Bachelorarbeit

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Lean Approach to Operations Management

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Lean Approach to Operations Management

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Zusammenfassung

Torben Schaft

Thema der Bachelorarbeit

Lean Approach to Operations Management

Stichworte

Lean Management, Lean Production, Lean Werkzeuge, Walking Worker, Montagelinien

Kurzzusammenfassung

Die Arbeit wurde basierend auf einer Untersuchung von Lean Prinzipien, die auf praktische Anwendung bezogen wurden, durchgeführt. Das Ziel des Projektes war es, Ursachen von Verschwendungen in Fertigungsprozessen zu identifizieren. Das Projekt wurde in Kooperation mit einem mittelständischen Unternehmen durchgeführt. Die Lean Methoden wurden unter der Anwendung in Montagelinien untersucht. Ein Model einer Montagelinie wurde mit einer Simulationssoftware erstellt, um die Systemleistung zu betrachten, die mit der Anwendung von Lean Methoden, wie Six Sigma, Kanban, 5S, TPM, Kaizen und Werstromanalyse, verbessert wurde.

Torben Schaft

Bachelor Thesis title

Lean Approach to Operations Management

Keywords

Lean Management, Lean Production, Lean Tools, Walking Worker, Assembly Lines

Abstract

The project has been carried out based on an investigation of the Lean Principles which are applied into a real-life production environment. The aim of this project was to identify sources of waste in manufacturing processes, and thus improvements for manufacturing systems can be developed. The project was done in collaboration with a small-sized manufacturing company. Furthermore, some Lean methods for application were investigated based on assembly lines. A simulation tool was used to model the assembly line providing an insight on the system performance, which was subsequently improved by implementing the suitable lean methods. These Lean methods or tools include Six Sigma, Kanban, 5S, TPM, Kaizen, Value Stream Analysis and their connections and improvements to the assembly line.

Abstract

The project has been carried out based on an investigation of the Lean Principles which are applied into a real-life production environment. The aim of this project was to identify sources of waste in manufacturing processes, and thus improvements for manufacturing systems can be developed. The project was done in collaboration with a small-sized manufacturing company. Furthermore, some Lean methods for application were investigated based on assembly lines. A simulation tool was used to model the assembly line providing an insight on the system performance, which was subsequently improved by implementing the suitable lean methods.

This report attempts to present the studies of the "Lean methods, or Lean tools" through a literature review and application of Lean techniques in an assembly line. These Lean methods or tools include Six Sigma, Kanban, 5S, TPM, Kaizen, Value Stream Analysis and their connections and improvements to the assembly line.

The report also presents an analysis of data collected from the company and interpretation of simulation results obtained from the simulation models The simulation were also investigated for developing alternative ideas and solutions to integrate the Lean and insure their outcome to be achievable in a practical environment in futures.

Acknowledgement

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List of Abbreviations

cf.	Confer
Conwip	Constant Work in Progress
DMADV	Define-Measure-Analyze-Design-Verifiy
DMAIC	Define-Measure-Analyze-Improve-Control
FW	Fixed Worker
IPWT	In Process Waiting Time
JIT	Just In Time
MIT	Massachusetts Institute of Technology
OEE	Overall Equipment Effectiveness
PDCA	Plan Do Check Act
σ	Sigma
TPM	Total Productive Maintenance
TPS	Toyota Production System
WS	Work Station
WW	Walking Worker

1 Introduction

Lean Management is a contemporary topic that forms the basis of many board room discussions. This dissertation focusses on the objectives, procedures and definitions related to this widely debated managerial concept. It is purposed to provide an overview of the various concepts and structures that constitute more cost-effective and efficient business management principles.

1.1 Problem Statement

The recent entrepreneurial and economical developments are characterised by saturation effects in the markets and individualisations of the demand. In order to survive, many manufacturing companies have to considerately shorten cycle time in terms of product innovation and development as well as manufacturing operations of making these products. (Westkämper, 1998) Due to the consistently increasing complexity of current manufacturing activities new challenges for manufacturing companies such as the satisfaction of customers' requirements arise. Companies have to react consistently and precise to the customer's requirements and demands to be successful in the future. (Spath & Rasch, 2002) Meantime, these companies need to remain a continuous improvement in terms of efficiency and productivity of their manufacturing systems in order to reduce unnecessary production costs by identifying and removing any wasteful non-value added activities during a production. One of approaches to achieve this is to apply lean approaches into their existing production systems in order to maintain a cost-effective production pace whilst the requirement of their customers can be met.

The concept of Lean was originally introduced by the Japanese Toyota Production System (TPS) in the 1990 and this strategy has been becoming popular in many manufacturing sectors across Europe.

The concept of Lean has been implemented by many companies, partially because it demonstrates a great success. The implementation of Lean principles can optimise the manufacturing process providing a shorter cycle time as well as setup/changeover times for production flexibility dealing with smaller batch-sizes and create a higher output. Lean offers a variety of tools and possibility to improve the manufacturing systems, but with the application of single tools it will not be enough to get most benefits of Lean. The whole Lean culture has to be implemented in every department in terms of, each area of workplaces as well as employees of the entire company from top management to shop floor levels. (Schulze, 2010)

For production lines, one of lean approaches is to implement highly skilled workforce who has flexibility and capability to carry out multiple tasks in a number of different workplaces in a production area (like in a production line). Therefore, a Lean manufacturing system has to be designed to incorporate this strategy in order to react to different demand in terms of production volumes and variation of different product models produced on the same production line. Such a system has the ability to adjust system capacity, adapt changes in production conditions rapidly and produce several varieties of products in different and unstable quantities. (Mehrabi MG, 2000)

1.2 Aims and Objectives

The project is aimed at studying lean principles and lean techniques in order to identify suitable lean approaches and apply them into manufacturing systems based on two industrial case studies. The objectives of this work were carried out through a comprehensive literature review in manufacturing systems design, lean methods in terms of manufacturing sectors and application of selected lean approaches into two case studies using a modelling simulation tool for system performance analysis. The simulation shows a possibility to reduce the seven wastes by creating a walking worker production system which is able to produce a variety of products in unpredictable quantities. A practical example at the end should clarify the way of application of the theoretical aspects given in the first part of this report.

1.3 Report Structure

This section gives an overview over the structure and composition of the report and the procedure to cover the aspects of the problem statement.

The contents of the single chapters will be described here for a better orientation.

The second chapter treats the main concept of Lean. A short definition of Lean itself and the terms value and waste will be given. Then the historical development and the actual view of Lean will be described. The circuit of the five Lean principles of identify value - map the value stream - create flow - establish pull - seek perfection will be illustrated and six main Lean tools and their application will be further characterised.

In the third chapter the specific type of Lean the Lean Production will be shortly introduced. The Lean Production in the area of assembly lines will be further treated and the main aspects and properties of assembly lines will be introduced to the reader.

The fourth chapter covers two case studies. The first case study is about a redesign of an assembly line by implementing a walking worker to create a higher flexibility, labour utilization and a smoother production to react to different demands in case of product types, numbers and technologies. The second case study describes the implementation of Lean Management in the German company Herose GmbH Armaturen und Metalle. It shows how a Lean implementation process can be handled and which benefits can be gained and which problems can occur.

The outcomes of the literature review as well as the two case studies will be combined and critically evaluated in the last chapter.

2 Lean Techniques - a Literature Review

In this chapter the theoretical basics of Lean Management are reconsidered and described. The term Lean is defined and explained. Then the basics of value and waste are introduced. The five principles of Lean are illustrated. To get an overview over the possibilities of lean the six main Lean tools are described. The theoretical elements, basics of assembly lines and the integration of Lean Management in assembly lines by using Lean Production methods and tools will be reconsidered after the main Lean tools.

2.1 Definition Lean

Lean is defined as the creating of more value for customers by using fewer resources. (Lean Enterprise Institute, www.lean.org, 2009)

Lean is to do more work with less resources. The use of Lean manufacturing adheres to never end efforts to eliminate or reduce waste in the processes of design, distribution, manufacturing, and customer service processes. It is also called Lean Production. (Business Dictionary, 2013)

The main objective of Lean Management is to produce a perfect value for the customer with a perfect value creation process which has zero waste. (Lean Enterprise Institute, 2009)

Pfeiffer and Weiss (1994) describe Lean Management as the consequent, permanent and integrated application of a several principles, methods and provisions for an efficient and effective planning control and composition of the whole value stream of goods and services. It covers the strategically, long termed aspects, the tactical, intermediate termed and the operative, short termed aspects. (Pfeiffer & Weiß, 1994)

2.2 Value

Parter defines value, “In competitive terms, value is the amount buyers are willing to pay for what a firm provides them. Value is measured by total revenue, a reflection of the price a firms’ product commands and the units it can sell.” (Bicheno & Holweg, 2009)

Another definition by Gitlow says that value is a function of time, place and form. Time stands for the delivery time. Place means doing something with the convenience of the customer. Form has to do with design and utility. At least one of the three functions has to be improved. (Bicheno & Holweg, 2009)

Furthermore value should be split into present and future value. Present value stands for the value what present customers are willing to pay for. The future value is defined by what tomorrow’s customers are willing to pay for, but the present customers may not. The research, design and development have to look at the future value. (Bicheno & Holweg, 2009)

2.3 Seven Types of Waste

Taiichi Ohno defined seven types of waste. This chapter gives a short overview of these seven types.

1. Overproduction

   Overproduction is making too much, to early or ‘just in case’.

2. Waiting

   Waiting is directly relevant to flow. An item which is not moved or having value added is at any time an indication of waste.

3. Unnecessary Motions

   The unnecessary motions refer to human and layout. A poor arrangement of a workplace leads to micro waste of movements. These movements and so these wastes are repeated many times a day.

4. Transporting

   Every movement of material is waste. This waste can never be fully eliminated. But it should be reduced as much as possible.

5. Overprocessing

   Inappropriate processing refers to machines and processes which are overdimensioned or overdesigned for their specific task. Also machines and processes that are not quality capable belong to this type of waste.

6. Unnecessary Inventory

   Too much inventory increases lead time, prevents identification of problems and increases space. Inventory causes costs, because it binds capital in the storage and products not in use.

7. Defects

   Every defect costs money. The costs increase the longer the defect is undetected.

(Bicheno & Holweg, 2009)

2.4 Historical Development

The term Lean Production was formed about 20 years ago. The first appendages can be found much earlier. The following chapter shows the basic milestones in the 20th century, which were used from Lean Production to combine and practise the positive aspects of each. It starts with the traditional craft production. Then there is a description of the two most important developments at the beginning of the 20th century: The Taylor-System and the mass production by Henry Ford.

