what types of questions are suitable for which positions. In such a way, the researchers were satisfied by the choice of respondents chosen for this research.

A significant drawback of focus groups could be tracked down to its validity due to the low sample sizes. Therefore, due to constraints on time, inadequate resources, and number of respondents; the focus group could have neglected critical sources of information in this study. In line with (Williamson, 2002), researchers acknowledge the fact that the basis of analysis and discussions from the focus group might not correspond to the actual reality; due to the dynamic nature of the response from respondents. Also, the measurement and analysis done in this study were driven by the researcher’s as well as the industry’s common interests. Therefore, the involvement of the researcher as a moderator in focus groups could have influenced the study; thereby subjecting the focus group to self-reported data. This could be a critical source of researcher’s bias in this study, which in line with (Miyazaki & Taylor, 2008), could have systematically influenced the choice of workstation improvement opportunities chosen in this study. However, the researcher’s selection bias related to the choice of ‘workstation improvement’; was negated/counteracted by considering the contrary ‘barriers for improvement’ during the study. Overall, the discussions from the focus groups were fruitful for the researchers, as it not only generated innovative suggestions through brainstorming but also helped the researchers to comprehend common perspectives regarding the use of automated technologies at the preassembly area.
Discussion and conclusions

It must be acknowledged that the word ‘operator’ used in conjunction to observations carried at the shop floor, was a mere researcher’s mental representation/model of anyone conducting the activity and by no means intend to point out to the operator responsible in the area during the studies. The choice regarding the structure of observations, and what researchers chose to observe could possibly be influenced by the researchers motive and background, which may involve a selective researchers bias (Miyazaki & Taylor, 2008). The time constraints researchers had, in addition to high variety and low volumes of components manufactured at each workstation; certain components that were produced rarely were not possible to study in this thesis. Therefore, it should also be acknowledged that the results of this study could have neglected certain critical sources of data; that could have influenced/affected the results of this study. Clarifications were sought for various observations whenever possible, but there involved a chance of miscommunication due to inconsistent -/language backgrounds of the researchers. However, the instrumentation of observations as a research triangulation technique, in conjunction to various steps involved in DYNAMO++ methodology according to (Fasth, Stahre, & Dencker, 2008); (Fasth & Stahre, 2008); (Fasth, 2012); (Frohm J., 2008), proved meritorious for identifying improvement opportunities systematically, with reference to the measurement of current LoA.

The internal documents procured from the focal company, immensely improved the researcher’s efficiency while collecting, categorising, and synthesising useful information related to the schedule and flow of information within the organisation. Additionally, some documents procured from the ERP systems allowed the researchers to consider frequently occurring challenges faced in the production systems. Although, most importantly, internal documents related to standard operating procedures Sop’s; was one of the essential sources of information that was used as a reference for work measurement studies conducted to measure current LoA of the workstations.

(Yin, 1994) indicates that, while collecting case study evidence, for qualitative case studies; individual sources of data could hamper the validity of the findings and thereby suggests the use of multiple sources of evidences, to strengthen the conclusions and thus, enhance the validity of the results.

The source triangulation adopted in this study enabled cross investigation of the- ‘barriers to implement automation’; through different types of lenses of interactions, and settings, which were created due to use of multiple data collection techniques such as -

- Semistructured (open-ended interviews).
- Observations.
- Focus groups.
- Document analysis.

Therefore, enabling a comprehensive understanding of a subject to leverage commendable reliability and validity of the findings.

5.2 Discussion of findings

5.2.1 Discussions on RQ1-

“What are the current LoA in the preassembly area?”

The primary purpose behind selecting this research question was to investigate the underlying concepts of automation to figure out ways in which automation could be quantified or visualised in a production system. To find a solution to this inevitable question of this study, the researchers chose to conduct an in-depth literature review.
Discussion and conclusions

The initial literature review introduced the researchers to various studies done to quantify automation in a wide variety of applications, which was not directly relevant to the production systems. Although the insights from this initial literature review, helped the researchers to understand automation comprehensively; most importantly, it helped the researchers to surface upon the concept of 'Levels of Automation'. Further review of research literature about the concept of 'Levels of Automation', highlighted a wide variety of frameworks that ranged from the historical classification of different levels of automation; to recent articles that described various comprehensively structured methodologies, to measure and analyse Levels of Automation.

After a careful scrutinization of different methods, the researchers chose a method called Dynamo ++ which involved contributions from various authors such as (Fasth, Stahre, & Dencker, 2008) (Fasth & Stahre, 2008) (Fasth, 2012) (Frohm J, , 2008) (Frohm, Stahre, & Winroth, 2008) (Garnell, Frohm, Bruch, & Dencker, 2007). Researchers chose Dynamo++ methodology as it was well qualified to visualise current levels of automation; by use of a structured and quantifiable method. Additionally, the use of DYNAMO++ methodology was also preferred by the industry due to its simplicity, because it was easy to be comprehended by the people belonging to the work organisation (respondents of this study).

The contribution by, (Frohm, Stahre, & Winroth, 2008) that provided a model to assess the two-level of automation (LoA) continuums on seven-step reference scales(see Table 2); simplified the process of allocating different LoA to the various task performed during production — projecting such data on a 7 by 7 grid by (Fasth, Stahre, & Dencker, 2008) (Fasth, 2012); (see Figure 5) (See Appendix 4); Made it easier for the participants to understand the scope of the study; thereby maintaining trust with transparency by respecting research ethics.

