

# Strategy for automation and layout change in production systems

---

Master Thesis in Production

Royal Institute of Technology

Stockholm, 2010

Author: Kajsas Lööf

Tutor: Kerstin Dencker  
*Director KTH DMMS*  
*Researcher Production Strategies at Swerea IVF AB*

## **Abstract**

The main objective of this thesis is to identify changes in Level of Automation (LoA) and layout which are correlated. The thesis is aiming to contribute in the progressing research in automation with a practical aspect which is important to manufacturers.

A case study was conducted at Parker Hannifin since research material from 2007 was available of this production system. Data from two different points in time is a necessity to observe any correlation in LoA and layout changes. The thesis is also meant to document the production system at Parker Hannifin.

The research questions which will be attempted to answer are the two following:

- How does an increase of LoA affect the layout?
- Is there a specific point in the LoA where the layout changes dramatically?
- What improvements can be made to secure quality in Parker Hannifin's production system?

The DYNAMO methodology has been developed to measure and obtain an accurate picture of information flow and automation in production systems. The DYNAMO methodology uses a reference scale to measure LoA. This scale is divided into two parts, mechanical and cognitive, as both areas are considered when automating a production system. It proved to be an effective and objective technique to measure Parker Hannifin's production system and data could be analyzed and compared to the previous study from 2007 of the same production system.

The result from the case study at Parker Hannifin showed that the total LoA had increased and the layout had changed, however the two alterations were not correlated. The Parker Hannifin case was further analyzed and one other experience from Sandvik was illustrated to draw the conclusion that there is a specific point in the LoA where the layout changes dramatically. (1) A mechanical LoA alteration between value 1 and 4 does not in itself involve a layout change. (2) Alterations in which LoA increases to 5, 6 or 7 will most likely be followed by a layout change.

Exactly how the increase of LoA affects the layout is hard to tell. Layout changes due to LoA are an issue of factory space and material flow. Since layouts should be compatible with current production systems, LoA changes which infer in the production system might need a different space to be situated in, be it more space, less space or just a diverse positioning. Since cognitive LoA changes more frequently require equipment small in size, they are assumed to seldom cause layout changes.

Recommendations that have been specifically stated to improve the production system at Parker Hannifin:

- Make DFA a standard procedure
- Workshop for designers and assemblers to collaborate
- Designers join assembly line for half a day for assembly system understanding
- Color coding of slides to eliminate mistakes
- Place instructions visibly for assemblers to easily access at all times to eliminate mistakes

Using DFA at the developing stage for all valves is particularly important to minimize the costs and quality issues and ensure a smoother assembly.

**Key Words:** Level of Automation, DYNAMO, layout, Parker Hannifin

## **Preface**

I want to thank my tutor Kerstin Dencker for the support in writing this thesis. She has proven to be a great help both with inquiries in production systems and also as a mentor.

I would also like to thank Hakan Akillioglu who has been great help during the analysis stage; giving many practical tips and helping me conquer the ProAct website.

A special thank you to Jonas Carleljung who welcomed me at Parker Hannifin, let me film the production of the M200 valve and gave me more insight of their site issues.

# Table of Contents

<b>1</b>	<b>INTRODUCTION</b> .....	<b>1</b>
1.1	BACKGROUND .....	1
1.2	AIM AND OBJECTIVE .....	1
1.3	DELIMITATIONS.....	1
1.4	THESIS OUTLINE.....	2
<b>2</b>	<b>RESEARCH PROCESS</b> .....	<b>3</b>
<b>3</b>	<b>METHOD</b> .....	<b>4</b>
3.1	THE SCIENTIFIC APPROACH.....	4
3.2	EMPIRICAL METHODS .....	4
3.2.1	<i>Case studies</i> .....	4
3.3	THEORETICAL METHODS.....	5
3.3.1	<i>Literature review</i> .....	5
<b>4</b>	<b>FRAME OF REFERENCE</b> .....	<b>6</b>
4.1	MANUFACTURING LAYOUTS.....	6
4.2	AUTOMATION.....	8
4.2.1	<i>Research on Automation and the DYNAMO methodology</i> .....	9
4.3	ASSEMBLY .....	11
4.3.1	<i>Design For Assembly</i> .....	12
4.4	LEAN PRODUCTION.....	13
4.4.1	<i>Value Stream Mapping</i> .....	15
<b>5</b>	<b>PARKER HANNIFIN AND RESULTS FROM 2007</b> .....	<b>17</b>
5.1	ARTICLE M200 .....	18
5.1.1	<i>Assembly</i> .....	19
<b>6</b>	<b>PARKER HANNIFIN'S RESULTS FROM 2010</b> .....	<b>22</b>
6.1	A SHORT SANDVIK CASE .....	23
<b>7</b>	<b>DISCUSSION</b> .....	<b>24</b>
7.1	DISCUSSION OF RESULTS .....	24
7.1.1	<i>LoA and Layout</i> .....	24
7.1.2	<i>Parker Hannifin's production system</i> .....	25
7.2	ASSESSMENT OF RESEARCH QUALITY.....	27
7.3	FURTHER RESEARCH .....	27
<b>8</b>	<b>CONCLUSIONS</b> .....	<b>28</b>
	<b>REFERENCES</b> .....	<b>29</b>
	<b>APPENDIX</b> .....	<b>31</b>

---

## 1 Introduction

*The introduction begins with a brief background on Parker Hannifin and the research target. Then the aim and objectives, the main research questions and delimitations are to clarify the focus of the thesis. The chapter ends with an outline to guide the reader in the different parts of the thesis.*

### 1.1 Background

Parker Hannifin is the world's leading company in motion and control technologies and systems (parker.com). In Borås Parker Hannifin manufactures hydraulic valves of product name M200. In 2007, Åsa Fasth and Jessica Bruch executed a ProAct research project at the Borås factory to measure and analyze the Level of Automation (LoA). This particular manufacturing process has since then improved their production process in accordance with the ProAct suggestions from Fasth and Bruch and also according to lean production. These changes have led to improvements in manufacturing and physical alterations in the layout.

That the change of Level of Automation and factory layout is correlated is not difficult to imagine. An example is the installment of a conveyor belt which would require space to be laid out but also for related machines to be connected and thus in line with the conveyor belt. This case of installing a conveyor would probably involve an increase in LoA which would cause a change of layout. This is the character of correlation this research will target. The correlation must be compared in the same production system, comparing data from different points in time. This made Parker Hannifin a suitable candidate for the case study since documentation from 2007 is available.

### 1.2 Aim and Objective

The main objective of this thesis is to identify changes in Level of Automation and layout which are correlated. The thesis is aiming to contribute in the progressing research in automation with a practical aspect which is important to manufacturers. The thesis is also meant to document the manufacturing system at Parker Hannifin.







The research questions which will be attempted to answer are the two following:

- How does the increase LoA affect the layout?
- Is there a specific point in the LoA where the layout changes dramatically?
- What improvements can be made to secure quality in Parker Hannifin's manufacturing system?

### 1.3 Delimitations

This report is limited to studying production systems and in terms of factory layouts, level of automation, assembly systems and lean production. The case study at Parker Hannifin is limited to the assembly station for the hydraulic valve M200. The main analysis will be on LoA and layout correlations, though Parker Hannifin's production process will also be analyzed to a lesser extent.

## 1.4 Thesis Outline

<b>Chapter 1 - Introduction</b>	This chapter introduces the thesis and the area of research by providing a background and problem area, followed by aim and objectives and delimitations. The chapter ends with an outline of the thesis.
<b>Chapter 2 - Research Process</b> 	The research process has consisted of a literature review, observations at Parker Hannifin and analyzing of data from studies conducted in 2007 and 2010 and finally comparing the data. This process is described in this chapter.
<b>Chapter 3 - Method</b> 	This chapter will describe the methodological research approach of the thesis. It presents the empirical and theoretical methods used while conducting the thesis.
<b>Chapter 4 - Frame of Reference</b> 	This chapter concerns the theoretical framework that has its base in production systems. The chapter is divided into four parts; manufacturing layouts, automation, assembly and Lean Production. Each sub chapter will include the definition of the concept as well as an in-depth review on the most relevant issues. Levels of Automation and the DYNAMO methodology will be the essential parts in the automation chapter.
<b>Chapter 5 - Parker Hannifin 2007</b> 	In this chapter Parker Hannifin is presented to get an understanding of the company. The footage from the study 2007 was re-analyzed to obtain LoA values presented in this chapter. This enabled an analysis and comparison with the current state of LoA and layout.
<b>Chapter 6 - Parker Hannifin 2010</b> 	This chapter presents the results of the study performed at Parker Hannifin April 13 2010. The results are of the form of Parker Hannifin's current LoA values and the current production layout.
<b>Chapter 7 - Discussion</b> 	The following chapter will first present the results from the comparison of Parker Hannifin's production system. Then the correlation between changes in LoA and layout will be discussed and reasoned, partly in contrast of the case study. Then Parker Hannifin's production system will be discussed and what alterations can be made to guarantee quality. Finally an assessment of the research is provided and areas of further research.
<b>Chapter 8 - Conclusions</b>	This last chapter restates the conclusions from the discussion.

## 2 Research Process

*The research process has generally consisted of a literature review, observations at Parker Hannifin and analyzing of data from studies conducted in 2007 and 2010 and finally comparing the data. This process is further described in this chapter.*

The research process started with an introductory literature review in automation, Levels of Automation (LoA), layouts, assembly techniques and the principles of lean production. This was followed by a general study of the company for the case study, the hydraulic valve producer Parker Hannifin. The study continued by including material from a research at Parker Hannifin carried out by Fasth and Bruch in 2007. The material from 2007 was re-analyzed for the thesis' specific purpose and to enable a comparison with new material.

New material was collected during a visit to Parker Hannifin in April 13 2010. The current situation was mainly captured by video and layout sketches. While the study was conducted informal interviews took place with the production leader and several assemblers. The material was then analyzed according to the DYNAMO methodology which is described in detail in section 4.2.1. The results from 2007 and 2010 were then compared which enabled an analysis.