Traditional craft production

The features of the traditional craft production were high qualified workers. The organisation was decentralized and the workers used multi-purposed machine tools to produce a low volume of high quality products. The methodology to produce the parts were not limited. The specifications needed by the customers were handled very detailed. Every product was different to the next. The diversity of variants was not limited. A high production time was a result of the craft production. (Pfeiffer & Weiß, 1994)

Taylor-System

The Taylor-System was invented by Frederick Winslow Taylor (1856-1915) and was the beginning of the scientific management. It introduced following management principles:

- Scientific method of work
- Systematic time and motion study
- Separation of hand and head work
- Control by the management
- Functional organisation
- Differentiation of chord sets

(Staehle, 1999)

Taylor wanted to handle different problems. Taylor introduced a planning department for the rationalization of the production to get a better planning and control of the production. He reorganized the setting of machines, their maintenance and their tools and equipment. He ran extensive time and motion studies on which a new pay model was based. (Pfeiffer & Weiß, 1994)

Mass Production by Henry Ford

The mass production was basically invented by Henry Ford (1863-1947) in the 1920th. Ford invented following principles:

- High typification of the products (only one model in one colour)
- High mechanization of the production (flow production)
- Selection of the best workers
- High payment and low prices to create an affluent demand
- Trade ban in his factories

(Staehle, 1999)

Ford invented the band conveyor, which sets the working pace and the working routine of each worker without personal intervention. (Kieser, 2003)

The ford factories could produce a high volume of cars with no variants. The production was using special machines which were configured for one type of product without any tool change. (Jones, 2001)

Toyota

The Lean Production is based on the Toyota Production System (TPS) invented by Taiichi Ohno (1912-1990) and Eiji Toyoda (1913-today). They discovered that the system of mass production wouldn't work in Japan. So they reworked and improved it. (Womack, Jones, & Roos, 1991) The main objective was to increase the economy of the production by consequent and thoroughly elimination of waste. Ohno orientated his production on the flow principle of Henry Ford. (Ohno, 1998) He improved it by using simple upgrades which made fast tool changes possible. He could produce many variants with low batch sizes. (Jones, 2001)

Lean Today

In the book “the machine that changed the world” the differences between the European, the American and the Japanese automobile industry was shown. The car producers all over the world were analysed in a five year study at the Massachusetts Institute of Technology (MIT). (Womack, Jones, & Roos, 1991) The study was arranged because Japanese automobile producers had a high advantage against their competitors in areas like flexibility, quality and productivity (Taylor & Brunt, 2001) The Japanese Methodology was called Lean Production. This term became popular due to this book and with it the Japanese techniques of Lean Production. (Womack, Jones, & Roos, 1991)

Since Lean Production became a popular principle this method has been applied in other areas than the automobile industry, too. Institutes analyse the theoretical basics of Lean Production and test them in companies to their practical adaptability to improve them further. (Taylor & Brunt, 2001)

Lean is not suited to manufacturing anymore. It became a way of thinking and acting for a whole organisation. It is applied in different areas of a company like logistic, distribution, healthcare, design or administration. (Lean Enterprise Institute, 2009)

It is necessary to introduce *Lean Management* which is not limited to the production. It involves all different functions, structures and processes of an organisation. (Pfeiffer & Weiß, 1994) Lean Management shows an organization and leadership concept. (Bloech & Ihde, 1997) It is based on the transfer from a process layout and a central organisation to a product layout with less interface elements. The management controls whether the lean principles and methodologies are consequent at any time applied. (Thomsen, 2006) To implement lean management it is necessary that in every section the philosophy of lean is internalized and accepted. Every member of the company has to implement it into his all day work. A cultural change in the company has to be developed. (Liker, 2004) Another important aspect is to involve the entire supply chain system and the customers into the lean philosophy. (Pfeiffer & Weiß, 1994)

2.5 5 Basic Lean Principles

There are five basic Lean Principles which are arranged in a circuit consist of Identify value - map the value stream - create flow - establish push - seek perfection. This circuit illustrates a guideline how to implement lean in a company.

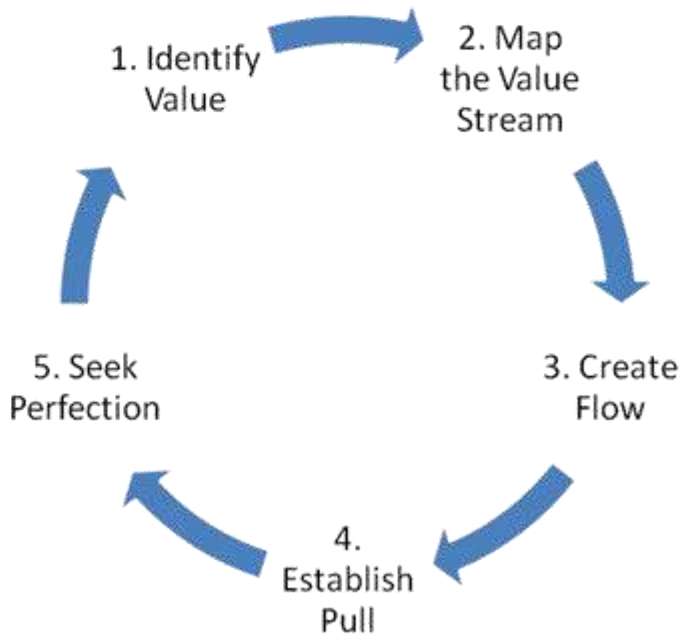

Figure 1 - The Five Lean Principles (Lean Enterprise Institute, 2009)

1. Identify Value

The first step is to "… specify value from the point of view of the customer". (Bicheno, 2004) It is important to know who the next customer, the final customer or the next company along the supply chain is. The customer's requirements are essential for this step, hence it is not important what is convenient for the manufacturer or deemed economic for the customer. The design of new products should be constrained by customer requirements and not by existing manufacturing facilities. (Bicheno & Holweg, 2009). Womack and Jones 2003 said, "… define value in terms specific products with specific capabilities offered at specific prices through a dialogue with specific customers." It is necessary to get a clear idea of what is really needed by the customer. (Womack & Jones, 2003)

2. Map the Value Stream

The next step is to identify the value stream. The value stream analysis should be illustrated in a map. The focus has to be horizontally not vertically. (Bicheno, 2004) There are three critical management tasks a specific product has to pass through. First the problem solving task, where the product runs from a concept to a detailed design to entering the production. The next problem is the information management task, which runs from taking the order through a detailed scheduling to the final delivery. The third is the physical transformation. The stream goes from the raw material to a finished product into the ownership of the customer. (Womack & Jones, 2003)

Generally there are three types of activities by analysing the value stream. (Hines & Rich, 2001)

1. *Value adding activity:* This is the main part for the customer, because of developing a gain for him e.g. the converting of raw material or semi-finished goods.
2. *Necessary but not value adding activity:* These activities do not create value and illustrate waste. But they can't be eliminated immediately and without bigger changes out of the system. They are under the current circumstances inalienable e.g. an additional quality control.
3. *Non value adding activity:* These activities create only waste and should be removed from the system immediately e.g. waiting times, unessential transports or duplication of effort.

3. Create Flow

The third principle is the creation of flow. The value has to be made by flow. A one-piece flow should be aspired. Queues or batches should be avoided and continuously reduced. Also the barriers in their way have to be reduced or eliminated. (Bicheno & Holweg, 2009) The adjustment and the work of functions, departments and firms have to be redefined. So they have a positive effect to the value creation and the needs of employees at every point of the flow. (Womack & Jones, 2003)

4. Establish Pull

The fourth principle is the pull principle. It handles "…short term response to the customer's rates of demand, and not over producing" (Bicheno, 2004) The customer gives the pull signal by ordering certain products. Then the materials will be moved. The pull principle has to be implemented along the whole demand flow network. (Bicheno & Holweg, 2009) The cycle time is enormously reduced. So the customer can get products with their special requirements right away. (Womack & Jones, 2003)

5. Seek perfection

Perfection has to be aspired by continuous improvement in the step of the last principle. Perfection means the production of exactly what the customers want and in the time they want it with a fair price and minimum waste. (Bicheno, 2004) The first four principles interact with each other and they influence each other in a circuit. It is possible to expose hidden waste in the value stream, when the value is specified faster. Due to the implementation of the pull principle even more barriers are exposed and can be removed. Furthermore direct contacts to the customers can specify the value of a product further, which can cause that process steps can be identified as unneeded and can be eliminated as well. This reduces the cycle time so the customer gets his product more contemporary. (Womack & Jones, 2003)

"The five principles are not a sequential, one off procedure, but rather a journey of continuous improvement." (Bicheno, 2004, p. 11)

2.6 Lean Tools

In this chapter the basic lean tools are elucidated. Figure 2 shows that many different tools and instruments of lean exist. It shows the main tools. The graphic clarifies that a successful implementation of lean elements is only possible when the culture and the indicators of the company are edited to it.

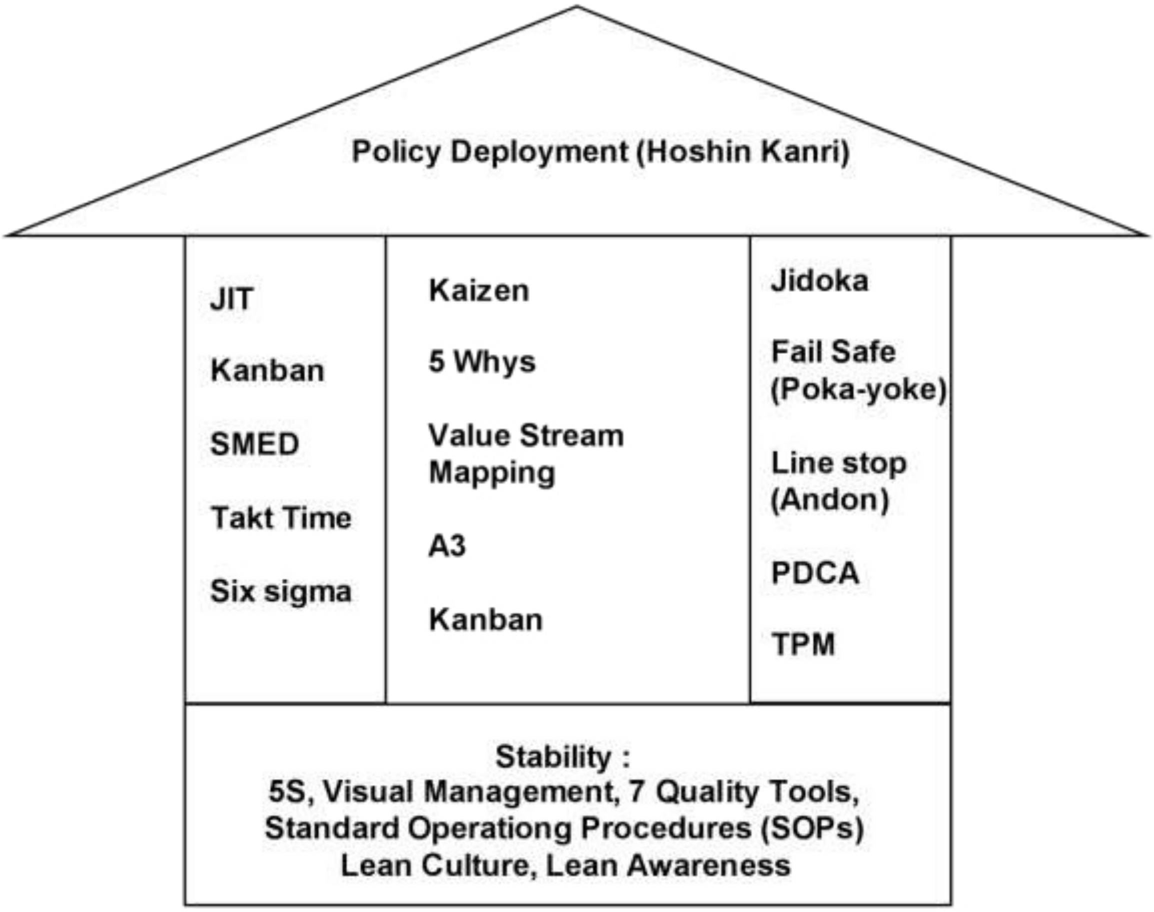

Figure 2 - The House of Lean cf. (Bicheno & Holweg, 2009)

In the following chapters six basic and main lean tools are described.