The value stream analysis suggested in various research articles such as (Fasth, Stahre, & Dencker, 2008) (Garnell, Frohm, Bruch, & Dencker, 2007) was beneficial in efficiently and effectively identifying the flow of materials and information. However, due to concern related to privacy and data security of the industry's internal documents, it was not possible to reveal the detailed value stream map/analysis of the industry. Additionally, the author's also suggested the use of videotaping the operator's work tasks (during the measurement phase), to accurately allocate levels of automation on a high degree of detail. The use of such videotaping in conjunction to computerised method-time studies software (AVIX); was considered earlier in this study, but the idea was dropped; to respect the ethics in research as well as maintain the privacy of the personnel's and the company data; as it was a higher priority for researchers in this study. However, to reduce this margin of error, the researchers compared the observations with Standard Operating Procedures (SOP’s) of the respective component studied; to achieve accuracy in this study. According to (Fasth, Stahre, & Dencker, 2010) the use of HTA, as well as CTA, suggested by (Shepherd, 1985) as cited in (Schaafstal & Schraagen, 1992); (Annett, 2003), also proved to be a valuable contribution in this study to allocate information control tasks accurately.

5.2.2 Discussions on RQ2

"What could be the desired level of automation in the preassembly part production according to the focal industry’s triggers for implementing automation?"

Once the current LoA of the preassembly was measured, the next objective of the researchers was to find ways in which LoA could be improved concerning the triggers of automation observed in the studied area. To answer RQ2, the researchers analysed in collaboration with the focus group. The analysis done in focus groups enabled the respondents to incorporate their practical experiences/contribution gained in the field.
Discussion and conclusions

From this analysis, the improvement opportunities considered in each workstation are as follows-

5.2.2.1 **Workstation 1 (Tap selector preassembly)**

For some parts assembled at workstation 1; it was found that, improvement opportunities for components such as valjare C and plusminusribba assembly; involved operation optimisation. Operation optimisation was done because improvements suggested from the analysis of LoA was to overcome the following-

a) Highly repetitive non-value-added preparatory operations.

b) Non-value adding workpiece interpolations, that reduced production performance.

The above-mentioned areas in which improvements suggested was not only found to be in line with the triggers for automation suggested by (Groover M. P., 2008); (Zairi, 1993); and (Ariss, Raghunathan, & Kunnathar, 2000); but also corresponded to the triggers of automation investigated through semi-structured interviews.

To fulfil the demands for the abovementioned triggers of automation, the analysis of this study suggested the following-

Improvement 1- Suggested use of YUMI Cobot for all lightweight preparatory operations conducted in the production unit. Such combined efforts to improve productivity will not only achieve a high utilisation of the available automation capability but will also relieve the operators from cognitively demanding repetitive tasks, thereby improving the LoA as mentioned in table 18 below.

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>LoA mechanical</td>
<td>1; <em>(Totally manual)</em></td>
<td>6; <em>(flexible machine/workstation)</em></td>
</tr>
<tr>
<td>LoA cognitive</td>
<td>2; <em>(Teaching)</em></td>
<td>7; <em>(totally automatic)</em></td>
</tr>
</tbody>
</table>

**Table 18 Current and Future LoA for improvement 1 in station 1**

Improvement 2- Suggested use of press automation, to automate the non-value adding workpiece interpolation - to increase production performance at workstations. Thereby improving the LoA, as mentioned in table 19 below.

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>LoA mechanical</td>
<td>5; <em>(Static machine/workstation)</em></td>
<td>6; <em>(flexible machine/workstation)</em></td>
</tr>
<tr>
<td>LoA cognitive</td>
<td>5; <em>(supervision)</em></td>
<td>6; <em>(Intervene)</em></td>
</tr>
</tbody>
</table>

**Table 19 Current and Future LoA for improvement 2 in station 1**

5.2.2.2 **Workstation 2 diverter switch housing assembly**

From the analysis, it was found that the improvement opportunity suggested in workstation 2 (diverter switch housing assembly) was related to operation optimisation, to reduce tool and fixture changes in the machining operations. The triggers for automation improvements investigated in this workstation was also found to be in line with (Zairi, 1993).

To fulfil the demands for the triggers of automation; the analysis suggested using special-purpose machining operations to automate- tool changing operations, fixture changing operations as well as workpiece handling operations (see Figure 25). Implementing SPM in the current production unit would then increase the LoA as shown in the table below-
Discussion and conclusions

Table 20 Current and Future LoA of improvement in station 2

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>LoA_{mechanical}</td>
<td>2; (Static hand tool)</td>
<td>6; (flexible machine/workstation)</td>
</tr>
<tr>
<td>LoA_{cognitive}</td>
<td>2; (Decision giving)</td>
<td>6 (intervening)</td>
</tr>
</tbody>
</table>

5.2.2.3 Workstation 3 and 6- diverter switch assembly and vacuum diverter switch assembly.

From the analysis, it was found that the improvement opportunities suggested in workstation 3 and 6 were found to be shared and was related to task optimisation as the task of circlip insertion was recommended to be automated.