The ProAct webpage (<http://lots.iip.kth.se/ProAct/>) has been used to collect data and to make the information accessible for current and future research. The ProAct webpage provides information on LoA and the DYNAMO methodology. The data which has been collected can be easily transferred to an excel-sheet with the push of a button where further analysis and descriptive figures can be semi automatically fabricated.

### 3 Method

*This chapter will describe the research approach of the thesis. It presents the empirical and theoretical methods used while conducting the thesis.*

#### 3.1 The Scientific Approach

There are several different forms of conducting research. Research is often classified as different approaches: deductive, inductive or abductive. The deductive approach implies that results are developed from existing theories and principals. Hypotheses are stated and are then tested empirically in the specific case (Patel & Davidsson, 1991). An inductive approach starts with empirical studies from which conclusions are made to formulate a theory. The abductive approach indicated that a combination of the deductive and inductive approaches is used; theory and empirics are combined through the research process. According to Holme and Solvang (1997) the *systematic combining* of theory and empery is necessary to obtain a complete understanding. The systematic combining provides different sources which contribute to the discovery of new dimensions to the research problem (Frohman J. , 2008).

The methods used in research can also be categorized as quantitative or qualitative. Quantitative studies contain information which is to be structured, analyzed and measured numerically. These studies strive to state a conclusion from data and statistics. The quantitative analysis usually has a standardized style of surveys and questionnaires. Quantitative research is accentuated by their flexibility. The objective is to obtain a deeper understanding in the problem which is studied. The research is conducted with the prerequisite of what is studied and the formulation of question can be altered during that time. The advantage of the quantitative research is the flexibility. However the method also causes difficulties in comparing different studies. (Holme & Solvang, 1997)

In this research, the abductive research was approach was chosen since the underlying data are based on qualitative analysis of the literature and case study, i.e. observations, as well as on individual and consensus views on LoA and layout.

#### 3.2 Empirical Methods

The objective of this thesis is to investigate how layout can alter due to increase of LoA. The thesis has a strong practical emphasis, thus empirical study methods are required to obtain adequate results.

##### 3.2.1 Case studies

Case studies are useful when studying situations which are hard to control. They can offer a wider view and therefore they enhance the possibility of understanding correlations, e.g. between LoA and layout changes. For this thesis, one case study has been carried out at Parker Hannifin and video material from a prior case study at the same company has been used. These are both primary source of information, since the author has collected data from it for this specific thesis.

Interviews are broken down into three categories: unstructured, semi-structured and structured. Unstructured interviews are appropriate when the interviewer has little knowledge of the subject and the interviewee has the opportunity to turn the discussion towards issues he or she sees as important. Semi-structured interviews have a guide line, but questions do not need to be asked in sequence.

A case study was conducted at Parker Hannifin where the working methods were observed. First hand observations are important to obtain better understanding of the manufacturing process and in this specific



case how the surrounding area, machines and tools are utilized. The case study at Parker Hannifin included interviews, in the unstructured manner. The objective with the interviews was to gain knowledge and opinions with high relevance to the subject studied. The staff involved includes the Production Leader and several Assemblers.

The footage of a prior study at Parker Hannifin in 2007 was used for analysis. Even though a report from 2007 was available it was important to extract correct information from the footage to be able to compare it with new data. Thus the analysis and maximum and minimum LoA values from 2007 were no longer compliant and could not be used. The material from 2007 also included a map of the layout.

### **3.3 Theoretical Methods**

As mentioned in 3.1 it is important to connect the empirical studies to theoretical data to get a full understanding of the research problem. Thus theory has been studied to fulfill the research objectives.

#### **3.3.1 Literature review**

A selection of articles, books and theses have been chosen as literature due to their relevance to production systems, particularly with focus on LoA and layouts of production facilities. This type of source is secondary since other people have collected data for their own purposes. The author has not found any literature regarding the correlation between LoA and layout.

## 4 Frame of Reference

*This chapter concerns the theoretical framework that has its base in production systems. The chapter is divided into four parts; manufacturing layouts, automation, assembly and Lean Production. Each sub chapter will include the definition of the concept as well as an in-depth review on the most relevant issues. The manufacturing layout chapter will briefly describe the most common layouts. Levels of Automation and the DYNAMO methodology will be the essential parts in the automation chapter and the assembly chapter will briefly describe important factors in the assembly process. In Lean Production the 7+1 wastes and the implementation method Value Stream Mapping (VSM) will be accounted for.*

Production Systems refer to an arrangement of components whose goal is to collaborate to achieve a specific goal, e.g. adding value to a product (Bellgran & Säfsten, 2005). These components include an overall organization, humans and technical and physical parts. Following sub chapters are closely related to the production system, from its physical appearance to easy coordination within the system.

### 4.1 Manufacturing layouts

Any space where manufacturing and production takes place has a layout. It is physically composed of facilities, machines, equipment and staff which determine the flow of materials and information. This affects the cost and general effectiveness of the operation (Slack, Chambers, & Johnston, 2007). The purpose of a production systems layout is usually to obtain high capacity utilization, short throughput times and flexibility (Ohlager, 2007). As Ohlager (2007) states, a short throughput time implies less Work-In-Progress (WIP) thus less tied-up capital. A sub optimal layout can for example cause long or confused flow patterns, long throughput time and high costs (Slack, Chambers, & Johnston, 2007).

An established layout is usually binding for a longer period of time since changes in the layout causes lose in operation time (Slack, Chambers, & Johnston, 2007). In the short-term perspective the layout has a great influence on costs and efficiency (Ohlager, 2007). Thus alterations have to be planned and the objectives of the re-laying assessed. An ideal layout comprises (Slack, Chambers, & Johnston, 2007):

- safety
- simple and secure flow
- short length of flow
- long-term flexibility
- accessibility
- good use of space
- management coordination

#### **Fixed position**

The fixed position layout is used for large objects which are tied to one location, e.g. boats, houses and power plants. Since the object is still, labor and machines are brought to it. The production system requires a large degree of adaption for every object (Ohlager, 2007). The production effectiveness is strongly tied to the scheduling of access to the site and reliability of delivery (Slack, Chambers, & Johnston, 2007)

### Functional layout

The functional layout is machine oriented from a functional or production technical aspect; similar resources and processes are located together, as in Figure 1. The layout creates flexibility in processing order; accordingly products will have their own specific routes between the function departments (Slack, Chambers, & Johnston, 2007). Therefore functional layout is suitable for low production volume of many variants or in case of largely differentiating operation times. When deciding the functional layout in detail the flow and weight (unit costs) patterns are important input information (Grajo, 1995). The negative aspect of the functional layout is the complex material flow and high work in progress (Ohlager, 2007).

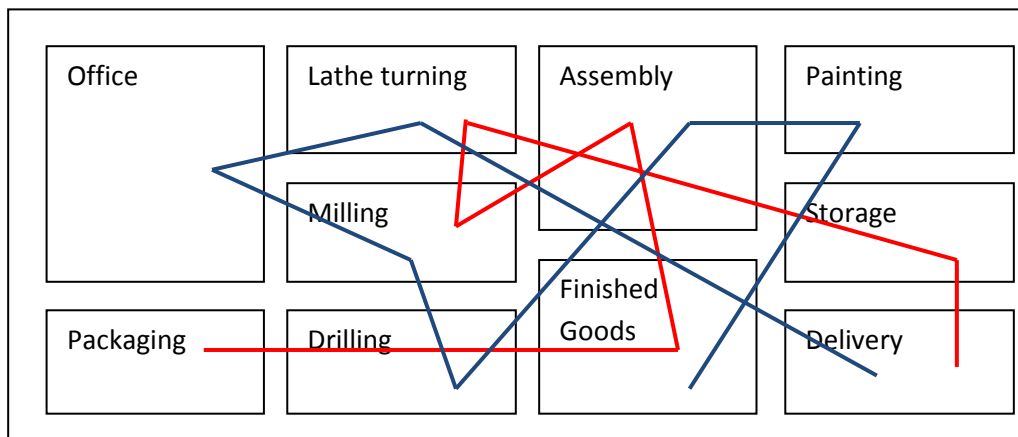


Figure 1. The functional layout with two product flows demonstrated (red and blue lines).

### Product layout

The product layout is product oriented; the physical layout is adapted to how the product is processed and creates a simple flow and shorter transportation, see Figure 2. It requires a high volume of limited products and variants and results in short throughput times, less WIP, simplifies planning and decentralizes the work (Ohlager, 2007; Slack, Chambers, & Johnston, 2007). Process layouts are often built around one governing resource, e.g. an expensive machine. The governing resource will always work to full capacity. Thus it will be the bottleneck and determine the entire capacity of the group (Ohlager, 2007).

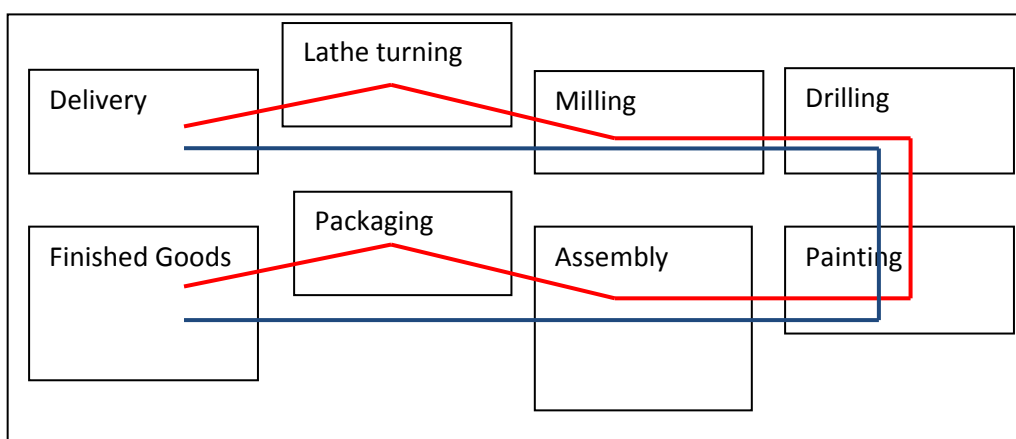


Figure 2. The product layout with two product flows demonstrated (red and blue lines).