2.6.1 Six Sigma

Bill Smith developed Six Sigma at Motorola in 1986 to improve the quality of processes. (Desai, 2010) Six Sigma is not an original lean method. Due to its interaction with the philosophy and methods of lean a term like “Lean Sigma” or “Lean Six Sigma” was created. (Bicheno & Holweg, 2009)

Six Sigma has three different meanings: (Desai, 2010)

- Continuous efforts to achieve a stable predictable process, i.e., to reduce process variation for business success.
- Measuring, improving, analysing and controlling of important characteristics of manufacturing and business processes.
- Dedication of continuous quality improvement

Six Sigma stands for six standard deviations from mean. Its methodology allocates the tools and techniques to reduce defects and improve the capability in any process. It is a tool for a statistical process and uses the Greek letter σ. Statisticians use this letter to measure the variability in a data set. The Six Sigma tool shows any type of defects. The defects of an analysed process should not be more than 3.4 per million opportunities. The performance of a company is measured by the sigma level of their business processes. Companies normally accept three or four as Six Sigma level, which processes create between 6200 and 67000 defects per million opportunities. (Desai, 2010) Six Sigma uses the normal distribution curve as a statistical process control element. Every part which is out of the control limits, defined by the customer’s requirements, is a defect. The Six Sigma methodology defines the different σ- ranges, shown in figure 3.

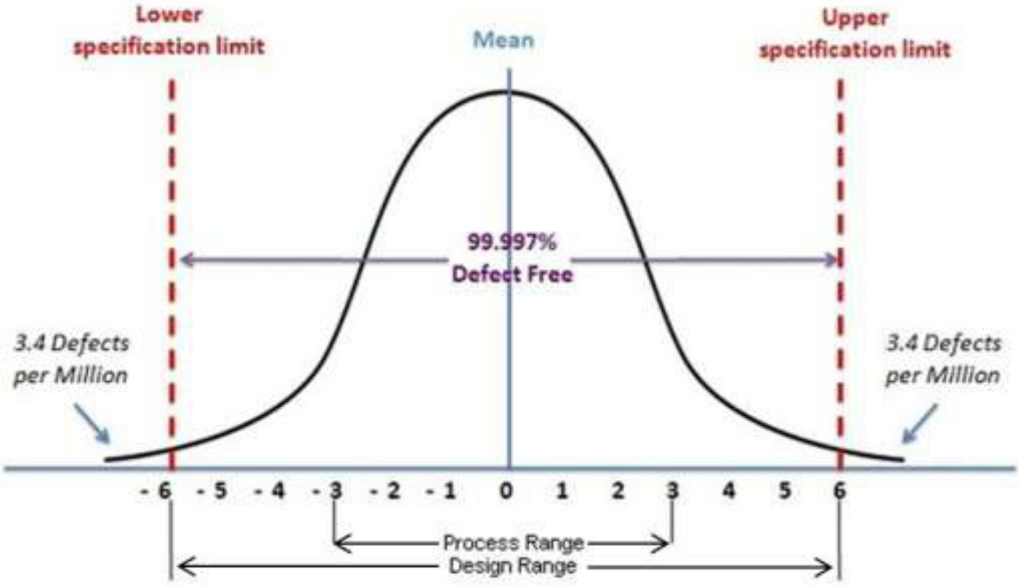

Figure 3 - Six Sigma Distribution cf. (Mindedge, 2013)

Impact of Process Capability of One Six Sigma through Six Sigma for Long Term When the Process Is Offset by 1.5 Sigma		
Sigma capability	Defect free per million	Defects per million
0.0 Sigma	67,000	993,000
1.0 Sigma	310,000	690,000
1.5 Sigma	500,000	500,000
2.0 Sigma	691,700	308,300
2.5 Sigma	841,350	158,650
3.0 Sigma	933,193	66,807 (Traditional Quality)
3.5 Sigma	977,300	22,700
4.0 Sigma	993,780	6,220
4.5 Sigma	998,650	1,350
5.0 Sigma	999,767	233
5.5 Sigma	999,968	32
6.0 Sigma	999,996,60	3,40

Table 1 - Process Capability, Defects per Million parts cf. (Bergbauer, 2003)

Figure 3 shows the process capability. The theoretical value of 100% cannot be reached, because the curve crosses the x-axis in infinity. (Taghizadegan, 2006) The process capability can reach from 1-6σ. The ideal case would be a 6σ defect-rate. That would be 0.002 defect parts per million. Under the consideration of a deviation of the process a standard deviation of ±1.5σ is assumed. The defect rate per million raises to 3.4 per million parts. (Bergbauer, 2003)

Table 1 shows that a process capability of 99% and a sigma level of four is not good enough for many processes, because at least 6220 customers wouldn't be satisfied.

There are two different types of Six Sigma existing. The first is DMAIC which stands for, define, measure, analyse, improve and control. The other one is DMADV which is the abbreviation of define, measure, analyse, design, verify. DMAIC is the improvement of existing processes and products. DMADV is the development of new products or processes. The two types are explained in the following table:

DMAIC Define-Measure-Analyse-Improve-Control	DMADI Define-Measure-Analyse-Design-Verify
Define Clarify the purpose and scope of the project. Customer's perceptions and expectations for quality have to be clear. Establish timeline and costs.	**Define** Define the project goals and customer deliverables.
Measure Getting as much information as possible about the process. Creating a detailed process map, gathering baseline data, summarizing and analysing the data.	**Measure** Measure and determine customer needs and specifications.
Analyse Identify the potential root, which causes problems. Confirm actual root with data. Identify the casual factors of the problem.	**Analyse** Analyse the process options to meet the customer's needs.
Improve Identify a solution of the problem. Brainstorming potential solutions. Selection solutions to test and evaluate the results.	**Design** Design the processes and products to meet the customer's needs.
Control Ensure that the gains obtained and are maintained. Standardize and document procedures. Plan for further monitoring and reactions to any arising problems.	**Verify** Verify the design performance and ability to meet the customer's needs.

Table 2 - The Two Types of Six Sigma cf. (Desai, 2010)

2.6.2 Push- and Pull-principle, Kanban

Normally it is distinguished between two types of production scheduling. First there is the push-system, which is a centralised type of control. The other one is the Kanban system, which is a decentralised type of production control, also called the pull-principle. Figure 4 shows the basic elements of both principles.

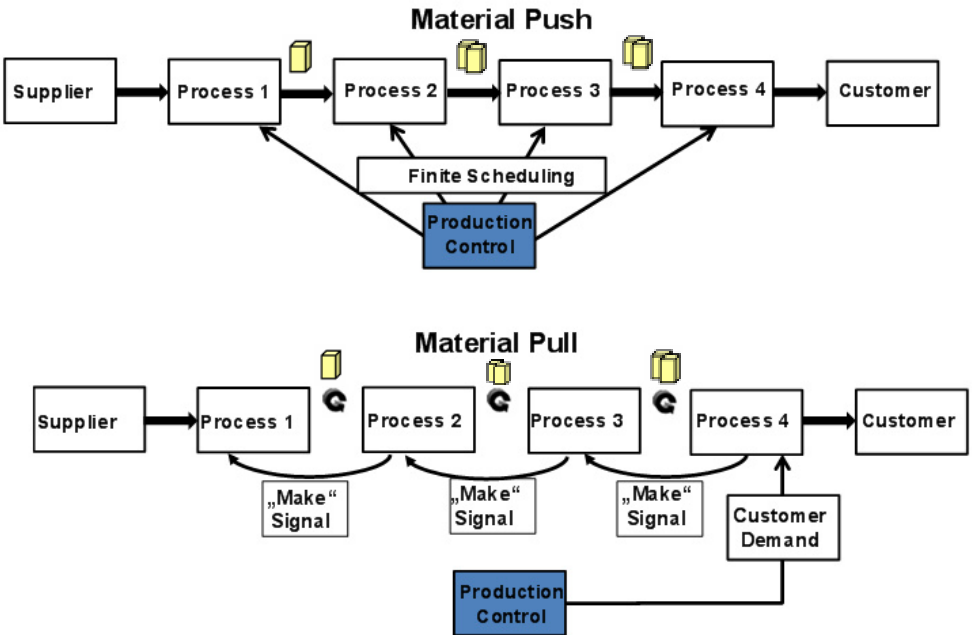

Figure 4 - Push- and Pull-System cf. (Else Inc., 2009)

Push-principle

The production orders are pushed through the logistic chain. The action is released by a clear defined plan. Every order is set by a central control department. (Verein Netzwerk Logistik, 2013) Every time a part is produced or finally edited in a certain process step it is pushed to the next. No matter if it is needed or if the next place has enough place to store it. (Vahrenkamp, 2008)

Pull-Principle, Kanban

The Pull-Principle is often also called Kanban System. Kanban was developed by Taichi Ohno at the TPS to control production between processes and to implement Just-in-time (JIT). Kanban can be translated as “signboard” and uses virtual signals to tell the operators what to do. Kanban is a demand scheduled using system. The products are produced by a demand and not by a forecast. The pull-principle has following rules: “Only produce product to replace the product consumed by its customer(s)” and “only produce product based on signal sent by its customer(s)”. (Gross & McInnis, 2003)

Figure 5 shows the principle of the Kanban signal and the following production process based on this signal.

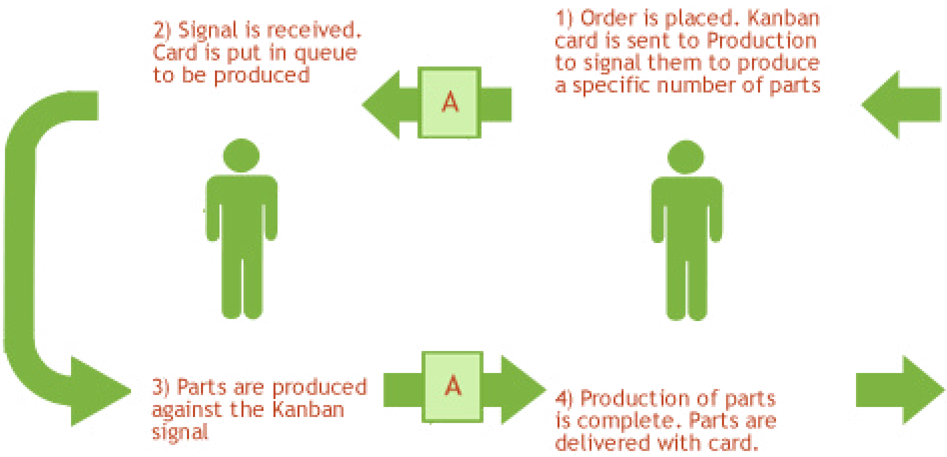

Figure 5 - The Kanban-Principle (Weinstock-Herman, 2010)

Kanban has several benefits: (Gross & McInnis, 2003)

1. Reduces inventory
2. Improves flow
3. Prevents overproduction
4. Places control by the operations level (with the operator)
5. Creates visual scheduling and management of the process
6. Improves responsiveness to change in demand
7. Minimizes risk of inventory obsolescence
8. Increases ability to manage the supply chain

Kanban is a method in the manufacturing process for the fourth principle of Lean, explained in chapter 2.5.

2.6.3 5S

5S is a popular Lean tool, which consists out of 5 steps. It improves quality and productivity. 5S has three main objectives: (Bicheno & Holweg, 2009)

- To reduce waste
- To reduce variation
- To improve productivity

5S can be used as a circuit. It is not an action that has to be done once, but should be improved continuously, like shown in figure 6.