The triggers for automation improvement investigated within the organisation also well resonated with the triggers of change mentioned by (Wickens, Lee, Liu, & Gordon-Becker, 2004) in the literature review.

To fulfill the demands for the triggers of automation, the analysis suggested using a circlip insertion fixture (designed in house) (see Figure 27 & Figure 28). This improvement was found to enhance safety in the preassembly operations, related to circlip insertion at this workstation. Implementing such improvements would increase the LoA to the following-

Table 21 Current and Future LoA of improvement in station 3

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>LoA_{mechanical}</td>
<td>2; (Static hand tool)</td>
<td>4 (Automated hand tool)</td>
</tr>
<tr>
<td>LoA_{cognitive}</td>
<td>2; (Decision giving)</td>
<td>4 (Questioning)</td>
</tr>
</tbody>
</table>

5.2.2.4 Workstation 4 Cylinder preassembly.

The analysis of current LoA suggested two improvement opportunities in this workstation. Both the improvements in LoA involved operation optimisation of the – contact assembly operation. The triggers investigated for such automation improvements were related to-

- Reducing repetitive tasks.
- Reducing chances of inspection errors.
- Improving aftermarket maintenance of the cylinder.

The abovementioned investigated triggers in the focal company; was also found to be in line with the triggers for automation mentioned by- (Ohlager, 2007); (Kandray, 2010); and (Meredith, 1987) in the literature review.

To fulfill the demands for the triggers of automation the analysis suggested two significant improvements as follows-

**Improvement opportunity 1-** Use of optical scanning device connected in closed-loop with servomotor; this improvement aided in reducing the mechanical workload on the operator due to repetitive tasks. This improvement was also found to enhance cognitive LoA by reducing inspection errors. Implementing such improvements led to an increase in LoA; as described in Table 22 below
Discussion and conclusions

Table 22 Current and Future LoA of improvement in station 4

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>LoA_mechanical</td>
<td>5; (Static machine/workstation)</td>
<td>6; (Flexible machine/workstation)</td>
</tr>
<tr>
<td>LoA_cognitive</td>
<td>5; (supervision)</td>
<td>6; (Intervene).</td>
</tr>
</tbody>
</table>

**Improvement opportunity 2**- Completely replacing the contact pressing operations with contact screwing operations (by making changes in the product design).

Implementing such actions was found to make no changes to the current as well as future LoA; but the improvements related to product design changes contributed significantly towards reducing repetitive operations; as well as improving the aftermarket maintenance ability of the component.

5.2.3 Discussions on RQ3-

“What are the foreseeable barriers that the focal company would face to increase the level of automation in the preassembly part production areas?”

This RQ3 focuses on the barriers faced by the focal companies when implementing automation. All the barriers that the researchers found in this thesis were through interviews, focus groups and observation techniques. With the help of RQ1 and RQ2, the current level of automation in each station and the improvements suggested in each station can be seen, the barriers for automation are discussed in terms of each improvement in each station.

In station 1 if YUMI cobot is utilised for preassembly procedures, then there would be a lack of business case since there is no existing knowledge transfer between various departments in the production system and each system acts as an individual unit like the R&D and production team focus on their part alone rather than working together to improve their processes. This was in line with (Zairi, 1993) who stated that various departments in an industry should work together, which would lead to innovativeness and development of robust automation strategies.

Additionally, during qualitative data collection at the operational level, it was found that there was considerable resistance towards the use of automation technologies, these resistances were mainly related to the loss of jobs due to automation. However, pertaining to the use of YUMI, the same respondents showed great acceptance towards cobot in the preassembly section, which made it clear that collaborative robots have an enormous scope to increase the level of automation by overcoming the classic barrier of automation, i.e., fear of losing jobs. This proved to be a significant advantage to overcome organisational barriers related to automation as- cobots could be the next gateway that industries could use to gain the confidence of the workforce regarding the ethical use of automation.

In station 2 an SPM machine was suggested, but a significant barrier regarding product architecture found was that substantial design changes were needed, and along with that, another barrier was high product variety (Frohm J., Lindström, Winroth, & Stahre, 2006) also stated the same reason where these factors would affect the use of automation.

Currently, the maintenance of the machines at the preassembly area is outsourced, that, in turn, prohibits knowledge transfer. Therefore an *in house maintenance* could
be seen as a critical requirement for developing the need for collective effort to realise the need for automation as well as knowledge transfer within various production units.

Some of the other barriers that were observed in other stations where a very low quantity or volume of products were made in the pre-assembly area which was seen as a drawback when implementing automation, (Löfving, Almström, Jarebrant, Wadman, & Wedfeldt, 2018) have also mentioned the same stating it won’t justify automating production lines with low volume.

Another significant barrier observed was related to the human perception that is- the operators fear to lose jobs, if a new machine is added to the existing system then the operators are required to learn to operate it, but it was noticed that, there was a reluctance to change amongst them. (Parasuraman & Mouloua, 1996) have also denoted the same and further concluded that this fear would be an obstacle to create a sense of urgency or need to implement automation in the organisation. (Ramchandran, 1986) also denoted about how training of the operators is essential for a company when implementing automation.