The production line is an extremity of a product layout and can be used if the demand is constantly high for a long period of time for a product or product group. It is designated to produce only one product or

product group and is usual in mass production of standardized products (Ohlager, 2007). The operations are often combined with automatic material transport. The investment in proper equipment is substantial and the flexibility low, however the throughput time of production lines are short and WIP low (Slack, Chambers, & Johnston, 2007).

### ***Continuous production***

In the continuous production the processes are physically attached and it is most common in paper, metal and brewery industries. The product selection is highly constrained and the equipment specialized and the investment cost large (Ohlager, 2007).

## **4.2 Automation**

Automation in manufacturing began in the late 19<sup>th</sup> century with the progress towards mass production of weapons and cars related to the American Civil War (Rundqvist & Sandberg, 2008). The development of automation was long focused on mass production to increase productivity per laborer. The motives for automatic manufacturing can be identified as (Rundqvist & Sandberg, 2008):

- Relieve humans from labor and risk
- Increase production rate, speed
- Lower costs
- Provide higher and regular quality
- Decrease throughput time and costs for WIP
- Increase reliability
- Increase flexibility
- Increase integration in the product development
- Create goodwill

According to Onori (2009), it is important to keep manufacturing in Europe since off-shoring of manufacturing may lead to off-shoring of research and development which results in loss of knowledge in Europe. Therefore automation is strategically important for European companies since it enables cost effectiveness which can compete with cheap labor and imitation can be avoided to a large extent. In addition automation ensures a stable quality level.

Currently automation is altering the traditional manufacturing labor to more qualified and intellectual work (Rundqvist & Sandberg, 2008). Workmen are no longer required to perform nor supervise the activities continuously. Instead machines alarm when problems are detected and workers can devote their time to planning, reparations, conversions to different products or variations, education and improvements in the production systems. An automatic system also requires time and resources spent on programming for individual robots and the integration of the entire system (Onori, Hanisch, Barata da Oliveira, & Maraldo, 2007).

Another important issue concerning automation is the flexibility of the system. Flexibility is a wide concept and may refer to changes in products, processes or capacity and volume. It is important that automatic manufacturing systems can respond to the constantly changing circumstances with high variation, shorter life cycles, larger customer adjustments and small series (Rundqvist & Sandberg, 2008) without delay and additional consumption of resources. Even though the industrial robots have become more sophisticated

there are still obstacles in their flexibility in contrast to today's amount and continuous renewal of product variants (Bellgran & Säfsten, 2005).

#### 4.2.1 Research on Automation and the DYNAMO methodology

Present research from Swerea IVF has confirmed that production processes are seldom fully automated. Production is still reliant on humans to control, at least for configuration and development of systems (Frohm J. , 2008). Traditionally automation has been focused on the physical and mechanical activities but Frohm et al. (2005) have recognized that automation also support human cognitive operations, i.e. to control the automatic movements. According to Frohm (2008) the purpose of the cognitive automation is to increase the information flow and provide decision support. Thus cognitive and mechanical automation have been distinguished, as illustrated in Figure 3, although they often co-operate to create a parallel chart (Frohm, Lindström, & Bellgran, 2005).

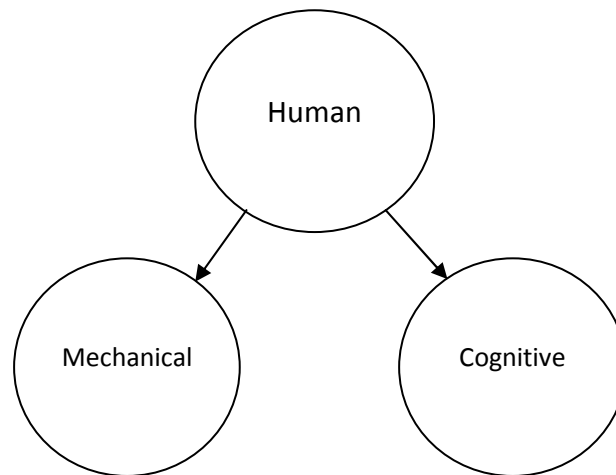


Figure 3. In automation both mechanical and cognitive activities support human labor.

The DYNAMO methodology was developed during the DYNAMO project (2004-2007). The project's objective was to develop a way for "measuring and obtaining an accurate picture of today's information flow and automation level in production systems" (Fath, Dencker, & Stahre, 2008). A reference scale was developed to measure different Levels of Automation (LoA), see Table 1. This scale is divided into two parts, mechanical and cognitive, as both areas are considered when automating a production system. (Fath, Dencker, & Stahre, 2008)

The LoA is relevant in several aspects. First, a company's current LoA can be placed on the 7 point scale to know where they are located. Second, individual operations can then be evaluated to decide which LoA range is most useful and relevant. Third, the company can identify where investments are best located, i.e. sub optimizing automation should be avoided. Activities that do not add value to the customer are not in a position to be automated, but eliminated.

LoA	Mechanical and Equipment	Information and Control
1	<b>Totally Manual</b> – Totally manual work, no tools are used, only the users own muscle power.	<b>Totally manual</b> – The user creates his/her own understanding of the situation and develops his/her course of action based on his/her earlier experience and knowledge.
2	<b>Static hand tool</b> – Manual work with support of a static tool. E.g. screwdriver.	<b>Decision giving</b> – The user gets information about what to do or a proposal for how the task can be achieved. E.g. Work order
3	<b>Flexible hand tool</b> – Manual work with the support of a flexible tool. E.g. adjustable spanner	<b>Teaching</b> – The user gets instructions about how the task can be achieved. E.g. Checklists, manuals
4	<b>Automated hand tool</b> – Manual work with the support of an automated tool. E.g. hydraulic bolt driver	<b>Questioning</b> – The technology questions the execution, if the execution deviates from what the technology considers suitable. E.g. Verification before action
5	<b>Static machine/workstation</b> – Automatic work by a machine that is designed for a specific task. E.g. Lathe	<b>Supervision</b> – The technology calls for the users' attention, and directs it to the present task. E.g. Alarms
6	<b>Flexible machine/workstation</b> – Automatic work by a machine that can be reconfigured for different tasks. E.g. CNC machine	<b>Intervene</b> – The technology takes over and corrects the action, if the executions deviate from what the technology considers suitable. E.g. Thermostat
7	<b>Totally Automatic</b> – Totally automatic work. The machine solves all deviations or problems that occur by itself. E.g. Autonomous systems	<b>Totally automatic</b> – All information and control are handled by the technology. The user is never involved. E.g. Autonomous systems

Tabel 1. The Levels of Automation in the DYNAMO methodology (Frohm J. , 2008)

To practically carry out measurements of LoA the nine steps are to be followed, concluded in Table 2 and shortly described below. The procedure provides a structured process to ensure the quality of work. (Frohm J. , 2008; Fasth, Dencker, & Stahre, 2008)

Step 1: The first step is an off-site preparation where a goal, purpose and delimitations are discussed. Conducting a pre-LoA measurement (Step 4-6) can help understand the process and estimate the time needed for on-site observation.

Step 2: An on-site, pre-study to identify and document the purpose of the production flow from the company's point of view. The work organization of humans and machines are documented as well as the products and variants in the production flow. Personnel should be informed about the proceedings.

Step 3: The production flow is visualized with symbols. By walking with the production flow its sections and cells can be defined and each purpose and task respectively is identified. This step also includes collecting data such as:

- Number of products/variants that pass through each section/cell
- Which physical and cognitive task are allocated to technology or human

## Frame of reference

- Number of operators per section/cell or responsibilities for more than one section/cell

Step 4: The main task for each section/cell is identified.

Step 5: The sub tasks for each section/cell are identified by breaking down the main task to individual operations. Video recordings and operation instructions are a major help in defining the individual sub tasks. The order in which the tasks are conducted is not important for the LoA measurement since the tasks are measured individually.

Step 6: Based on how sub tasks are performed and what interaction is observed, they are judged against the LoA chart to be individually graded on the LoA scale.

Step 7: Together with a smaller group the relevant max and min values for the activities are assessed. The group would most likely consist of an operator, a production engineer, a designer and other people who are closely related to the product. It is important to have the help of on-site personnel for a realistic and adapted judgment. The LoA values are during this process translated in to hypothetical on-site activities.

Step 8: The automation potential is analyzed, based on the LoA measurement, collected data and assessment of relevant max and min LoA.

Step 9: Later research has identified a ninth step to the DYNAMO methodology. The implementation should begin with planning which improvements are most important and will be carried out. A manager for the project has to be appointed so that someone carries the responsibility and a realistic time schedule set. Professional help is recommended for the first round of improvements. (Fath, Dencker, & Stahre, 2008)

1. Plan ahead before the measurement
2. On-site, start with a pre-study to identify the process
3. Visualise and document the production flow
4. Identify the main task for each section/cell
5. Identify sub tasks for each section/cell
6. Measure LoA
7. Assess LoA, set relevant maximum and minimum levels
8. Analysis of results
9. Implementation

Table 2. The steps of the DYNAMO methodology (Frohm J. , 2008; Fath, Dencker, & Stahre, 2008)

### 4.3 Assembly

The assembly system is often used as a synonym to the production system though there are a few fundamental differences. The definition of the assembly system is narrower and specifically refers to the action of putting together parts to create a product (Bellgran & Säfsten, 2005). Assembly systems can include both automatic and/or manual labor. One reason for the dominance of manual labor in assembly is that many tasks are technically difficult to maneuver or impossible to automate (Monteringsteknik, 2005).