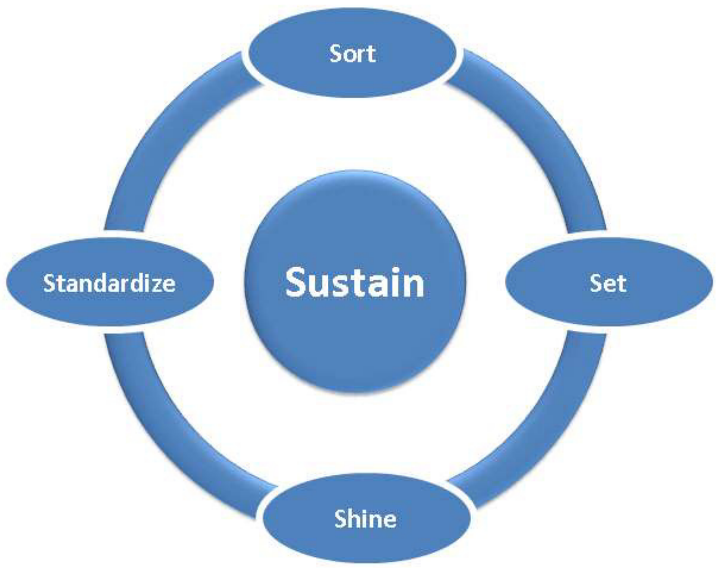

Figure 6 - The 5S-Circuit (Work Wise Inc, 2013)

1. Sort - Seiri

The first S is Sort. It has to be decided which items are not used or needed. This decision has to be made with the local team. Items which can be kept at the work place are used every week, are needed for important quick customer response or are necessary for health and safety. (Bicheno & Holweg, 2009) In the sorting step the frequency of usage for every item has to be determined. The items which are not in use have to be marked. The items which are not in use should be thrown out, which includes auction, recycling or donation. Sources of clutter or unwanted items have to be eliminated. (Peterson & Smith, 1998) Items which are never used get a Red Tag. This is a label with the date of analyse. If this item is not used in a certain time it should be thrown away. The step of sorting has to be done regularly, e.g. once every six months. (Bicheno & Holweg, 2009)

2. Simplify (Set-in-Order) - Seiton

The second step is to arrange the items in a good order in the working area. Items should be placed by frequency of usage. (Peterson & Smith, 1998) That minimises stretching and bending of the worker. (Bicheno & Holweg, 2009) The tools and items should be placed at standardised locations. This step has to be repeated whenever products or parts change. (Bicheno, 2004)

3. Sweep (Shine) - Seiso

In the Sweep step the work place should be tidied up and visual scanned. The worker has always to be in search of anything out of place and correct it immediately. In the cleaning step a checking step is involved. A check for any abnormality and its sources is always made besides the cleaning activity. A standard routine for the cleaning procedure is useful to keep the working place clean and tidied up. (Bicheno & Holweg, 2009)

4. Standardise - Seiketsu

The fourth step is to standardise the first three steps. It includes measuring, training, recording and work balancing. (Bicheno, 2004) The information about locations of tools and items become more recognizable. This step has the advantages that it is easier to visually sweep through the labels when they are always in the same order. It is easier to locate items quickly, if their procedures of receiving and returning and their information are uniform. (Peterson & Smith, 1998)

5. Sustain (Self Discipline) - Shitsuke

The final task by implementing 5S is the self-discipline, which includes the routine practice of all the steps that precede it. (Peterson & Smith, 1998) The step is about participation and improvement. The other 5S activities should become consuetude. (Bicheno & Holweg, 2009)

In some cases a sixth step is introduced, called Safety. The safety aspect should be implemented in the regularly five steps and may confuse as an individual step. (Bicheno & Holweg, 2009)

The tool 5S has several benefits, a few of them are listed as followed: (Peterson & Smith, 1998)

- Reduced cycle time
- Increased floor space
- Improved working conditions
- Improved work team performance
- Established operating procedures
- Reduced lead times
- Reduced number of accidents

2.6.4 Total Productive Maintenance

Total Productive Maintenance (TPM) was introduced to Japan by the US in the 1950s. (McCarthy & Rich, 2004)

TPM can be hold as integral to Lean. It handles the issues of breakdowns and covers availability, performance, quality, safety and capital investment. It extends the lifetime of a product. TPM stands in relation to the bathtub curve, figure 7.

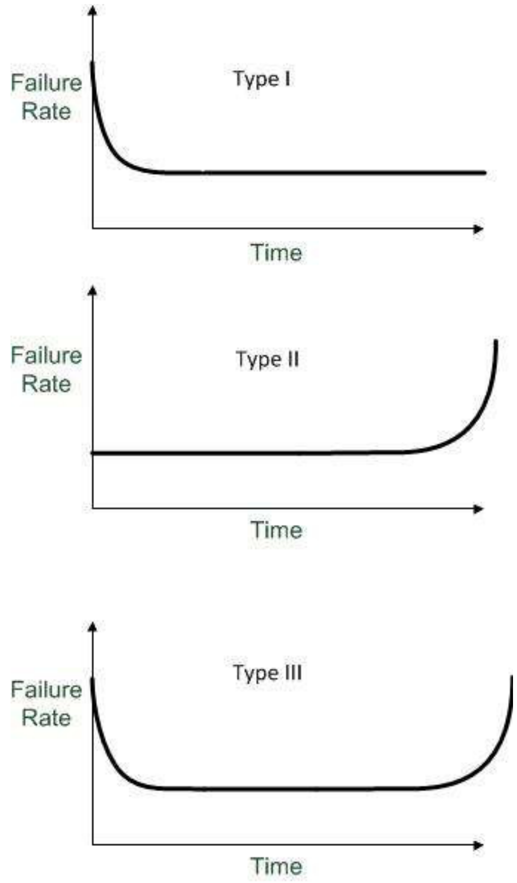

Figure 7 - Three Bath Tube Curves cf. (Bicheno & Holweg, 2009)

The failure rate can be divided into three types. Type one includes a high failure rate at the beginning of a products lifetime and a stable operation after it, e.g. electronics. Type two describes a high failure rate at the end of a products lifetime, e.g. cars, engines or motors. Type three is the traditional bathtub-curve. It describes the failure rate of many products. It includes a high failure rate at the beginning and the end of the lifetime.

TPM focuses on the different types of failures during a products lifetime. The type of maintenance is adapted to the failure profile, figure 8.

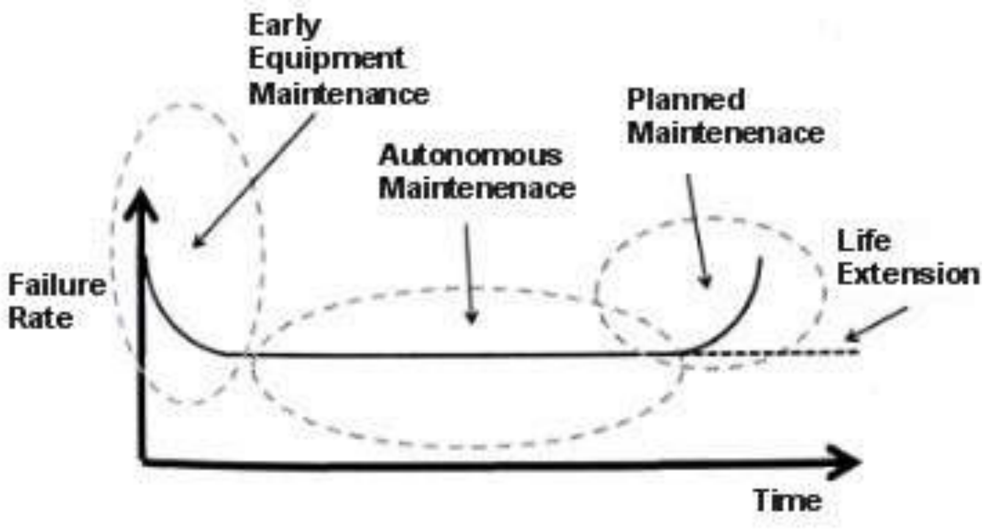

Figure 8 - Failure Profile cf. (Bicheno & Holweg, 2009)

TPM divides the losses to be handled in three categories. The categories contain six big losses. The six big losses and the three categories are shown in figure 9.

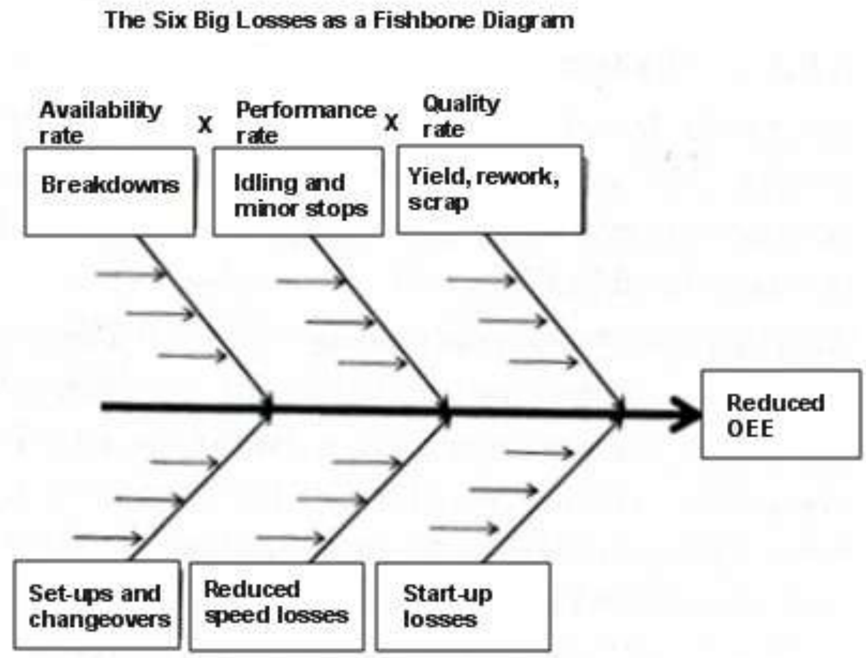

Figure 9 - Fishbone-Diagramm cf. (Bicheno & Holweg, 2009)

The three categories are described by Bicheno & Holweg as followed.

Availability

The category availability includes breakdowns and changeovers. Breakdowns are mentioned as unplanned stops of the production which take over 10 minutes and are requiring repair. The change between different products causes adjustment and changeover losses. The changeover time is defined as the time between the last product of the last batch and the first good product of the next batch.

Performance

The performance rate includes the loss for minor stops and reduced speeds. These stops take less than ten minutes. Minor stops are often frequent and difficult to measure. They are caused by tip breakage, coolant top-up, jams or small adjustments. The loss of reduced speed results from the fact that machines often run at less than the design speed. This is often aroused by flow restriction or program errors on a CNC machine.

Quality

The first loss of the quality category is scrap or rework. It appears when the machine works not in the specification limits. The other losses are start-up losses. They result out of scrap or rework during changeover.

By using the three categories of losses the overall equipment effectiveness (OEE) can be calculated. OEE is the result of “Availability x Performance x Quality” and is expressed in percentage. (Bicheno & Holweg, 2009)

McCarthy describes five basic principles of TPM, which have to be introduced by the management. (McCarthy & Rich, 2004)

1. Adopt improvement activities designed to increase the overall equipment effectiveness by attacking the six losses;
2. Improve existing planned and predictive maintenance systems;
3. Establish a level of self-maintenance and cleaning carried out by highly trained operators;

4. Increase the skills and motivation of operators and engineers by individual and group development;
5. Apply early management techniques to design in low life cycle costs by creating reliable and safe equipment and processes, which are easy to operate and maintain.