### 5.3 Conclusions

The purpose of this study was to identify the barriers a company would face to increase the level of automation. The production unit, preassembly that was studied- showed a classic case of low volume high variety with an MTO production unit. Where, the production flexibility was achieved successfully with low levels of automation, due to the use of simple types of machinery; which also accommodates for quick design changes due to a wide variety and customizability offered. However, this study conducted an LoA measurement by using DYNAMO++ methodology pointed out certain aspects where automation could be incorporated to improve production performance by reducing repetitive tasks, improve productivity, improve quality, etc; these triggers for improving LoA was also found to be congruent not only to the triggers for automation investigated through literature review; but it was also well resonating with the qualitative data collected by the use of source data triangulation- to evaluate perception of the workforce towards automation efforts in the production unit.

Once the current level of LoA was analysed, data collection techniques highlighted barriers corresponding to- improvements found to achieve the triggers of change. These barriers were identified against the literature review and were classified further into internal as well as external aspects. These barriers would be the factors that the company must consider before implying automation in their preassembly production area.

One significant implied contribution made in this study related to using of YUMI cobot for preassembly operations was that- collaborative robots have an enormous scope to increase the Level of Automation by overcoming the classic barrier of automation, i.e., fear of losing jobs. This proved to be a significant advantage to overcome organisational barriers related to automation; as cobots could be the next gateway that industries could use to gain the confidence of the workforce, regarding the ethical use of automation.

With this study, the researchers also concluded that, the dynamo++ as by (Fasth, Stahre, & Dencker, 2008) (Fasth & Stahre, 2008) (Fasth, 2012) (Frohm J., 2008) (Frohm, Stahre, & Winroth, 2008) (Garnell, Frohm, Bruch, & Dencker, 2007); was an efficient and straightforward methodology that industries could incorporate as a part of their improvement activities. To visualise and analyse the implications that a production system would face by implementing automation. Which could, through the
Discussion and conclusions

knowledge transfer throughout the manufacturing unit, could help to generate a sense of need for automation amongst the workforce that would then help the industries to effectively overcome the organisational as well other barriers to increase LoA.

5.4 Future scope of research.
Researchers suggest that in future, quantitative studies conducted over various other sections with a higher level of accuracy with the use of detailed task allocation could help find concrete scope of improvements -by considering both economic aspects as well as ethical automation aspects to overcome the barriers, which would help the focal company to consider, examine and highlight critical course of actions that the upcoming automation projects must consider.

Regarding the improvement opportunity of utilising YUMI collaborative robot, researchers highly suggest the production unit to carry out collaborative- economic as well as technological feasibility study; to investigate possibilities for allocating lightweight assemblies to YUMI due to its high acceptance from the operational level.

“Currently doing a Yumi pilot test to see how it fits today- we realised in our pilot tests that implementing Yumi cobot automation is way complicated than we think (cannot be used with heavy screwdrivers). But the operators don’t see any threat to their job using Yumi, so Yumi is an excellent way to start with, to get all the operators on board with interest to use automated technologies.
6 References

Fasth, Å. (2012). Quantifying levels of automation to enable a competitive assembly system. Gothenburg, Sweden: Chalmers University of Technology.


Fitts, P. (1951). *Human engineering for an effective air-navigation and traffic-control system.*


References


References


7 Search terms

The search terms list is produced automatically by Word if you have specified search terms in the text. To update the list, place the cursor in the list and press [F9]. Use the Help function in Word to learn how to insert search terms (index words).

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Appendices

8 Appendices

8.1 Appendix 1. interviews.

Interview questions for production manager.

Opening questions related to work experience:

| 1. What is your current position at ABB tap changers component? |
| 2. What are the responsibilities/duties you currently hold in this position? |
| 3. For how long you have been in the current position? |
| 4. Have you held any previous positions in this company? |

Questions related to strategic goals and decision making in the production system.

5. What are the key strategic goals that the production unit of tap changers seeks to achieve?
6. Are there any existing strategies already formulated about automation in the production unit?
   - If yes, what are they?
   - If no, do you think there should be any strategies formulated which support automation decisions in the tap changers production unit? Why?
7. On what factors does the production unit at tap changers currently evaluate its production performance?
8. In your perspective, how do you think implementing automation would be advantageous to improve the production performance at tap changers production unit?
9. On what factors, are the decisions usually made in the tap changers production unit; regarding the use of automation technologies?
   - (note to the interviewee- some examples of the different factors are listed below if others please specify)
   a) To achieve production capacity demands.
   b) To improve the quality of the product.
   c) To improve the working environment in the production units?
   d) To reduce manufacturing costs?
   e) To gain a competitive edge in the market?
   f) To improve employee skills and competencies?
   g) To improve the company image/ status?
   h) Demands from external stakeholders? (if yes, who are the stakeholders? And how do you think are their demands fulfilled by implementing automation in the production unit if tap changers?)
   i) Other.
10. How are the new production technologies acquired in the production unit of tap changers?
    - What is the formal procedure?
    - Which departments are involved in the project?
11. Do you have a separate department for research and development within the production units of tap changers? And how are the new production technologies developed in the tap changers component production unit?
Questions related to competitive priorities (external factors that affect automation decisions).