Assembly is often the last phase of the production flow its value adding factor is higher than previous procedures (Monteringsteknik, 2005). This implies that a quick flow in the assembly is preferred since the WIP is extremely high during this phase; a short throughput time and delivery to customer result in direct revenue. Nevertheless many factors such as design, sourcing and production planning have a large effect on the assembly, thus a holistic perspective of the assembly system is required (Monteringsteknik, 2005).

## Frame of reference

This also means that these practices should be involved in the assembly system to develop it into a smoothly functioning system (Bellgran & Säfsten, 2005). *Design For Assembly* is one method of collaborating between practices, further described in 4.3.1.

Säfsten and Aresu (2000) researched assembly systems in 15 manufacturing companies in Sweden in 2000. They asked the companies what a successful assembly system is achieved and how a good system behaves. The results of the study are summarized in Table 3.

Prerequisites		Characteristics of the assembly system	Results
<b>Technical aspects</b>	Good system supplier Good suppliers Modularized product Sub assembly connected to final assembly Good product design	Modularized process Rapid changeover Reconstruction possibilities of equipment Standard system Integration between assembly and other processes Assembly capacity in balance with entire factory Balanced flows Sparse material management Parallel processes Free of disruptions Right dimensions in comparison to other sub systems Different material sourcing available Efficiency	Flexibility – product mix, volume Delivery secure, trusted and precise Competitive prices Quality assurance Qualitative products Quick assembly, short time frame Cheap
<b>Social aspects</b>	Good work methods and instructions Competence development Broad competence Competent staff Group organization Minimized work force	Simplicity Visual Cleanliness Rotational opportunities Good control of flow Whole responsibility Flexibility for staff change Good ergonomics Good organization	Job satisfaction Operationally friendly Consideration of the individual Healthy employees

Table 3. Characteristics of a good assembly system. Source: (Säfsten & Aresu, 2000)

### 4.3.1 Design For Assembly

In many cases products are design with little or no awareness of the assembly which can cause the assembly system to be unnecessarily complicated and expensive. Research has estimated that design represents 10% of the products total cost. However during the design process 70% of the production cost is decided, thus there lies a major opportunity to rationalize the assembly system at the design phase (Monteringsteknik, 2005). *Design For Assembly – Monteringsanpassad konstruktion* is a handbook with guidelines and worksheets (<http://www.iip.kth.se/documents/courses/4K1112/DFAHandbok1.pdf>).

*Design For Assembly* (DFA) and is a tool and philosophy used to simplify and secure the assembly process. In manual assembly the grasp and localization of the part is closer analyzed. DFA is differentiated from *Design For Automatic Assembly* which is abbreviated DFAA or DFA2. Guide lines for DFA are following (Svebeus, 2009):

- Reduce number of parts and article numbers



### Frame of reference

- Eliminate the need of adjustments
- Design parts to be self steering and localizing, e.g. as in Figure 4
- Secure accessibility and avoid assembly tasks which are out of sight
- Secure simple management of parts
- Minimize the need for rotation during the assembly
- Design parts which are impossible to assemble in the wrong way
- Maximize part symmetry when possible, otherwise make parts distinctly asymmetric

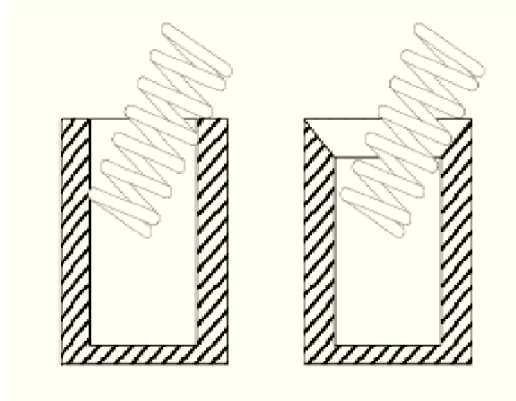


Figure 4. An example of DFA, the beveling of the cylinders opening simplifies the localization of the spring. The spring is less probable to get caught.

To reduce the number of parts four questions can be asked for each individual part. If for a specific part, the answer to all four questions are *no*, it can either be eliminated or integrated with an adjacent part. These four questions are:

1. Does the part need to be of a different material than the adjacent?
2. Does the part need to be able to move relative the adjacent part?
3. Does the part need to be removable for service or maintenance?
4. Does the part need to be movable to enable assembly of another part?

Besides accomplishing a product designed for assembly, cooperation between designers and production staff at the developing stage is desirable. This allows for expensive design mishaps to be eliminated at an early phase and provides for an optimal design, balanced between the product and assembly system.

#### 4.4 Lean Production

Lean production is originally a concept from Toyota Industries and is founded on doing simple things well and with time to do them better and, most importantly, to eliminate all sorts of waste throughout the whole process (Slack, Chambers, & Johnston, 2007). The lean philosophy also emphasizes the drive to operate continuous improvements and the involvement of staff (Stjernstoft, 2009).

Womack & Jones (2003) explain five principles in *Lean Thinking*. *Value* is created by the producer but can only be defined by the ultimate customer, thus it is important to know what the customer values. The *value stream* consists of the actions needed to produce a good or service. The entire value stream should be identified to be able to eliminate waste and should then be optimized to create a *flow*. The customer

### Frame of reference

should demand the product hence creating a *pull* in the production. The process of improving is endless, thus *perfection* should be sought to come closer to what the customer actually wants.

Waste is any activity which consumes resources but does not create value (Womack & Jones, 2003). Today the lean philosophy accounts for eight types of waste, seven from the former Toyota executive Taiichi Ohno and one added by Womack and Jones (Womack & Jones, 2003). By eliminating unnecessary actions and objects the flow of material and information becomes more comprehensible and easier to coordinate. The 7 + 1 wastes are illustrated in Figure 5 and are described as following (Stjernstoft, 2009):

- *Overproduction*: encompasses excess production of items, excess information and producing/acquiring items before they are actually required. Overproduction is the most serious waste since it causes other types of wastes such as inventory, transport and over processing/handling
- *Transporting*: of goods from one place to another without any purpose, i.e. no value is added from the customer point of view. Each time a product is moved it stands the risk of being damaged, lost, delayed, etc.
- *Defects*: Quality defects prevent the customers from accepting the product. The process in which the defect was produced is waste. In addition, rectification is needed in effort to reclaim some value for the otherwise scrap product.
- *Waiting*: e.g. the time when waiting for information, materials or equipment. One tangible example is groups of people in a downstream activity standing and waiting because an upstream activity has not delivered on time
- *Inventory*: ties capital in raw materials, work-in-progress (WIP), or finished goods. Any of these three items not being actively processed to add value is waste. Inventories also occupy space, require managing and products risk obsolescence and getting lost.
- *Excess motion*: refers to the motion of the laborer or equipment. Examples of excess motions are bending, stretching, walks, searching for equipment or material, etc. This has significance to damage, wear, fixed assets, and expenses incurred in the production process.
- *Inappropriate processing*: unnecessary performance that the customer does not require. E.g. excess controls and labor, excessive quality, packing and unpacking for in-house transports.
- There is a particular problem with this item as regarding people. People may need to perform tasks that they are over qualified for so as to maintain their competency. This training cost can be used to offset the waste associated with over processing
- *Unused creativity*: workers' knowledge and ideas are not utilized

### Frame of reference

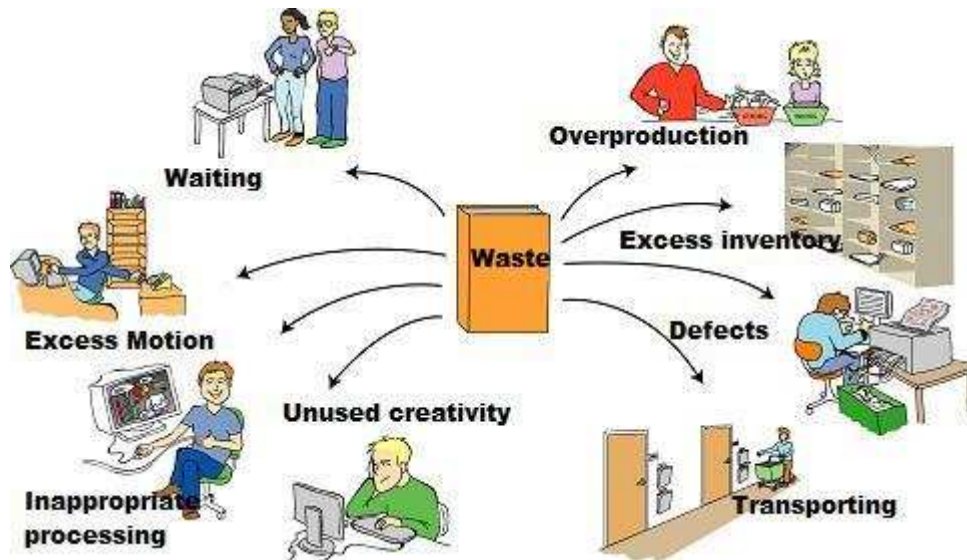


Figure 5. The eight wastes. Source: (IVF)

#### 4.4.1 Value Stream Mapping

One effective method to employ lean is *Value Stream Mapping* (VSM) which describes the flow of material and information through a production processes or supply chain (Slack, Chambers, & Johnston, 2007). VSM visualizes the production in one moment and provides a wide depiction rather than individual processes (Stjernstoft, 2009). Therefore VSM helps identify bottlenecks and waste and serves as a base for improvements to create an overall optimal flow (Womack & Jones, 2003). Stjernstoft expresses that optimizing an individual process by itself can be wasteful if the other processes still are bottlenecks and lack capacity.

VSM is carried out by drawing a map of material and information flows for a product or product family (Stjernstoft, 2009). The value adding activities are differentiated from non-value adding activities (Slack, Chambers, & Johnston, 2007), which composes the *Current State* as the example in Figure 6. The *Current State* is analyzed, in particular to eliminate waste and cut throughput time (Stjernstoft, 2009). The ideas for upgrading are then depicted in a map of the *Future State*. A plan of action should be arranged in accordance with the *Future State* and delegation of the responsibility so that improvements in the value stream are realized. This process can be repeated for continuous improvements (Womack & Jones, 2003).