To gain benefits out of introducing TPM the six losses have to be analysed and the five principles should be introduced by the management. To implement the whole TPM-system into a company P. Willmot describes a 9-step model.

The steps are:

1. Collect equipment history and performance Analysis
2. Define and calculate OEE
3. Asses six big losses and set priorities
4. Critical assessment
5. Initial cleanup and condition appraisal
6. Plan refurbishment
7. Develop asset care
8. Develop best practice routines and standards
9. Problem prevention

The first three steps are named the measurement cycle. Measurement objectives have to be set, the OEE interpretation has to be clarified and the six big losses should be analysed as shown above.

The steps four to seven are called the condition cycle. This cycle includes the production of a list of all relevant machines and the role of single components in detail. After that the cleaning area should be agreed upon and the cleaning equipment should be accessible. So that the area can be cleaned. A refurbishment schedule, which covers items, labour hours, planned completion and PDCA cycle stage, has to be installed. To complete the condition cycle the role and tasks of operators have to be defined and a clean and check list should be installed. All components and tools should be labelled by referencing their manuals.

The last two steps are defined as the problem prevention cycle. The first seven steps are assembled in a best practice manual. To complete the nine steps the problem prevention cycle has to be run through. The problem has to be identified and a solution can be found. (Bicheno & Holweg, 2009)

The benefits which can be gained by using TPM are listed in table 3.

Measure	Impact of TPM	Impact of lean thinking
Productivity	• Reduce need for intervention • Reduce breakdowns	• Reduce non-value-adding activities • increase added value per labour hour
Quality	• Potential to reduce tolerance • Control of technology • Reduce start-up loss	• Highlight quality defects early
Cost	• Reduce material, spares	• Lower inventories
Delivery	• Zero breakdowns • Predictability	• Shorter lead times • Faster conversions processes
Safety	• Less unplanned events • Less intervention • Controlled wear	• Less movement • Less clutter • Abnormal conditions become visible easily
Morale	• Better understanding of technology • More time to manage	• Less clutter • Closer to the customer • Higher appreciation of what constitutes customer value
Environment	• Closer control of equipment • Less unplanned events/human errors	• No ‘over-production’ • Systems geared to needs not to theoretical batching rules

Table 3 - The Benefits of TPM cf. (McCarthy & Rich, 2004)

2.6.5 Kaizen

The Japanese term Kaizen can be translated as: “change for the better”. It is a philosophy that stands for a gradual and methodical process which improves productivity and reduces waste. (Investopia US, 2013) Kaizen uses small but continuous improvements. The process involves the whole company from the chief manager to the lowest level workers. (Business Dictionary, 2013)

But “Kaizen isn’t limited to the single purpose of making small continuous improvements. Used in the correct manner, it can serve as the chief mechanism in fully inverting Lean Manufacturing throughout an entire business enterprise.” (Davis, 2011)

Four types of Kaizen exist.

1. High-Impact Kaizen
2. Training and Implementation Kaizen
3. Problem Resolution Kaizen
4. Sustaining Kaizen

The first type, High-Impact Kaizen, stands for large changes to a whole production area. It includes an extensive training and re-methodizing and rearranging of the entire area which is involved. For the High-Impact Kaizen the highest level of participation from almost every support function is necessary.

The Training and Implementation Kaizen is applied to provide knowledge to the whole workforce over an adjusted period of time. The implementation objective of this type is to make expedient changes on the shop floor.

Problem and Resolution Kaizen handles problems of quality, throughput or the ability to reach customer requirements.

The fourth type is Sustaining Kaizen and stands for incremental improvements to an area, which had a high impact to other types of kaizen, which were performed before. (Davis, 2011)

To establish Kaizen an important step of the process is the plan-do-check-act (PDCA) cycle.

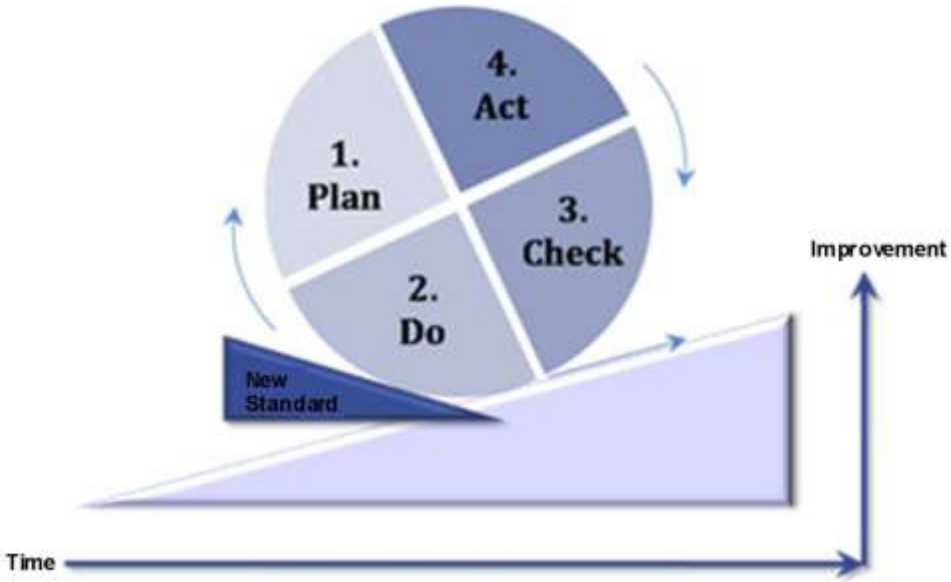

Figure 10 - The Kaizen PDCA-Cycle cf. (Bauer, 2013)

The first action of the PDCA-cycle is to *plan* the process and set a defined target for improvement and create an action plan to achieve the target.

After the plan the step is to do the *do* activity. It implements the plan.

Check decides if the implementation stays on course and brings the anticipated improvements and results.

The fourth step is *act* and it refers to performing and standardizing the new procedures. It should prevent recurrence of the original problem and set new targets for new improvements. (Imai, 1997)

The PDCA cycle has to be repeated continuously. It stands for "never being satisfied with status quo". (Imai, 1997)

Two procedures can be used to achieve improvements. The first one is to use Kaizen and achieve the goals with small steps. The other is to make big steps with innovations. (Imai, 1986) Innovations are connected with high costs, because they implement new technologies and theories. Kaizen improves the actual stand of technique. The effects given by innovations are big but of short-term, because competitors can capture this innovations easily by copying them. (Imai, 1986) Although these two procedures have apparent differences, they can support each other and add to an effective improvement spiral, as shown in figure 11. (Thomsen, 2006)

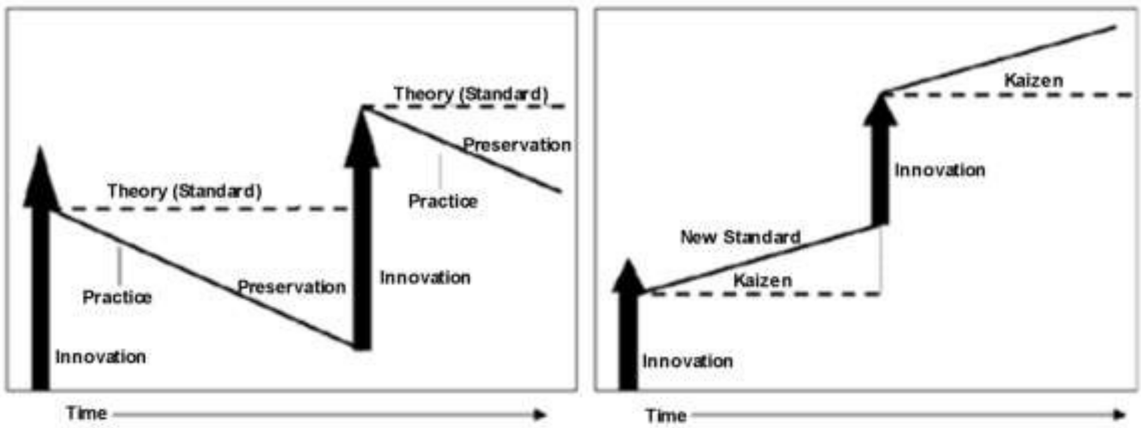

Figure 11 - Innovation without and with Kaizen cf. (Imai, 1986)

The picture shows on the left side how improvements lose their worth after their implementation. The right side shows how the worth of an innovation can be kept by using Kaizen and through the continuous improvements it can be upgraded. (Imai, 1986)

Burton and Boeder list the main benefits of institutionalizing Kaizen in a company as followed:

- Workers think all the time about problems and solutions in their all day activities.
- The continual adjustment process is institutionalized into the daily fabric of the company.
- Process and departmental needs are easily identified by the people, which work in the area, because they are the most knowledgeable about their processes.
- Every individual is included in the improvement process, hence the resistance to change is minimized.

- Solutions emphasize common sense and low-cost approaches.
- The upper management is not always necessary to cause change. The worker involved in the process is responsible for the change.
- Efficiency improvements of 20 to 50% realized.
- Inventory reductions of 20 to 80% realized.
- Distance traveled reduced up to 40m to 90%.
- Setup times reduced 50 to 80%.
- Process time reduction of 40 to 80%.

(Burton, 2003)

2.6.6 Value Stream Analysis

The Value Stream Analysis is a method to illustrate the current state of a production clearly and considerably. It considers production processes, material and information flow. It visualizes these issues with simple symbols. The target of a value stream analysis is the efficient acquisition and well-arranged presentation of real circumstances out of a fabric. The main point is to create the analysis out of the customers sight, because the customer defines the requirements for the whole production and every single production step. (IPA, 2013)

One of the first steps is to define the products families. Products with the same requirements of operating resources and similar production processes shall be put in the same production family. The illustration is handled downstream. The suppliers are illustrated on the left and the customers on the right side of the value stream. (Erlach, 2007)

The main solution of a value stream analysis is the value stream map. Different symbols are used to illustrate production processes with their characteristics, material flows with inventory and the information flows with the business process and documents. The value stream helps to discover waste and the development of an ideal value stream should create a stream without any waste. After the development of this new value stream the conversion follows due to the usage of an action schedule. The common symbols can be seen in figure 12. (Bicheno & Holweg, 2009)