12. In your perspective, how fierce is the competition to the ABB tap changers production unit from other tap changers manufacturers currently prevalent in the market?
13. What are the key attributes observed in the competitors’ products that the tap changers production unit at ABB must tackle?
14. In your perspective, what do you think are the factors that give ABB a competitive upper hand, as compared to other tap changers manufacturers in the market?
15. Do you have any idea regarding the automation technologies used by other tap changers manufacturers in their production units?
16. Do you think, implementing automation in the tap changers production unit would give ABB a competitive edge over other tap changers manufacturers? How?
17. Does ABB provide more variants/ high customisation in tap changers; as compared to the competitors?
- If yes, does that help ABB tap changers gain a competitive upper edge?
- If no, does that give competitors an added advantage?
18. Does the market competition affect the decisions regarding the use of automated manufacturing systems in the tap changers production unit?

Questions related to Internal factors that affect the use of automation technologies.

19. How would you describe the current Preassembly (Förmontage) production unit with respect to automation? Why?
   - (note to the interviewee)
     a) Automated?
     b) Semi-automated?
     c) Manual?
20. In your perception, which areas of the tap changers production unit make the best use of automation technologies? Why?
   - (note to the interviewee)
   - Due to higher production volumes?
   -Due to Unsafe/impossible working conditions?
   -other?
21. Do you think that the company uses automation technologies more predominantly in certain production units but not in others?
   -If yes, what could be the reasons?
   - (note to the interviewee) Some of the examples could be-
   -Because its easier to automate that process?
   -Because skilled operators are suitable for that area?
   - if other, please specify.
22. Do you think that manufacturing of certain components is more suitable to be used for automation? Why?
(Follow up question) If yes- which production unit/line is more suitable? Why?
23. Would you think that the current production systems are well of, without the use of automated technologies? Why?
24. What do you think are the main issues/ barriers associated with the use of automation technologies in the preassembly areas?
25. Has there been any previous attempts made to automate the production unit of the tap changers production unit? What were the outcomes?
26. Has there been any previous attempts made to automate the preassembly (Förmontage) production unit of the tap changers production unit? What were the outcomes?
Questions related to production characteristics at preassembly (Förmontage) production unit of the tap changers.
27. How do you think that the use of automation would affect the production characteristics of the pre-assembly production units?
-- (note to the interviewee) the following production characteristics are listed below if other, please specify.
   a) Production volumes.
   b) Production complexity.
   c) Production flexibility.
   d) Economic feasibility.
   e) Maintenance costs of machines; (is it worth?)
   f) Workshop floorspace considerations.
   g) Workshop safety and ergonomics considerations.
   h) Other.
   - (follow up question) What could be other production-related factors, that might affect the use of automation technologies/advanced manufacturing processes?

28. How do you think that the use of automation would affect the product characteristics of the components assembled in pre-assembly production?
-- (note to the interviewee) the following product characteristics are listed below.
   a) Effect on the product variety offered (product standardisation)
   b) Effect on customisability of the product/component.
   c) Effect on quality.
   d) Effect on product life.
   e) Effect on competitive strategies related to the product/component.
   f) Effect on product designs.
   g) Effect on the ease in inspection. (Use of automated machines sometimes does not allow the operator to intervene in the process)
   h) What could be other product-related factors, that might affect the use of automation technologies/advanced manufacturing processes?
   i) - (follow up question) What could be other production-related factors, that might affect the use of automation technologies/advanced manufacturing processes?

29. Overall, do you think that the preassembly (Förmontage) production unit at tap changers require the use of automated machineries or advanced manufacturing processes?

Questions related to the organisational factors that affect the use of automation technologies.
30. Would you think that the organisation is taking any steps towards improving the skill set of the workforce? How?
   - What are the common advantages to the tap changers production unit of such skill development projects?
   - Would you be able to discuss the outcomes of previous efforts?

Questions based on other external factors that affect automation decisions.
31. How would you describe the current situation of the market demand of tap changers /tap changers components?
   - High?
   - Low?
   - Fluctuates greatly?
32. Would you like to think that the current decisions regarding the use of automated technologies affected by the market conditions of the tap changers component?
33. What do you think are the factors related to the customer issues that affect the use of automation technologies in the tap changers production unit?
34. How? and in what ways do the country rules and regulations, affect the implementation of automation technologies within the tap changers production units?
35. Are there any social issues related to the implementation of automation technologies in the tap changers production unit?
36. Do you have the support from the suppliers (supplier integration); while introducing automated systems in the production units?
   - (Follow up question)- In your opinion, what are the challenges faced with supplier integration, regarding the use of automation technologies in the tap changers production units?
   -
Interview questions for production supervisor/team leader.

Opening questions related to work experience:

1. What is your current position at ABB tap changers component?
2. What are the responsibilities/duties you currently hold in this position?
3. For how long have you been in the current position?
4. Have you held any previous positions in this company?

Questions related to Internal factors that affect the use of automation technologies.

5. How would you describe the current Preassembly (Förmontage) production unit with respect to automation? Why?
   - (note to the interviewee)
     a) Automated?
     b) Semi-automated?
     c) Manual?
6. What are your views regarding the balance between the automated and unautomated processes/tasks in the preassembly (Förmontage) production unit?
7. What are the current issues/problems/challenges in the preassembly (Förmontage) production unit?
8. What are the common suggestions for improving the production performance in the preassembly (Förmontage) production unit?
9. What aspects of the preassembly (Förmontage) production unit, could be improved using automation technologies/advanced manufacturing processes? Why?