# Frame of reference

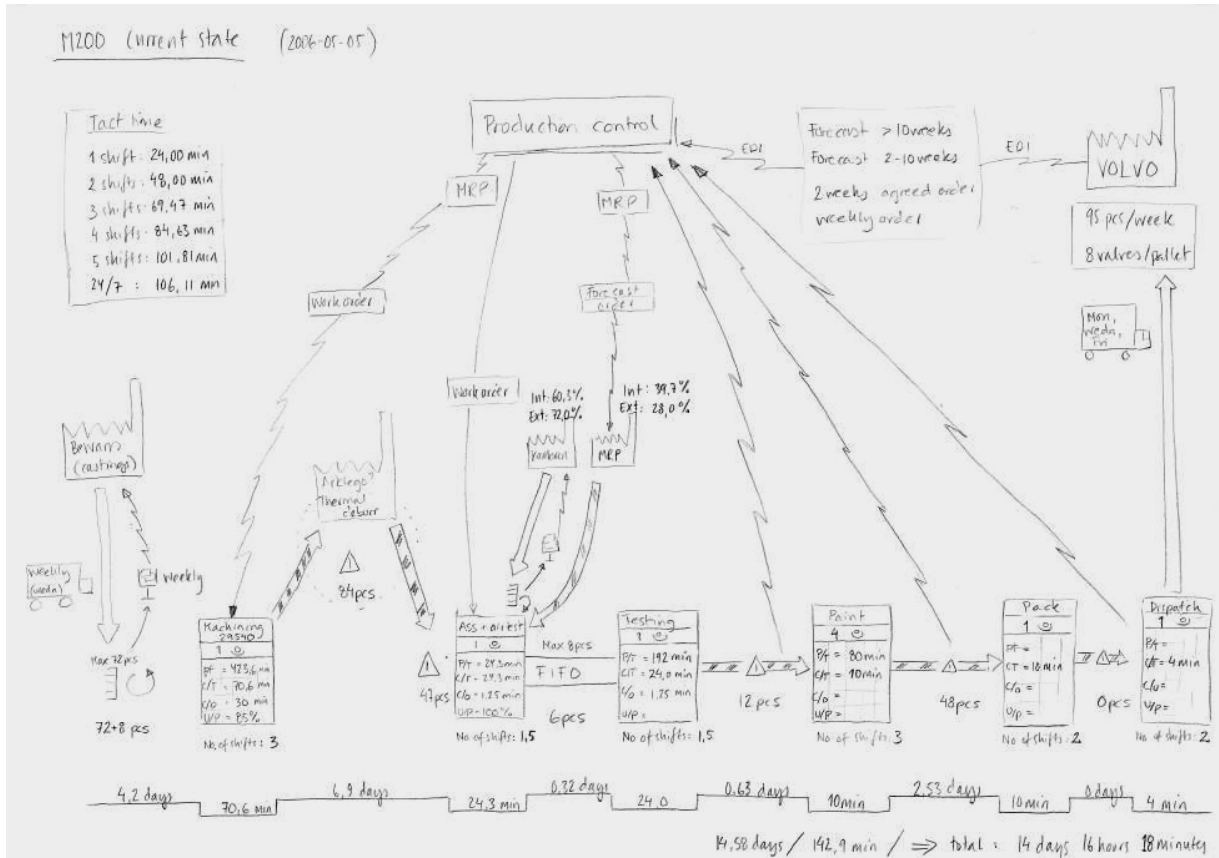


Figure 6. A Value Stream Map of the M200 information and material flow at Parker Hannifin in 2007. A larger image is provided, see Appendix 1.

## 5 Parker Hannifin and Results from 2007

In this chapter Parker Hannifin is presented to get an understanding of the company. The footage from the study 2007 was re-analyzed to obtain LoA values presented in the chapter. This enabled an analysis and comparison with the current state of LoA and layout.

Parker Hannifin's history begins in 1918 when Arthur L. Parker founded Parker Appliance Company to develop a unique pneumatic brake system for trucks and busses. Almost a century later the annual sales at Parker Hannifin Corporation exceed 10 billion dollars, which makes it the largest diversified manufacturer of motion and control technology and systems (Parker Hannifin, 2009). Today they provide mobile, industrial, and aerospace markets with solutions and their products are essential to anything that requires movement and control. Parker Hannifin is traded on the New York Stock Exchange as "PH". The company employs 52 000 people in 48 countries worldwide.

In the beginning of the 21<sup>st</sup> century Parker Hannifin developed the "Win Strategy" to cope with the fast changes in the global market and to ensure a future successful concept (Parker Hannifin, 2009). The win strategy encompasses the vision of being the number one company in motion and control and goals such as premier customer service, financial performance and profitable growth. See the whole strategy in Figure 7.



Figure 7. Parker Hannifin's Win Strategy (Parker Hannifin, 2009)

## 5.1 Article M200

In 2007 Bruch and Fasth analyzed Parker Hannifin's manufacturing processes of the hydraulic valve of article M200, see Figure 8. This type of valve is used as a part of the steering and lifting device in construction vehicles such as loaders. The different parts of a valve and proper naming are in Appendix 2.



Figure 8. The M200 hydraulic valve manufactured at Parker Hannifin, Borås

For the M200 manufacturing process four stations are identified: Kitting, Assembly, Air Test and Oil Test. Figure 9 illustrates the manufacturing flow: the kitting is detached whilst the assembly, air and oil test are conducted in a U-formed production layout. According to the DYNAMO methodology, main tasks have then been identified at each station. The main tasks have then been broken down into sub tasks.

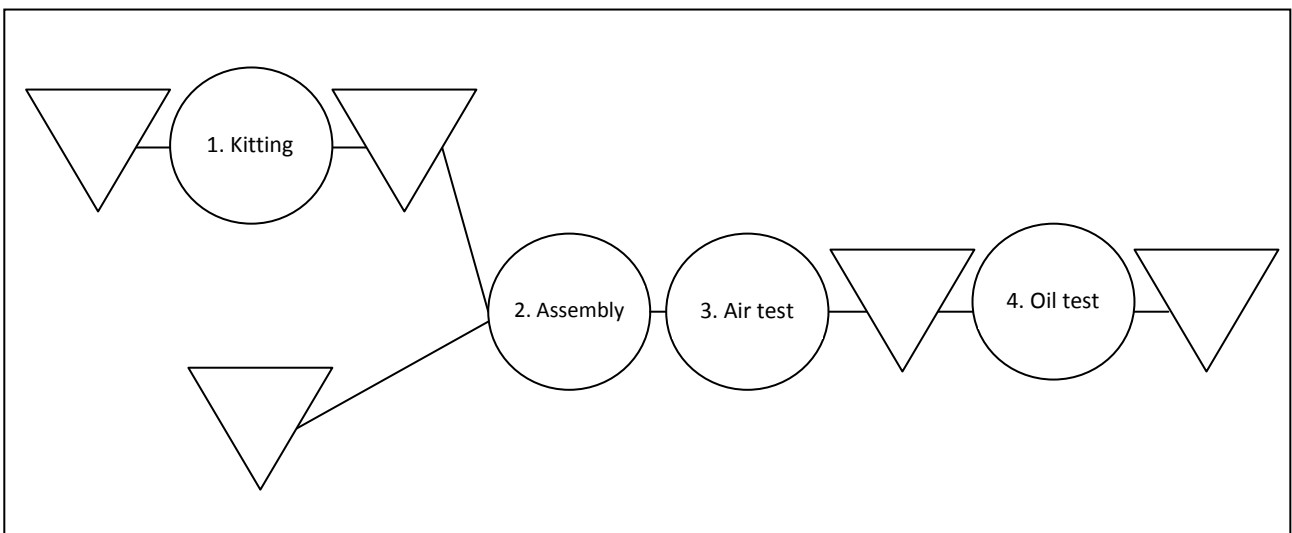


Figure 9. Manufacturing flow of M200. The circles represent the manufacturing stations and the triangles stock or buffers.

To obtain an understanding for the stations, short descriptions are presented. At the Kitting station trays are prepared with components which will be assembled at the second station Assembly. The function is to secure an assembly of correct parts since many of these have similar appearance. The kitting trays are then transported manually to the assembly station.

The Assembly station the valve is fully assembled with the help of a fixture and a multitude of tools, both static and automatic. The assembly station is followed by the Air Test. When a valve is fully assembled the assembler immediately moves the valve to the Air Test station. The air test is directly set up and runs while

another valve is assembled. Since the assembly and air test station are run simultaneously by the same person, the time consumption for one cycle is the most reasonable time measure.

After the Air Test the valve is placed in a buffer. The oil test is the last operation which is physically separated from the other stations. It has the longest throughput time and at risk of being the bottle neck. When assessing the production flow with value stream mapping, generally it is negative to have a longer throughput time at the end of production. This is because the product has large value after going through all the previous processes and needs to generate an income rather than having capital in queue for the last process.

### 5.1.1 Assembly

The assembly is performed on a large valve which is fastened in a fixture. The components which are to be assembled are partially picked from shelves and partially from the kitting trays. The tools which are needed in the assembly of the valve are wrenches, torque wrenches, a puncher, hammers and cordless screwdrivers. The suggested improvements for the assembly station in 2007 were following:

- Since there is only one order sheet per batch it is hard to know which batch the kitting trays belong to. Thus a mark on the trays can indicate which batch the tray belongs to.
- Confirmation of correct assembly. E.g a fixture with sensors which can alarm or with a monitoring camera and a status light.
- Decrease number of tools required.
- A fixture which does not require manual attaching of valve. This can be completed with sensors which are activated when the valve is put down and holds the valve with vacuum.

From the film material from 2007 main tasks, sub tasks and mechanical and cognitive LoA values have been identified, Table 4-6. The tasks have been extracted to be easily compared with results from 2010. When only dividing tasks and LoA values, the chronological time order has no influence. Thus sub tasks which are not conducted directly in sequence are rearranged and located under the same main task. One specific example is that both sub tasks punching and assemble casing (A) correspond to the main task, but are not carried out in order. The sub tasks still belong to the main task Assembly of casing, and must be located here for a correct LoA value for the task.