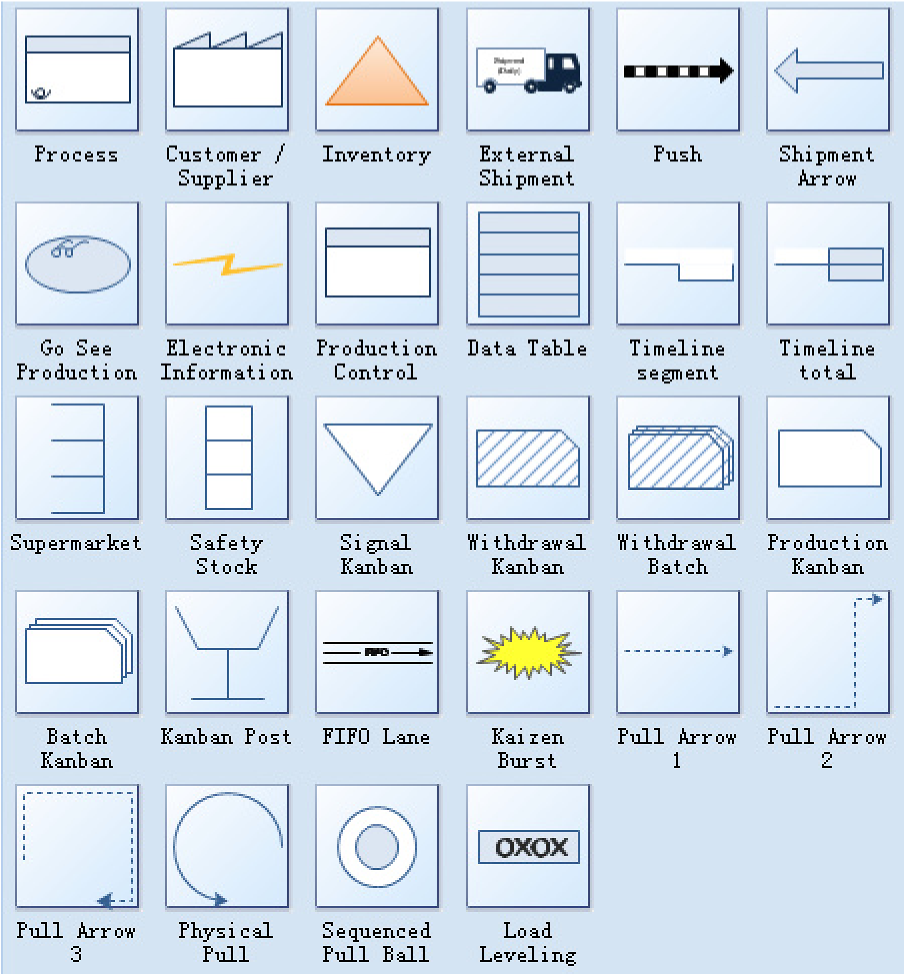

Figure 12 - Value Stream-Symbols (Edrasoft, 2004)

2.7 Lean Production

This chapter covers the specific type of Lean the Lean Production. First the Lean Production is briefly explained and after that its correlation to assembly lines is explained.

Lean Production is the effective and efficient use of the production factors operating resources, human resources, raw material, strategy and organisation as part of all business activities. (Gabler, 2013)

The objectives of Lean Production refer to the optimization of production systems in terms of its system design, implementation and operations order to increase productivity and efficiency and minimise wastes therefore costs, improve quality of products and increase the flexibility of the production system. (Gabler, 2013)

To achieve better productivity and efficiency of the system it is necessary to reduce the use of all production factors but still have the same output. One of approaches is to reduce unnecessary in progress inventory and underutilized capacities or implementing shorter cycle-times and flexible working times. (Gabler, 2013)

The quality of products can be improved by improving manufacturing processes. Constant and total quality controls, immediate post-processing of defect parts, avoidance of waste in production and better cooperation with suppliers can be useful instruments to handle it. (Gabler, 2013)

The flexibility is the ability to produce a high variety of products and product numbers with low costs in the right time. This objective can be achieved by using flexible working times and with it the use of temporary capacities, through the implementation of flexible system or job rotation. (Gabler, 2013)

2.7.1 Lean Elements in Assembly Lines

In this chapter the main objectives of implementing Lean elements in assembly lines and the different lines with their properties are described.

Objectives

When assembly lines are characterised by reactive, customized single production and informal structures in a job shop production it makes sense to restructure the line with lean tools, hence higher number of requests and faster delivery times can be achieved. The cycle time, the assembly time and the inventory in the assembly line should be reduced. The production costs can be reduced and the customer satisfaction in case of shorter delivery times can be raised. (TCW Transfer-Centrum, 2013)

To achieve the main objectives shown above it is necessary to analyse and optimize the processes. Single assembly steps can be parallelised as well as up- and downstream process-steps. Non value-adding and non-quality relevant assembly steps should be outsourced to suppliers. To reorganize the assembly line one main step is to categorise the products in different product families. So the line can be segmented by the volume of the products. (TCW Transfer-Centrum, 2013)

Line Layouts

The structure of the line can have several layouts. The different layouts have different advantages. Hence it is necessary to connect the requirement of the product families and the facility layout to the layout of the assembly line.

One of the main layouts is the U-Shape-line, which has the main advantage to be laid out using a fairly small footprint and the workers can carry out tasks at both sides of the line.

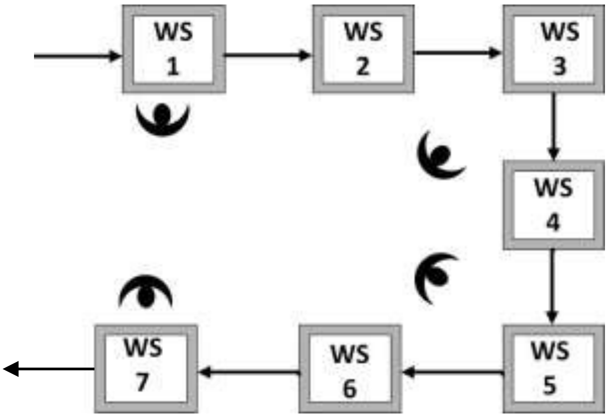

Figure 13 - U-Shape Line

The straight-through or I-shape-line is mostly the best flow pattern for long, narrow buildings. The I-shaped line is used in the following simulation and will be further described in the chapter 3.1.2.

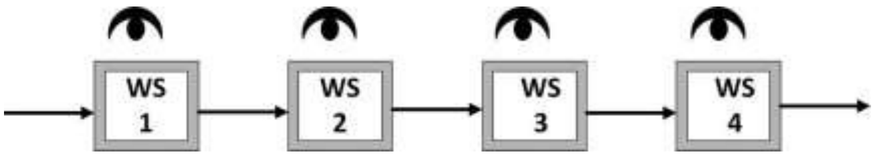

Figure 14 - I-Shape Layout

Another one is the L-shape-line which works best for square-shaped buildings when several similar processes lines are nested together.

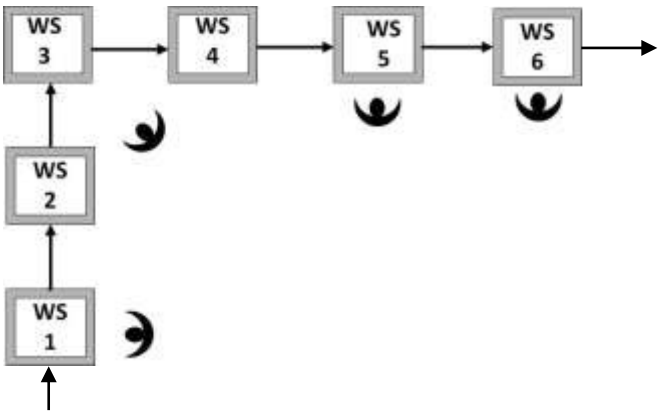

Figure 15 - L-Shape Layout

The next basic layout can be the comb & spine arrangement. This is useful for assembly operations when products must exit the process flow at various levels of assembly.

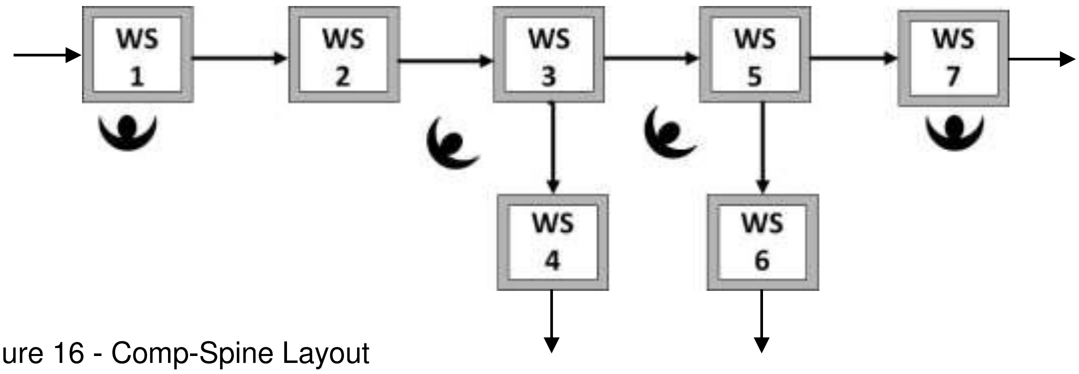

Figure 16 - Comp-Spine Layout

Other common line layouts are the S-shaped and the M-shaped lines which are used to compress the footprint of long process flows.

(Engineering Ressource, 2013)

3 Lean Elements in Assembly Lines - Two Case Studies

3.1 Simulation of a Walking Worker System

3.1.1 The Walking Worker – A Lean Approach

In the following chapter an assembly line is simulated and optimized with the simulation software Enterprise Dynamics. The line is improved by using different numbers of *walking workers*. The theory of this walking worker is covered in the following chapter.

The walking worker is one effective method to achieve the Lean improvement of production systems so that these systems can react to unpredictable conditions like varying production volumes or product variants with a small batch size. It further allows for rapid achievement of high quality, low costs and economical viability. This is possible because the adoption of the walking worker technique creates a more flexible, highly skilled and agile workforce. These workers are previously trained to perform multiple tasks in a different number of workplaces in a production zone, compared to the traditional strategy using fixed workers who only perform a single and repetitive task at one workplace. (Wang, Lassalle, Mileham, & Owen, 2009)

The walking worker interacts and associates with the whole assembly line. Each walking worker moves along the line and handles each assembly task at each station. Every worker accomplishes the assembly of a whole unit from the start to the end. With such a walking worker production system, each walking worker also replaces the virtual signal of the Kanban principle, described in chapter 2.6.2. The worker acts as the pull-signal to get new products instead of a card or a box. (Wang, Lassalle, Mileham, & Owen, 2009)

These walking workers constitute a flexible workforce and can improve productivity and efficiency by being present wherever they are needed and when they are needed along the assembly line to accommodate the change of production conditions on a daily basis. Multiple or all required tasks in a production area can be handled by these crossed trained workers. The benefits gained by the adoption of walking workers related to of costs, time quality and variety over the traditional allocation of workers to workstations, where each worker only works on a single repetitive task. (Wang, Lassalle, Mileham, & Owen, 2009)

In a classic assembly flow-line every operator has one workstation on the line where he/she serves only his/her own station and is skilled in one task only. In the linear walking worker assembly line which is used in the simulation the worker travels with a partially assembled product on the line and stops at each station, where a walking worker handles the essential assembly work as scheduled. The worker is trained to be capable of building a product completely from the start to the end. In this pull-system a new product which has to be assembled enters the line whenever the walking worker is available he assembles the former product completely. Then this walking worker moves back to the start of the line to start the new product. These methods ensure that this system prevents unnecessary in-progress inventory and decreases the buffer requirement. The worker stays with his/her product and his/her responsibility is to complete the assembled product within an expected cycle time, the loss of labour efficiency is decreased and the utilization of the worker is maximized. (Wang, Lassalle, Mileham, & Owen, 2009)

3.1.2 Linear Design of the Assembly Line

The line which is simulated with the walking worker that has been introduced above has a linear design and five work stations. The main benefits of a linear design of an assembly line are: (Wang, Lassalle, Mileham, & Owen, 2009)

- The walking worker is cross-trained and can perform all the tasks required for the assembly of the unit. Cross-trained worker can improve the system efficiency in the form of higher output and shorter cycle times without significant additional investment.
- Fewer conventional buffers are required; low-variation balanced systems require no buffers.
- Varying production volumes become possible; blocking rates and in-process waiting times can be altered and decreased by using an optimal number of walking workers.
- The slowest worker can easily be identified and simply removed from the line for further in-house training. Hence the line has a high labour utilization and a better use of human resources.
- A non-powered simple conveyance transport system can be used.