Follow up: - Do you think that there is a need to use automation technologies/advanced manufacturing processes in the preassembly (Förmontage) production unit? Why?
10. Have you/any of the team members of Förmontage unit suggested improvement opportunities regarding automation/use of advanced manufacturing processes?
11. What are the general viewpoints of the managers, when the team provide suggestions regarding the use of automation/advanced manufacturing processes?
12. On what factors, are the decisions usually made in the tap changers Förmontage production unit; regarding the use of automation technologies?
   - (note to the interviewee- some examples of the different factors are listed below)
     a) To achieve production capacity demands.
     b) To improve the quality of the product.
     c) To improve the working environment in the production units?
     d) To reduce manufacturing costs?
     e) To improve employee skills and competencies?
     f) To improve the company image/status?
     g) if other, please specify.
13. Would you think that automation is more actively used in certain areas of the Förmontage unit; and not in others? Why?
   - (note to the interviewee) Some of the examples could be if other, please specify.
   - Because it’s easier to automate that process?
   - Because skilled operators are suitable for that area?
   - Because of the need for better ergonomics? (to eliminate unsafe/impossible working conditions)
   - other, please specify.

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14. What are the main issues regarding the implementation of automation/advanced manufacturing processes in the preassembly (Förmontage) production unit?

15. Are the complexities related to production in the preassembly (Förmontage) production unit well managed by the operators? Would you think that using automation/advanced manufacturing processes would unnecessarily/adversely complicate the production systems? Why? (what are the barriers?)

16. Would you think that the components assembled in the preassembly (Förmontage) production unit are subjected to high levels of customisation? What are its effects on the production performance?

17. How do you deal with the increased variety of components in the preassembly (Förmontage) production unit?

18. Would you like to outsource/eliminate certain components prepared in the preassembly Förmontage production unit? Why?

19. Could the raw material coming from the suppliers be improved to increase productivity at the shop floor? Has it ever happened before? Did the suppliers support you?

20. Are the drawings/design of the component parts manufactured in the preassembly (Förmontage) production unit subjected to high levels of revision?

Follow up question. - If yes, how are the design changes in the component parts conveyed at the shop floor? is there a formal procedure?

21. Have you considered standardising components dimensions to improve productivity at the shop floor? What were the outcomes?

- (note to the interviewee) one of the examples could be- Standardisation of part sizes to fit in one batch?

22. Would you consider the current setup times of the machines to be high?

Follow up question- would you like to improve it any further?

23. Have the preassembly (Förmontage) production team considered the use of special-purpose machines/use of automation to reduce the setup times of the machines?

-if yes- how and what were the outcomes? Is it still in use?

-if no, what are the factors that prohibit the use of advanced manufacturing processes?

24. How would you consider the current tooling costs to be?

(note to the interviewee) A) high? B) low? C) moderate?

25. Are the reworks/rejects/quality defects too high in the preassembly (Förmontage) unit?

- Follow up question- are there any common components that are usually reworked/rejected/defected?

26. Do you think that the preassembly (Förmontage) unit is lacking any infrastructural constraints regarding the use of automated technologies?

(note to the interviewee- Example- Space constraints to accommodate advanced manufacturing machines.; technological constraints; Constraints regarding operator skills; Training etc)

27. How often does it occur that the operator must pause his current task, in order to give a higher priority towards fulfilling the urgent requirements on the assembly line?

Follow up question- do you think that the use of automation would take away this flexibility of the operator?

28. How do you see the processes in the preassembly (förmontage) section in the coming ten years?

Questions related to the organisational factors that affect the use of automation technologies.

29. Is the research and development team invested/interested in the use of automated systems in the preassembly production unit?

Follow up question- If yes, how? (which aspects?)

30. Is the Process engineering team invested/interested in the use of automated systems in the preassembly production unit?

Follow up question- If yes, how? (which aspects?)

31. What are the observed common attitudes of the assembly operators, with regards to the use of automated technologies?
Appendices

32. Do the operators face any issues regarding safety/ergonomics at the workplace?
33. Would you think that the current skill set of the operators suit the use of advanced manufacturing processes/automation?
34. Would you like to think that there is a lack of trust in automation? amongst the assembly operators?
35. According to you, what are the important factors that must be considered regarding the use of automated technologies at the workplace?
36. Do you have any component related/workstation related specialists in the Formontage unit?
37. Do you think that the use of automation would degrade the current skills of the operator to maintain the quality of the component?

Note to the interviewee: e.g. The use of automation would reduce the inspection ability of the operators? (loss of personal touch with the production process?)
38. What do you think are the foreseeable consequences regarding the use of automation in the preassembly (Formontage) unit?

Interview questions for the design team.

Opening questions related to work experience:

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<tr>
<td>1</td>
<td>What is your current position at ABB tap changers component?</td>
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<td>What are the responsibilities/duties you currently hold in this position?</td>
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<tr>
<td>3</td>
<td>For how long have you been in the current position?</td>
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<tr>
<td>4</td>
<td>Have you held any previous positions in this company?</td>
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</table>

5. Would you consider the part variety of the tap changers components assembled at the preassembly (Formontage) to be high?
6. How often are the component designs customised for special orders?
7. Would you consider that there are high inconsistencies with the customised component designs?
8. How do you deal with the increased variety in components?
9. Could the component designs in the preassembly (Formontage) be suitable for automation? Why?
10. Have you considered part standardisation to deal with the variations in dimensions of the part?
11. How complicated would you consider the aspect of part standardisation to be?
12. Is it difficult to standardise parts for tap changers components? What are the common issues with part standardisation? How would you think it could be improved?
13. Would you consider reducing production complexity while designing component parts?
14. How often do you interact with the quality department?
15. What are the common quality issues that are related to part designs?
16. How often are the quality issues with the tap changers components resolved by redesigning the component part (to suit the production processes in a better way)? What could be such issues?
17. Do you think that the quality issues regarding the component materials could be solved by using automated technologies?