2007 Assembly, Station 2	
<b>Main task 2.1</b>	Read customer specification and order
<b>Main task 2.2</b>	Move valve from buffer to fixture
<b>Main task 2.3</b>	Lock vessel in fixture
<b>Main task 2.4</b>	Move kitting trays from buffer to the side of the fix
<b>Main task 2.5</b>	Rotate fixture
<b>Main task 2.6</b>	Assemble sequence slider (sekvensslid)
<b>Main task 2.7</b>	Assemble casing (kåpa)
<b>Main task 2.8</b>	Assemble pin (lasthållningskägla)
<b>Main task 2.9</b>	Assemble sequence and chock valves
<b>Main task 2.10</b>	Assemble gear valve
<b>Main task 2.11</b>	Assemble hook

Table 4. Main tasks at the Assembly station for 2007

LoA mech	Task 2.1	Task 2.2	Task 2.3	Task 2.4	Task 2.5	Task 2.6	Task 2.7	Task 2.8	Task 2.9	Task 2.10	Task 2.11
7											
6											
5											
4					B						
3		B									
2						B	B		B	B	
1	B		B	B				B			B

Table 5. 2007 Mechanical LoA for each main task respectively

LoA cog	Task 2.1	Task 2.2	Task 2.3	Task 2.4	Task 2.5	Task 2.6	Task 2.7	Task 2.8	Task 2.9	Task 2.10	Task 2.11
7											
6											
5											
4											
3	B										
2											
1		B	B	B	B	B	B	B	B	B	B

Table 6. 2007 Cognitive LoA for each main task respectively

From the *Value Stream Map (VSM)* in 2007 the time for a valve to pass through the assembly station and the air test station took 24 minutes and 30 seconds. Since the VSM is only a snap shot, this time measurement is not statistically correct.

The floor plan from 2007 had a *product layout* with a U-flow in the last three stations as shown in Figure 10. A larger view is illustrated in Appendix 3.



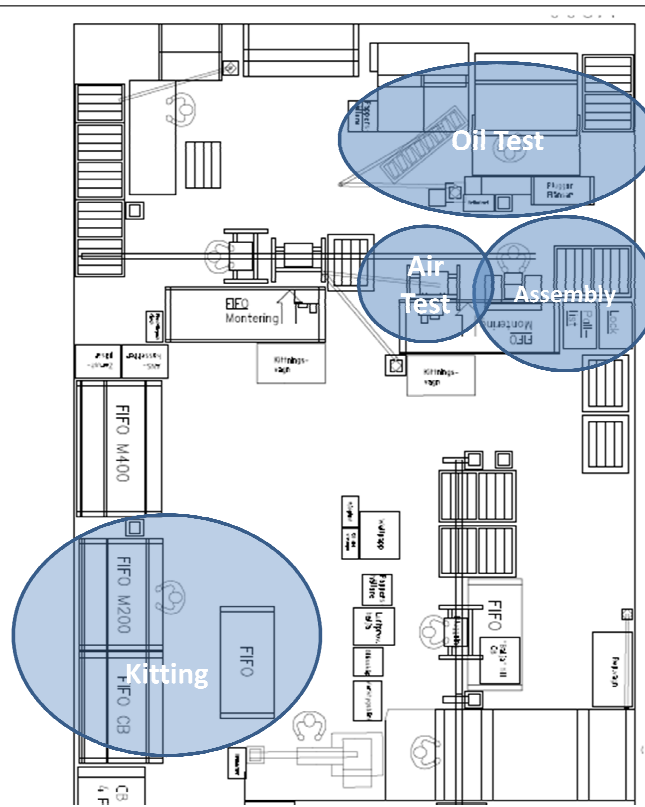


Figure 10. Layout 2007

## 6 Parker Hannifin's Results from 2010

This chapter presents the results of the study performed at Parker Hannifin April 13 2010. The results are of the form of Parker Hannifin's current LoA values and the current production layout.

April 13 2010 the current situation of the assembly process for M200 was captured. At the site two main assignments were conducted: the documentation of the assembly process by video recording and drawing a floor plan to document the layout. The documented material was then analyzed to identify main tasks sub tasks and observed LoA values. The main tasks and mechanical and cognitive LoA values are presented in Table 7-9.

2010 Assembly, Station 2	
<b>Main task 2.1</b>	Read customer specification and order
<b>Main task 2.2</b>	Move valve from buffer to fixture
<b>Main task 2.3</b>	Lock vessel in fixture
<b>Main task 2.4</b>	Move kitting trays from buffer to the side of the fix
<b>Main task 2.5</b>	Rotate fixture
<b>Main task 2.6</b>	Assemble sequence slider (sekvensslid)
<b>Main task 2.7</b>	Assemble casing (kåpa)
<b>Main task 2.8</b>	Assemble pin (lasthållningskägla)
<b>Main task 2.9</b>	Assemble sequence and chock valves
<b>Main task 2.10</b>	Assemble gear valve
<b>Main task 2.11</b>	Assemble hook
<b>Main task 2.12</b>	Punch hole

Table 7. Main tasks at the Assembly station for 2010

LoA mech	Task 2.1	Task 2.2	Task 2.3	Task 2.4	Task 2.5	Task 2.6	Task 2.7	Task 2.8	Task 2.9	Task 2.10	Task 2.11	Task 2.12
7												
6												
5					B							
4												
3		B				B						
2							B		B	B		B
1	B		B	B				B			B	

Table 8. 2010 Mechanical LoA for each main task respectively

LoA cog	Task 2.1	Task 2.2	Task 2.3	Task 2.4	Task 2.5	Task 2.6	Task 2.7	Task 2.8	Task 2.9	Task 2.10	Task 2.11	Task 2.12
7												
6												
5												
4												
3	B											
2												
1		B	B	B	B	B	B	B	B	B	B	B

Table 9. 2010 Cognitive LoA for each main task respectively

No min and max values for the tasks have been established since this is to be done in collaboration with a group from Parker Hannifin which has a close production relation to the M200 valve.

At the time of the visit the assembly defects stood for the largest cause of returned parts with approximately 150- 200 returned parts per million. Jonas Carleljung, Production Leader for M200, states that most of the defects could have been avoided with a smarter construction (2010). He also describes that investments of this division at Parker Hannifin have a pay-back time of one year, enforced by the head quarter (Carleljung, 2010). A brief interview with an Assembler provides the information that, after five months working of assembling the M200, there is no need for instructions.

April 13 2010, the median time of a whole cycle of assembly and air test was 13 minutes and 45 seconds. During this particular time measurement a new batch of valves where fetched. A total of three cycles were measured. The exact time per M200 is not measured at Parker Hannifin. The production is planned to produce a specific number of valves per day. The time to assemble each individual valve is varying, one factor being the assembly of the o-rings which on the footage proved to be difficult.

The present layout has a *product layout* with a linear flow. At the kitting station kitting trays are laid for more valves than the M200. The assembly, air test and oil test handle the M200 and the newer valve M250. In Figure 11 the layout which is relevant for the M200 is displayed, though it is only a fraction of a larger production site. A slightly better view of the area is demonstrated in Appendix 4.

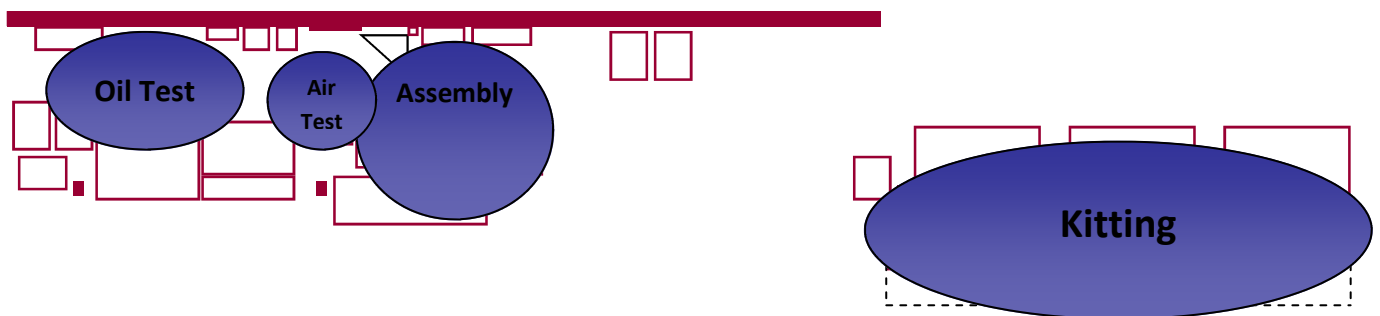


Figure 11. Layout 2010

## 6.1 A short Sandvik case

From the authors prior experience there have been other cases in which the increase in LoA has required a layout change. A specific case is at Sandvik Coromant in Gimo where the production system of cutting tools was updated. This included investments in many robots and automatic transport between processes which replaces human mechanical labor, an increase to 6 or 7 on the mechanical LoA scale. As the guide stated, the investments in automation had required considerable alterations to the placements of machines, robots and paths wide enough for the robots to pass (Johansson, 2009).

## 7 Discussion

The following chapter will first present the results from the comparison of Parker Hannifin's production system. Then the correlation between changes in LoA and layout will be discussed and reasoned, partly in contrast of the case study. Then Parker Hannifin's production system will be discussed and what alterations can be made to guarantee quality. Finally an assessment of the research is provided and areas of further research.

### 7.1 Discussion of results

When comparing the current state of the assembly system with the 2007 state, two differences can easily be recognized. The first is that the mechanical LoA has increased for main tasks 2.5 and 2.6, marked by the shaded area in Table 10. The second difference is the apparent adjustment of the layout from a U-shaped to a straight material flow. An alarming similarity between the studies 2007 and 2010 is the cognitive LoA.