On the other hand there are three main disadvantages, which are mainly caused by human factors.

- The efficiency of the line can be affected by human factors such as by uneven skilled workers, which have different working speeds or individual abilities.
- A slower worker can block faster workers along the linear line.
- The possibility of adopting the linear walking worker line depends on the characteristics of assembled products and the level of cross-training. (Wang, Lassalle, Mileham, & Owen, 2009)

3.1.3 Simulation

The assembly line was modelled and simulated with the software Enterprise Dynamics. The line was taken out of a bigger engine assembly line. For the whole engine assembly factory see appendix D. The simulated line consists of five workstations which assemble one product. At the first stage each workstation has one operator to work on the products. The second stage was to implement the walking worker instead of five workers which are fixed to their workstation. The simulation covers the use of one to five walking workers.

Former research by Wang Lasalle and Mileham revealed that blocking or starving of the single workers can be significantly reduced when the line has one more work station than workers. (Wang, Manickam, Mileham, & Owen, 2008) The line has a linear layout and consists out of five workstations using fixed workers and six rebalanced workstations using the walking workers, see figure 17.

The input for the line is carried out with a robot, which pushes the parts into the line. The parts go to a queue, where they wait for their processing. Every workstation needs 91 seconds, which are taken out of the given information from the factory layout, appendix E. These 91 seconds are simulated with a normal distribution. The inter-arrival time of the products depends on the input the robot gets. It is assumed that the robot is not fed permanently with new parts. In front of the robot are several workstations with different workers, so it is assumed that the inter-arrival time for the robot is higher than the 91 seconds cycle time for each work step. It is set to 136 seconds and is simulated with a negative exponential distribution.

Figure 17 shows the basic layout of the assembly line in two stages. The first is the original assembly line with five work stations and five fixed workers and the second is the rebalanced line with one additional work station and one to five walking workers.

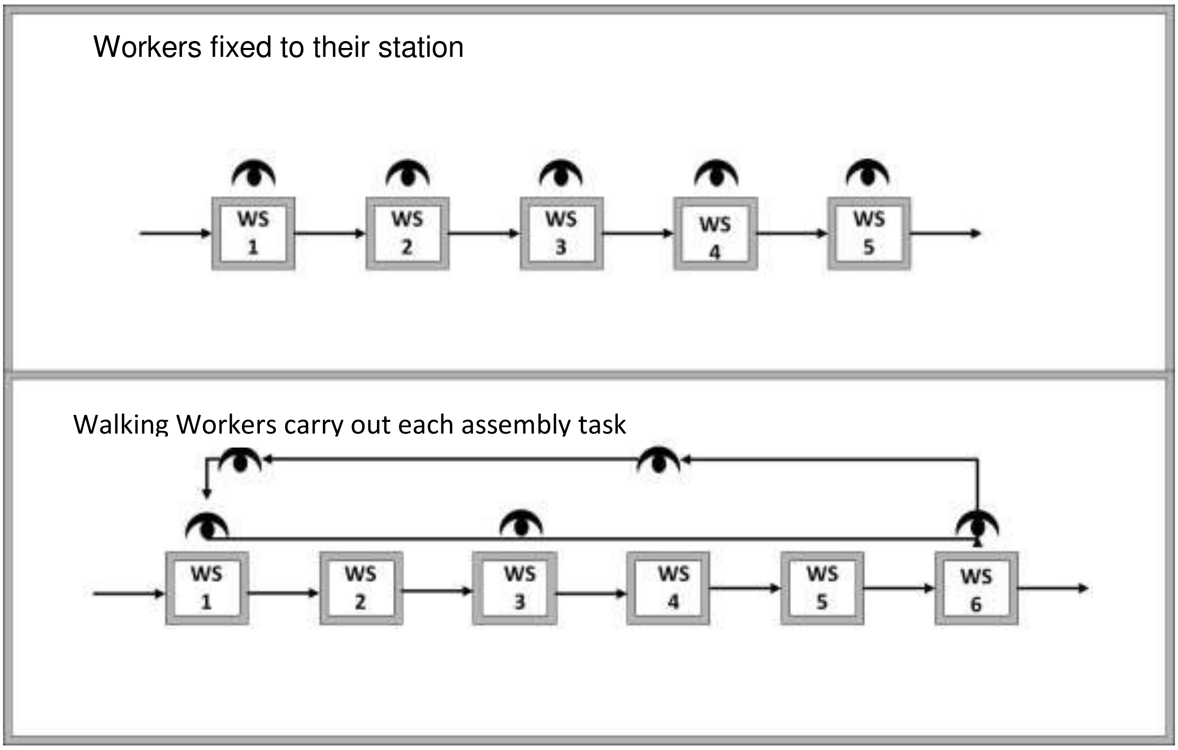

Figure 17 - Line Layout with fixed and Walking Workers

In table 4 the times of each work station are illustrated. In the original design each work station had a cycle time of 91 seconds. In the rebalanced line the cycle times are lower and the line has one additional work station. The sum of the cycle times stays the same.

Work station	Original cycle time	Rebalanced cycle time
1	91s	75s
2	91s	75s
3	91s	75s
4	91s	77s
5	91s	75s
6	n/a	78s
Total cycle time	455s	455s

Table 4 - Rebalanced Cycle Times

The simulation was run over one week. The week covers five workdays with three seven hours shifts, thus 15 shifts with 105 hours were simulated. The results are discussed in the next chapter. Figure 18 shows the 3D-view of the simulation. Six lines have been simulated with different numbers and types of workers.

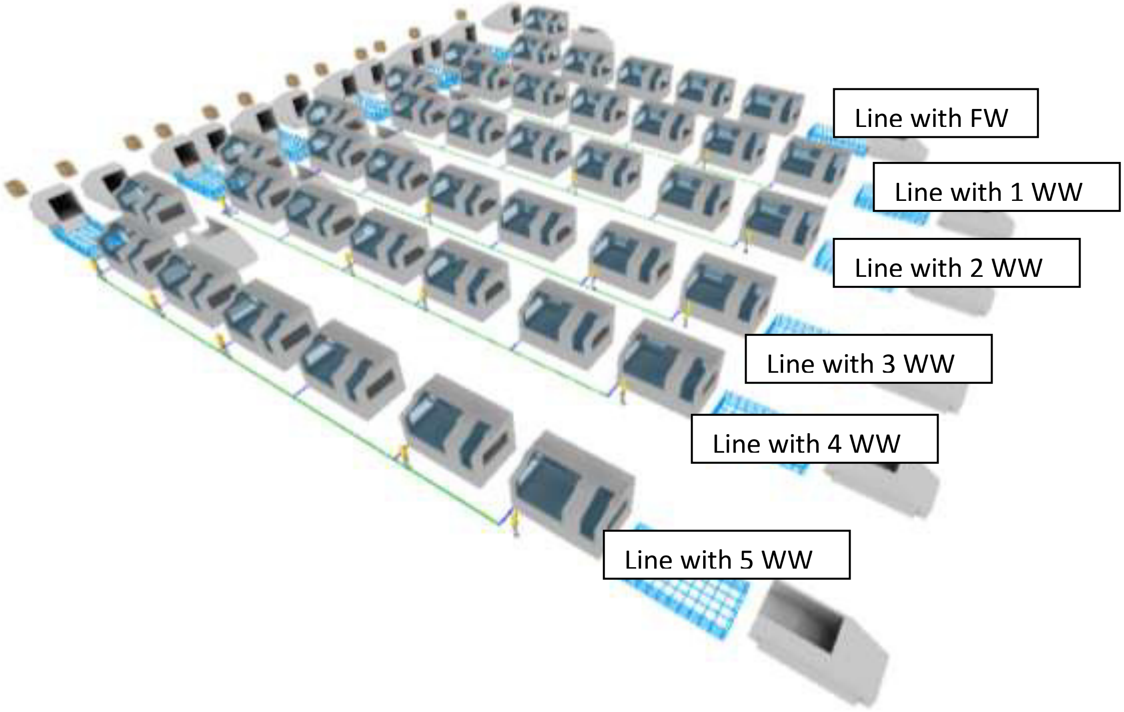

Figure 18 - 3D-View of the simulation

3.1.4 Simulation Results

The different number of workers causes a different number of finished products at the end of the week. The total output is illustrated in figure 19. The output runs in a linear way from the beginning to the end of the week.

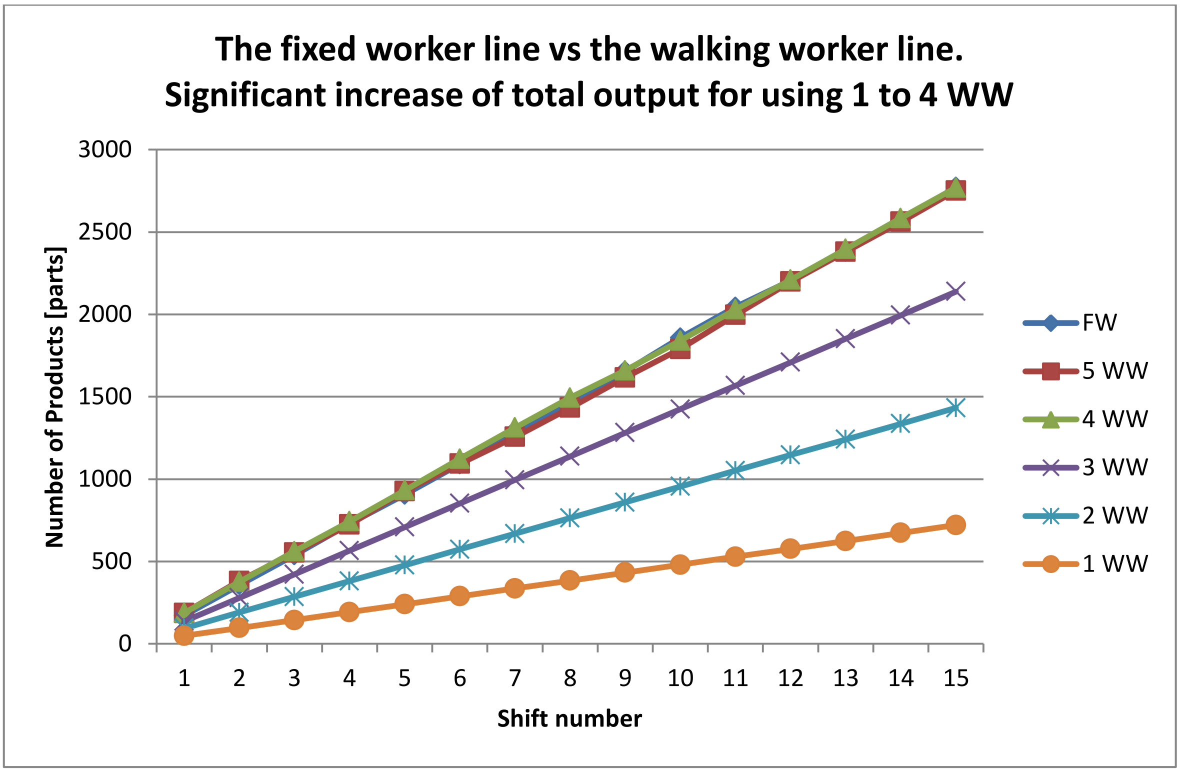

Figure 19 - Total Output

The line with one walking worker has the lowest output with 721 units. By using two walking workers the output could be increased to 1432 units. One additional worker increases the total output again to 2138 units. Using four or five walking workers or the five fixed workers increase the total output to the maximum of over 2700 units. The three lines are in the diagram very close together. They should be further analysed. This is done in figure 20 - Input/Output.