Note: E.G: Use of optical scanning systems to identify part defects?
18. What could be the other design approaches that the design team could take to manage the high variety in component parts?
19. To what extent do you consider the machining processes, while designing component parts?
20. Do you consider (design for manufacturing) DFM/ (Design for automation) DFA; while designing the component parts for tap changers?

-If yes, what are the common issues and challenges faced while considering DFM/DFA?

21. To what extent do you consider the inputs from the production/manufacturing/process engineering team while designing parts?

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22. Could the machining process be improved/automated to manage the increasing variety of component parts? That would suit DFM/ DFA?
23. Do you have interactions with the maintenance department to design effective tools for increasing productivity at the shop floor?

Follow up question – If yes, to what extent does the design team suggests using automated tooling/machining systems as an alternative?

24. Has the design team ever considered using design for automation?

Follow up- if yes, what were the outcomes of such efforts?

If no, what are the barriers from your perspective to accommodate design for automation?

25. Do you have interactions with the raw material suppliers?

26. In what ways does the raw material supplier support the design team to make changes in the component designs so that the components could be manufactured in an improved manner?

27. Would you think that the component supplier would support you to make changes in the component designs to better suit for DFM/ DFA?

28. What are the common perceptions of the design department with regards to the use of automated technologies at the production unit?

8.2 Appendix 2- Focus Groups

Research goals-
- Determining the ways in which LoA could be improved from current levels.
- To understand the common perspectives of the participants related to the use of automated technologies in the preassembly area.
- To understand the challenges perceived by the operators regarding the use of automated technologies at the preassembly area.

Respondent profiles-
- Employees with key knowledge regarding the preassembly production processes.
- Employees who were a part of previous projects that was undertaken to implement automation in the preassembly unit.

Topics to cover
- Participant analysis of study results undertaken to evaluate current LoA in the Preassembly.
- Common perceptions of the participants related to the use of automated technologies.
- Challenges perceived by the participants related to the use of automated technologies at the preassembly area.

Focus group schedule.
Total time 120 mins- excluding breaks.
- Introduction- 5 mins.
- Presentation of the study results and observations conducted to measure current LoA- 20 mins.
- Clarification of participant doubts- 10 mins.
- Analysis of workstations 1-8- 45 mins.
- Break.
- Discussions related to participant perceptions related to- the use of automation technologies in the preassembly area. - 20 mins.
- Discussions related to challenges perceived by operators related to the use of automated technologies at the preassembly area. - 20 mins.
Purpose of the focus group session.

The main objective of focus groups was to incorporate first-hand experiences from the people directly involved in the preassembly production processes, into the findings of the study that was conducted to measure current LoA; with the aim of brainstorming and generating suggestions regarding the ways in which LoA could be improved from current levels.

Disclosures pertaining to data collection methods.
- Consent for incorporating/reporting of the results into the study.
- Audio taping.

Prerequisites for discussions.
- Perspectives are treated naturally for exploratory purposes; which means there does not exist right or wrong answers.
- Equal participation - let the conversations flow naturally.

Question guides related to challenges and perceptions.
- What are your views related to the use of automation at the shop floor?
- Why do you think automation is beneficial/ not beneficial to be used at the preassembly area?
- What were the outcomes of the previous projects related to implementing automation?
- What could have been done previously to enhance the efficiency/effectivity of such projects?
- What are the major challenges perceived currently, regarding the use of automation technologies at the shop floor?

8.3 Appendix 3 - tables

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<th>Valjare 3 Formontage Forvaljarrm 1zsc002629-aaa</th>
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<tbody>
<tr>
<td>1 preassembly</td>
<td>1 3</td>
</tr>
<tr>
<td>2 place 4 contacts aligned with housing</td>
<td>1 1</td>
</tr>
<tr>
<td>3 assemble springs and bolts</td>
<td>1 1</td>
</tr>
<tr>
<td>4 insert bolt and spring assembly on each holes</td>
<td>1 1</td>
</tr>
<tr>
<td>5 flip the product and place a spring on the rail</td>
<td>1 1</td>
</tr>
<tr>
<td>6 insert contacts over spring</td>
<td>1 1</td>
</tr>
<tr>
<td>7 place washer over the spring</td>
<td>2 1</td>
</tr>
<tr>
<td>8 insert locking pins to secure the washers</td>
<td>2 1</td>
</tr>
<tr>
<td>9 repeat step 7 and 8; 4 times in a loop</td>
<td>2 1</td>
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<tr>
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<tbody>
<tr>
<td>1 preassembly for pins (mounting pins with spring and lock)</td>
<td>1 1</td>
</tr>
<tr>
<td>2 preassembly for copper contacts</td>
<td>1 1</td>
</tr>
<tr>
<td>3 place contacts</td>
<td>1 1</td>
</tr>
<tr>
<td>4 place 2 small rings in cylinder</td>
<td>1 1</td>
</tr>
<tr>
<td>5 place one ring other side and insert pin</td>
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<tr>
<th>Mellanlänk UCG</th>
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<tr>
<td>Preassembly- Collections of tools, and inventory</td>
<td>1 1</td>
</tr>
<tr>
<td>Insert a circlip.</td>
<td>2 2</td>
</tr>
<tr>
<td>Drive the bearing with the bearing tool</td>
<td>2 2</td>
</tr>
<tr>
<td>Insert a circlip.</td>
<td>2 2</td>
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### Lastopplare UCL Förmontage-Mellanlänk