Assembly, Station 2		LoA <sub>mech</sub>		LoA <sub>cog</sub>	
		2007	2010	2007	2010
<b>Task 2.1</b>	Read customer specification and order	1	1	3	3
<b>Task 2.2</b>	Move valve from buffer to fixture	3	3	1	1
<b>Task 2.3</b>	Lock vessel in fixture	1	1	1	1
<b>Task 2.4</b>	Move kitting trays from buffer to the side of the fix	1	1	1	1
<b>Task 2.5</b>	Rotate fixture	4	5	1	1
<b>Task 2.6</b>	Assemble sequence slider (sekvensslid)	2	3	1	1
<b>Task 2.7</b>	Assemble casing (kåpa)	2	2	1	1
<b>Task 2.8</b>	Assemble pin (lasthållningskägla)	1	1	1	1
<b>Task 2.9</b>	Assemble sequence and chock valves	2	2	1	1
<b>Task 2.10</b>	Assemble gear valve	2	2	1	1
<b>Task 2.11</b>	Assemble hook	1	1	1	1
<b>Task 2.12</b>	Punch hole	-	2	-	1

Table 10. A direct comparison of LoA values

The DYNAMO methodology proved to be an effective and objective technique to measure the production system. At Parker Hannifin the assembly of the M200 hydraulic valve had surprisingly frequently first grade rating for the mechanical LoA (totally manual). In addition LoA values provide a solid base for comparing production systems' automation and work methods. When working through the steps of the DYNAMO methodology the entire production system which is studied is scrutinized which also assists in finding other divergences or problems.

#### 7.1.1 LoA and Layout

As the conveyor belt example in the introduction, the correlation of LoA and layout changes can be easily reasoned, though no research has been found to prove this hypothesis. At Parker Hannifin the total LoA has increased and the layout has changed. The hard facts from the case study support that LoA and layout changes can be correlated. Analyzing the source of change, the outcome shows that the LoA has increased due to the use of more automatic tools and fixture movements and also because of the sub assembly of the sequence slide in the 2010 state. The layout changed from a U-shaped flow to a straight flow to increase visibility, i.e. a lean production improvement, and to avoid assemblers' crooked movements. It can be concluded that the LoA increase is not the cause of the layout change; LoA and layout change are not correlated in this specific case.

LoA	Mechanical and Equipment	Information and Control
1	Totally Manual	Totally manual
2	Static hand tool	Decision giving
3	Flexible hand tool	Teaching
4	Automated hand tool	Questioning
5	Static machine/workstation	Supervision
6	Flexible machine/workstation	Intervene
7	Totally Automatic	Totally automatic

Table 11. Compressed table of LoA values. See Table 1 for LoA table for descriptions of each value.

The two different cases at Parker Hannifin and Sandvik prove that LoA changes can, but do not necessarily require layout alterations. Further analysis and comparison of the two cases enlighten a significant difference. While both LoA values were increased, the changes were on different areas of the LoA scale. A change from flexible hand tool to automatic hand tool, as at Parker Hannifin, still required a person standing at the same station handling the assembly. At Sandvik Coromant however the mechanical LoA changed from manual to automatic which resulted in a layout change. From these cases two outcomes can be deduced to answer the research question if there is a specific point in the LoA where the layout changes dramatically: (1) a mechanical LoA alteration between value 1 and 4 does not in itself involve a layout change and (2) alterations in which LoA increases to 5, 6 or 7 will most likely be followed by a layout change. Observe Table 11 for LoA grading. The types of changes in (2) are beneficial to take consideration when this type of alteration is planned to be able to predict layout and costs.

The second research question concerning how the increase of LoA affects the layout is more ambivalent. Layout changes due to LoA are an issue of factory space and material flow. It is important to understand that depending on how the original layout is planned, alterations will vary in extent. Since layouts should be compatible with current production systems, LoA changes which infer in the production system might need a different space to be situated in, be it more space, less space or just a diverse positioning. Cameras, alarms, thermostat and other computing equipment which alter the cognitive LoA are often small in size. Therefore it can be assumed cognitive LoA changes more seldom require layout changes.

### 7.1.2 Parker Hannifin's production system

As Production Leader Jonas Carleljung mentioned, many of the assembly defects of the M200 valve could have been avoided if the assembly process had been taken into consideration during the designing (Carleljung, 2010). Therefore the method *Design For Assembly*, DFA, should have been applied in the developing stage. Because the M200 valve has been in production for several years it might be at the end of its life cycle. Hence, it might be phased out soon and redesigning it at this stage would be wasteful. If the M200 valve will be in production for several more years it is of interest to revise the design, specifically the reduction of parts for the M200. The basics of DFA are described in 4.3. Neglect in the design becomes costly for assembly since it requires redesigning or change in the assembly system. At the same time, the assembly system should be reduced to eliminate all types of waste. Thus it is up to the design team to draw a smart construction from the start. Even though the system has been improved at Parker Hannifin it has been difficult to guarantee quality. The M200 has too many possibilities for mistakes during assembly due to the design.

When in the process of developing new valves, Parker Hannifin should in the future have DFA as a standard method to ensure a smoother assembly and secure the quality of the products. A suggestion for the

## Discussion

company is to arrange workshops during the design phase. This gives designers and assemblers designated time to discuss how the product will be designed according to its function but also to fit with the assembly system. Another recommendation is that the designers are placed at the assembly line for half a day to learn the system and acquire firsthand experience. This experience makes it possible for the designers to take the assembly system into consideration and avoid common problems at the design phase.

Since several valves are assembled at Parker Hannifin there might also be a need to compare the different designs and what parts they need. Given that slides have been a problem earlier due to similarity, new valve designs could opt to either use exactly the same slides or notably diverse. Another suggestion is to use colors to code the slides. Each slide is then marked with specific color so it is easily distinguished.

It should also be mentioned that all the kitting trays of one batch are in 2010 transported together. The kitting trays also carry more valve specific parts to reduce mistakes in assembly. There is no vision equipment used at present to ensure correct assembly. The valve is still manually fastened to the fixture, though its movements are now automated and controlled with two buttons. Since the pay-back time of investments is set to one year (Carleljung, 2010), it limits what investments which are pulled through.

### *The Cognitive LoA aspect*

As previously mentioned the cognitive LoA remained unchanged from 2007. Even though Assemblers feel confident on how to assemble the M200 valve, mistakes can easily occur and obviously do occur since it is the single most frequent reason for returned valves. Therefore there is a need for the assembly process to be further secured. The cognitive LoA has two aspects to take into consideration: contents and presentation. Since the contents already exist, the mission is to present it strategically. This can be done by placing the instructions in front of the assembler which enables easy access, see Figure 12. The instructions can be turned around a vertical or horizontal axis. By placing the instructions suitably – both visible and able to turn the instruction pages – the assemblers never need to guess on the tasks.

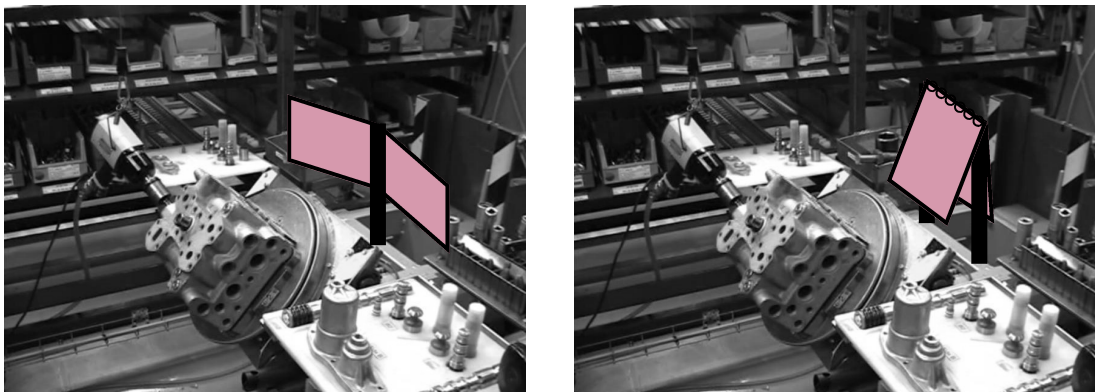


Figure 12. Assembly instructions, in pink, are placed in front of the workstation to provide visibility at all times.

The content of the instructions may need to be upgraded to larger images or clarified tasks if they are unclear at present. In addition, the instructions can be displayed on a touch-screen to avoid turning pages which can both be space and time consuming. Other ways in which the cognitive LoA can be increased is by installing a vision system which controls that right parts are assembled before proceeding to the next step.

## **7.2 Assessment of research quality**

The general credibility of this thesis is intermediate. Literature and data has been objectively collected and analyzed and only logical reasoning with motives lie behind statements. However the main base lies on only one case study at Parker Hannifin which is only able to provide one scenario. This implies that the amount of empirical data has been limited and it would have been preferred to have conducted several case studies to obtain a variety of scenarios. Still, this thesis has been performed within a restricted time-frame. In addition, the analysis required for the DYNAMO methodology is thorough and time consuming.

The transferability of the study can be applied to most industrial production systems. Interested persons can easily embrace the analysis and probably be able to make their own estimation of LoA and layout correlation for their specific purpose.

## **7.3 Further research**

Due to the limited time frame and scope of this thesis it is suggested that further research is conducted to have more data to support the argument to which extent changes in LoA and facility layout is correlated. Specifically quantitative analysis on additional case studies can be made.

Investigations on how the DYNAMO methodology and measurements of LoA can be used more practically by the industry would also be valuable. It is crucial that industries to not misinterpret the function of DYNAMO, since there is no reason to make investments for the sole task to increase LoA.

## 8 Conclusions

*This last chapter will restate the conclusions from the previous discussion.*

The DYNAMO methodology proved to be an effective and objective technique to measure a production systems automation and information flow. LoA values provide a solid base for comparing production systems' automation and work methods. When working through the steps of the DYNAMO methodology the entire production system which is studied is scrutinized which also assists in finding other divergences or problems.

At Parker Hannifin the total LoA has increased and the layout has changed, though the two alterations were not correlated. The Parker Hannifin case was further analyzed and one other experience from Sandvik was illustrated to draw the conclusion that there is a specific point in the LoA where the layout changes dramatically. (1) A mechanical LoA alteration between value 1 and 4 does not in itself involve a layout change. (2) Alterations in which LoA increases to 5, 6 or 7 will most likely be followed by a layout change.

Exactly how the increase of LoA affects the layout is still hard to tell. Layout changes due to LoA are an issue of factory space and material flow. Since layouts should be compatible with current production systems, LoA changes which infer in the production system might need a different space to be situated in, be it more space, less space or just a diverse positioning. Since cognitive changes in LoA more frequently require equipment small in size, they are assumed to seldom cause layout changes.

Recommendations that have been specifically announced to improve the production system at Parker Hannifin:

- Make DFA a standard procedure
- Workshop for designers and assemblers to collaborate
- Designers join assembly line for half a day for assembly system understanding
- Color coding of slides to eliminate mistakes
- Place instructions visibly for assemblers to easily access at all times to eliminate mistakes

Using DFA at the developing stage for all valves is particularly important to minimize the costs and quality issues and ensure a smoother assembly.



## References

- Bellgran, M., & Säfsten, K. (2005). *Produktionsutveckling: Utveckling och Drift i Produktionssystem*. Lund: Studentlitteratur.
- Carleljung, J. (den 13 April 2010). Production Leader. (K. Lööf, Intervjuare)
- Design For Assembly - Monteringsanpassad Konstruktion*. (u.d.). Hämtat från Industriell Produktion, KTH: <http://www.iip.kth.se/documents/courses/4K1112/DFAHandbok1.pdf> den 12 May 2010
- Fasth, Å., Dencker, K., & Stahre, J. (2008). Measuring and analysing Levels of Automation in an assembly system. *The 41st CIRP Conference on Manufacturing Systems*, (ss. 169-172). Tokyo.
- Frohm, J. (2008). *Levels of Automation in Production Systems*. Göteborg: Chalmers.
- Frohm, J., Lindström, V., & Bellgran, M. (2005). A Model for Parallel Levels of Automation within Manufacturing. *18th International Conference on Production Research*. Serano.
- Grajo, E. S. (1995). Strategic Layout Planning and Simulation for Lean Manufacturing. *Winter Simulation Conference* (ss. 510-514). Michigan: Production Modeling Corporation.
- Holme, I., & Solvang, B. (1997). *Forskningsmetodik*. Lund: Studentlitteratur.
- IVF. (u.d.). Hämtat från <http://extra.ivf.se/leantttpublic/download/wastes.JPG>
- Johansson, H. (Artist). (den 2 November 2009). *Sandvik Coromant Guided Tour*. Sandvik Coromant, Gimo.
- Monteringsteknik*. (2005). Universitetservice.
- Ohlager, J. (2007). *Produktionsekonomi*. Poland: Studentlitteratur.
- Onori, M., Hanisch, C., Barata da Oliveira, J., & Maraldo, T. (2007). *Adaptive Assembly Technology Roadmap*.
- Parker Hannifin*. (2009). Hämtat från Parker Hannifin: Företagsinformation: <http://www.parker.com/portal/site/PARKER/menuitem.0684fe09f6d345faef40eae8237ad1ca/?vgnnextoid=4630724c84e22110VgnVCM100000d0da8c0RCRD&vgnnextfmt=SV> den 3 mars 2010
- Parker Hannifin*. (2009). Hämtat från Parker Hannifin: Företagets Historia: <http://www.parker.com/portal/site/PARKER/menuitem.e631b67dc0285c0566b049e1237ad1ca/?vgnnextoid=8cf6b5bbec622110VgnVCM10000032a71dacRCRD&vgnnextfmt=SV> den 3 mars 2010
- Patel, R., & Davidsson, B. (1991). *Forskningsmetodikens grunder*. Lund: Studentlitteratur.
- Rundqvist, B., & Sandberg, B. (2008). Automatiseringsteknik, översikt. *Produktionsautomatisering MG1018* (ss. 1-11). Stockholm: KTH.
- Slack, N., Chambers, S., & Johnston, R. (2007). *Operations Management* (5 uppl.). Madrid: Prentice Hall.
- Stjernstoft, T. (2009). *Ph. D.* KTH, Stockholm.

## References

Svebeus, J.-O. (Artist). (2009). Lecture at KTH, Stockholm.

Säfsten, K., & Aresu, E. (2000). *Vad är bra monteringsystem? En studie av utformning och utvärdering på 15 industriföretag i Sverige*. Linköping: Linköpings Universitet.

Womack, J. P., & Jones, D. T. (2003). *Lean Thinking: Banishing Waste and Create Wealth in Your Corporation*. London: Simon & Schulster.

## **Appendix**

Appendix 1: Value Stream Map of hydraulic valve M200, 2007

Appendix 2: Valve Components on Kitting Trays

Appendix 3: Layout for production of hydraulic valve M200, 2007

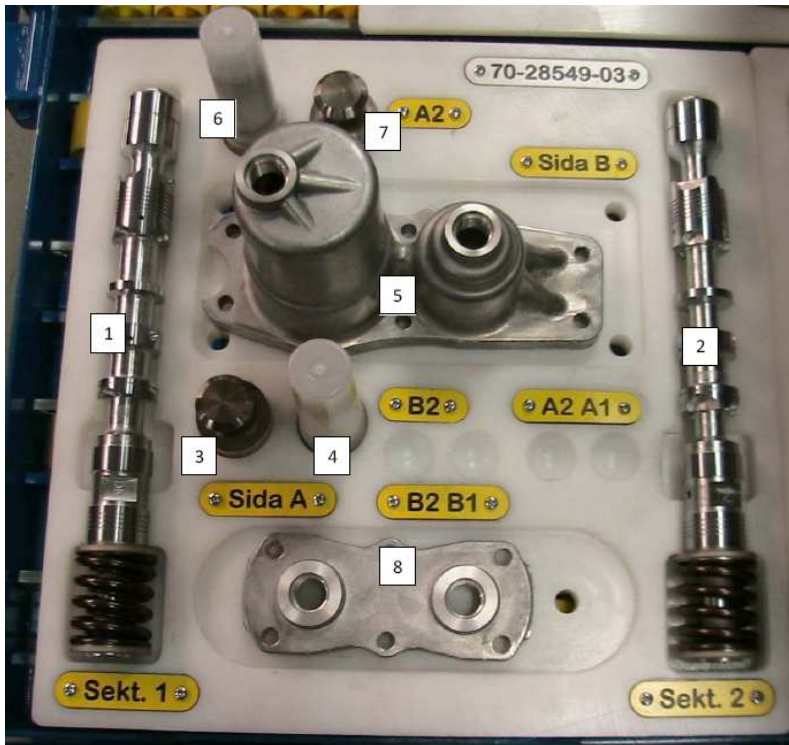
Appendix 4: Layout for production of hydraulic valve M200, April 13 2010



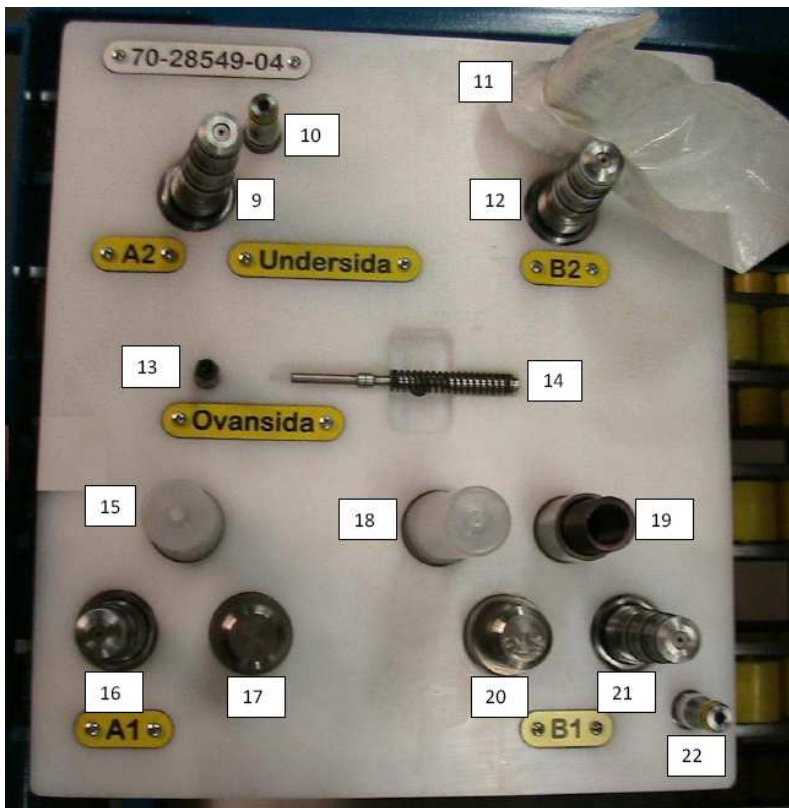
## Appendix

### Appendix 2: Valve Components on Kitting Trays.

OBS! Not kitting trays for M200. The pictures are used for component identification.



1. Slid med fjäderpaket sekt.1
2. Slid med fjäderpaket sekt.2
3. Lasthållningskägla
4. Chockventil
5. Kåpa
6. Chockventil
7. Lasthållningskägla
8. Kåpa (A)



9. Sekvensventil
10. Växelventil kpl.
11. Pilotreducerare
12. Sekvensventil
13. Backventilkägla LS
14. Sekvensslid kpl.
15. Chockventil
16. Sekvensventil
17. Lasthållningskägla
18. Chockventil
19. Mottryckskägla
20. Lasthållningskägla
21. Sekvensventil
22. Växelventil kpl.



Appendix 4: Layout for production of hydraulic valve M200, April 13 2010