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<td>Insert a circlip.</td>
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### Förmontage gaffelarm- Väljare f 1zsc003607aat-1zsc003607

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<tr>
<td>1</td>
<td>Preassembly- collect the required components, tools, fixtures and spacers required for the assembly operations.</td>
<td>1</td>
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</tr>
<tr>
<td>2</td>
<td>Fixture change to press.</td>
<td>3</td>
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<tr>
<td>3</td>
<td>Press using spacers 24,7</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Change spacers to 18.1 mm</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>Press</td>
<td>5</td>
<td>5</td>
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<td>Fixture change to drill. Using a special fixture</td>
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<td>Bore a 5 mm drill through the arm and shaft</td>
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<td>8</td>
<td>Cleaning and inspection pneumatic gun.</td>
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<td>Round off the edges using a grinder</td>
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### Valjore C Förmontage Valjarm

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<td>Preassembly for pins (mounting pins with spring and lock)</td>
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<td>place contacts</td>
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<td>place 2 small rings in cylinder</td>
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<td>place one ring other side and insert pin</td>
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### Väljare 3 förmontage - Arm22342311-ab

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<td>Fixture change and press operation</td>
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<td>Press!</td>
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<td>Check if the bearings fix on the axel, (if not, then replace the bearing/ arm)</td>
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<td>Place the arm on the fixture</td>
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<td>Punch two indents on the arm for the drilling operation.</td>
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<td>Drilling operation with 5 mm drill</td>
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<td>Hammer an impact locking pin (FRP) using a dowel.</td>
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<td>Hammer an impact locking pin (FRP) using a dowel.</td>
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<td>Round off the Edges using a Filer</td>
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### Väljare 3 Förmontage-NAV 2234204-h/2234

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<td>2</td>
<td>Apply oil to the Bult using hand brush, place the Bult in the holes of the axel (either use hammer or press)</td>
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Appendices

3. Place the slightly guided axel and Bult on the concentric circle fixture.

4. Press and disengage the product after pressing.

5. Fasten the assembled axel and bolt on the drill table fixture.

6. Drill the hole.

7. Place the pinF and hammer it.

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Postadress: Box 1026
Besöksadress: Gjuterigatan 5
Telefon: 036-10 10 00 (vx)
551 11 Jönköping
## Appendices

### Postadress:
Box 1026
551 11 Jönköping

### Besöksadress:
Gjuterigatan 5

### Telefon:
036-10 10 00 (vx)

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### Table 1: LOA Cognitive

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<td>9Cur, 10Cur</td>
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<td>11Cur, 12Cur</td>
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<tr>
<td>13Cur, 14Cur</td>
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<tr>
<td>15Cur, 16Cur</td>
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</tbody>
</table>

### Notes:
- **Max** indicates the maximum number of users for each workstation type.
- **Max**, **Max**, and **Max** represent different capacity levels for each category.
### Appendices

**Postadress:**
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551 11 Jönköping

**Besöksadress:**
Gjuterigatan 5

**Telefon:**
036-10 10 00 (vx)

---

#### LOA Physical

<table>
<thead>
<tr>
<th></th>
<th>LOA Cognitive</th>
<th>3Max</th>
<th>4Max, 5Max</th>
<th>6Max, 7Max</th>
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<tbody>
<tr>
<td>Totally manual</td>
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<tr>
<td>Auto hand tool</td>
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<td>12Max, 13Max</td>
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<tr>
<td>Flexible hand tool</td>
<td>5Max, 6Max, 13Max</td>
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<td>Static hand tool</td>
<td>7Max, 12Max, 13Max, 5Max</td>
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<tr>
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#### LOA Cognitive

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<tr>
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<tbody>
<tr>
<td>Totally automatic</td>
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</tr>
<tr>
<td>Static workstation</td>
<td>4Max, 6Max</td>
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</tr>
<tr>
<td>Auto hand tool</td>
<td>7Max</td>
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<tr>
<td>Flexible hand tool</td>
<td>5Max</td>
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<td></td>
</tr>
<tr>
<td>Static hand tool</td>
<td>2Max, 7Max, 8Max, 9Max</td>
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</tr>
<tr>
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<td>3Max</td>
<td>5Max</td>
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**Totally automatic**

<table>
<thead>
<tr>
<th></th>
<th>Decision</th>
<th>Teaching</th>
<th>Questioning</th>
<th>Supervising</th>
<th>Interacting</th>
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<tbody>
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<td>1Max</td>
<td>6Max</td>
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<tr>
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<tr>
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<td>3Max</td>
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