The relation between input and output is shown in figure 20. The fixed workers have the highest output with 2773 units. They are able to handle the total input immediately without building a high queue. The five walking worker were able to handle the input, too and produced an output of 2751 units. The four walking workers have a total output 2769 units, but the input in the simulation was with

2798 units almost the highest of all lines. Therefore the line with four flexible walking worker is not able to handle the whole input and a queue is built. This queue is also built in the lines with one, two and three walking workers. The total output can be increased by multiple times of the output of one walking worker by adding an additional worker. By adding fifth walking workers the total output is not increased anymore in the same way.

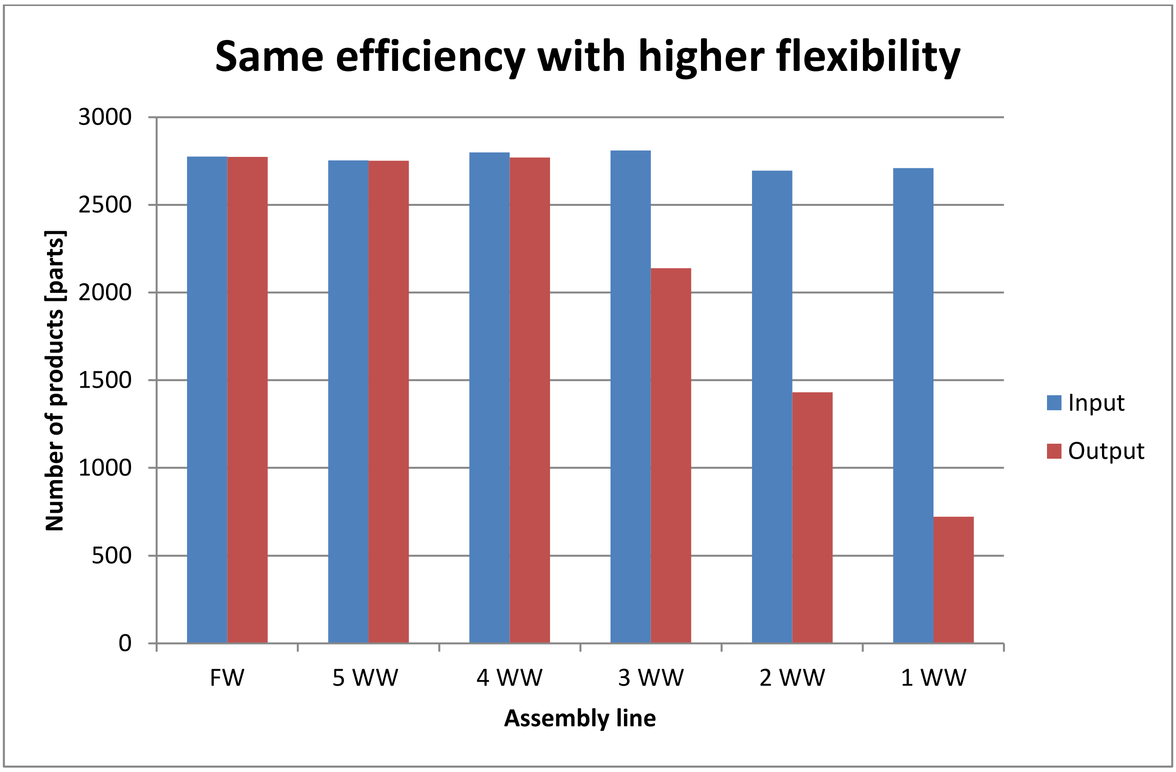

Figure 20 - Input/Output

The number of products in the queue in front of the line can be seen in figure 21.

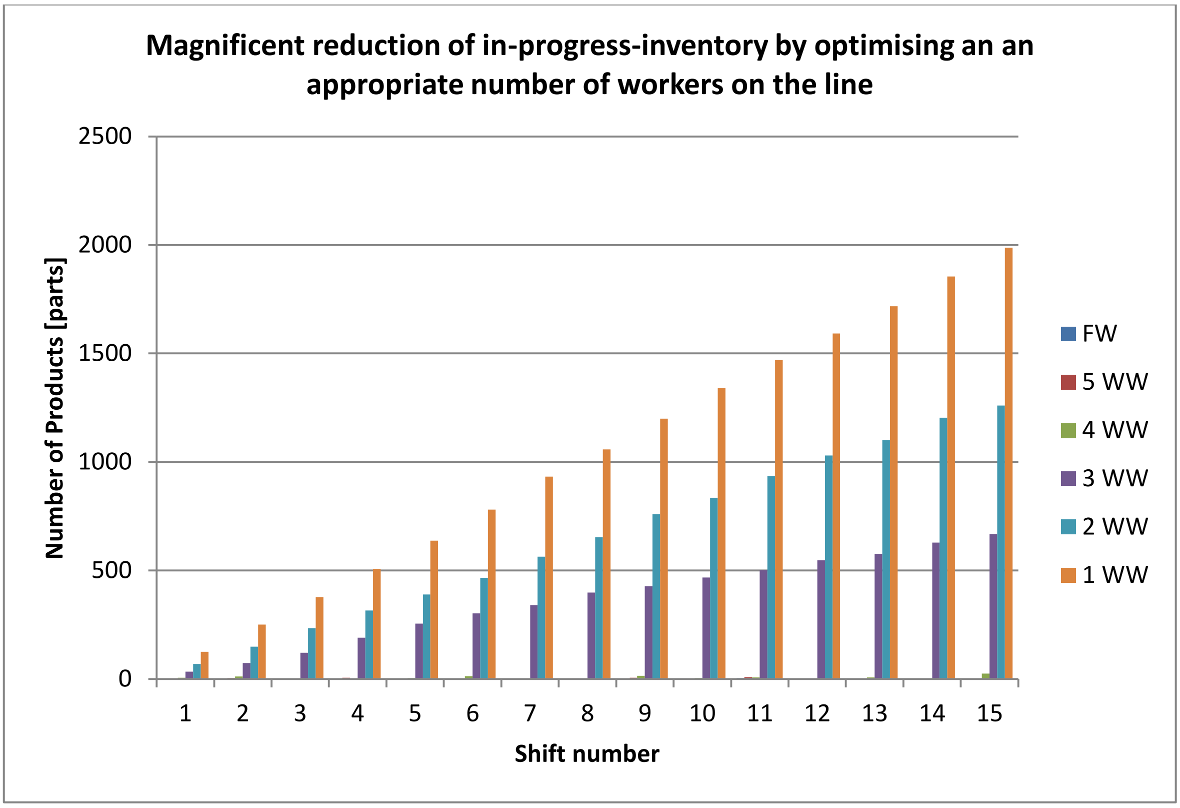

Figure 21 - Queue Content

The lines with one, two or three walking workers are not able to handle the continuous input, resulting in a queue that is built up in front of them in a linear way over the single shifts. The queue content after one week is for one walking worker nearly 2000 units. The queue content of two workers is at the end of the week by 1260 units. Using three walking worker the content built up to 668 units parts. These three contents would rise further by running the simulation over a longer period. The other three lines are able to reduce the queue content in a continuous way, like shown in figure 22. This figure is a close-up view of figure 21 to point the queue content of the lines with four or five walking workers and fixed workers. By using 4 walking workers the queue content rises up to 25 parts, but they are able to reduce the content to zero like in shifts three, seven, eight or fourteen. The queue content is reduced to zero in several shifts for each line. No linear, exponential or another statistical behaviour occurs in figure 22.

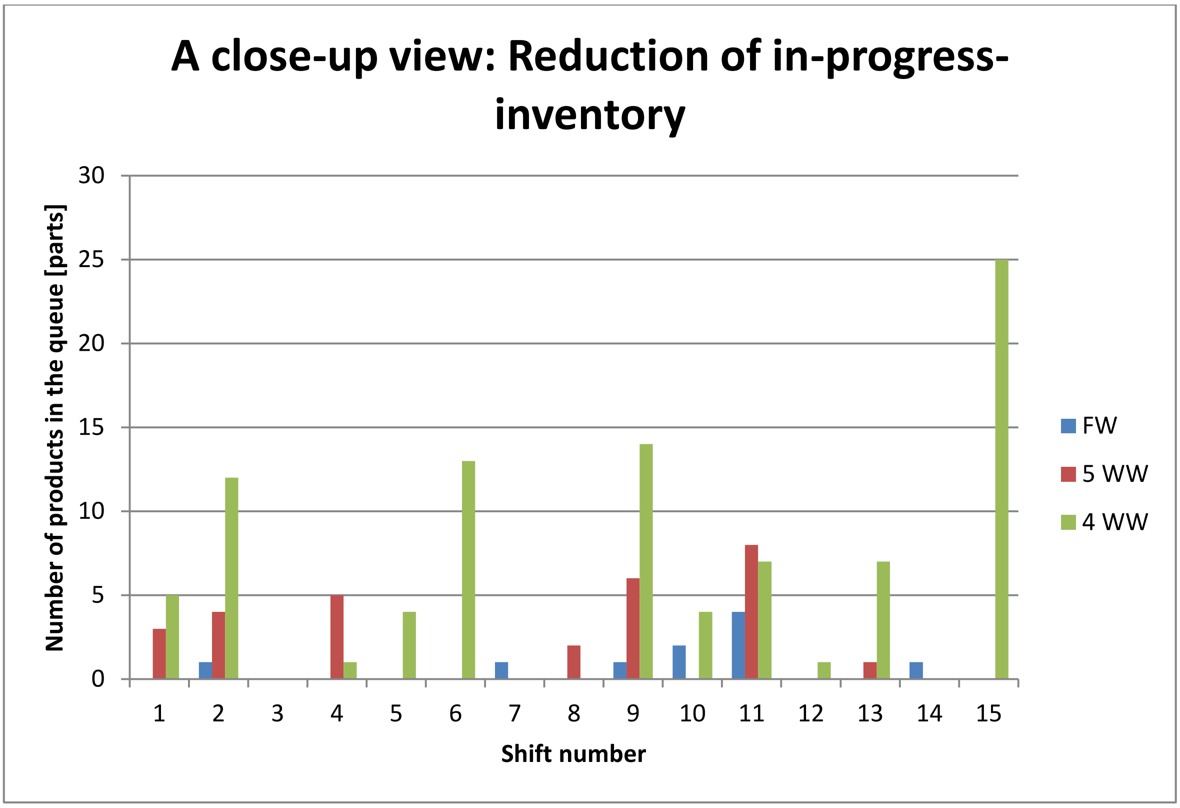

Figure 22 - Queue Content, Close-up View

The parts in the queue have to wait to be assembled. For the different lines different waiting times in the queue occur. Figure 23 shows the average stay time of each product in the queue, which can be seen as the in-process-waiting-time (IPWT) after one week. The stay time of each product in the queue was measured and the average was calculated for all of them. The parts in the line of the fixed worker have the lowest and the parts of the line of one walking worker have the highest waiting time. The products in the line of one walking worker stayed for nearly 40 hours in the queue. The usage of five walking workers decreases the IPWT to four minutes. The IPWT of the line with the fixed workers is two minutes. Due to the usage of five walking workers instead of fixed workers the IPWT is 100% higher.

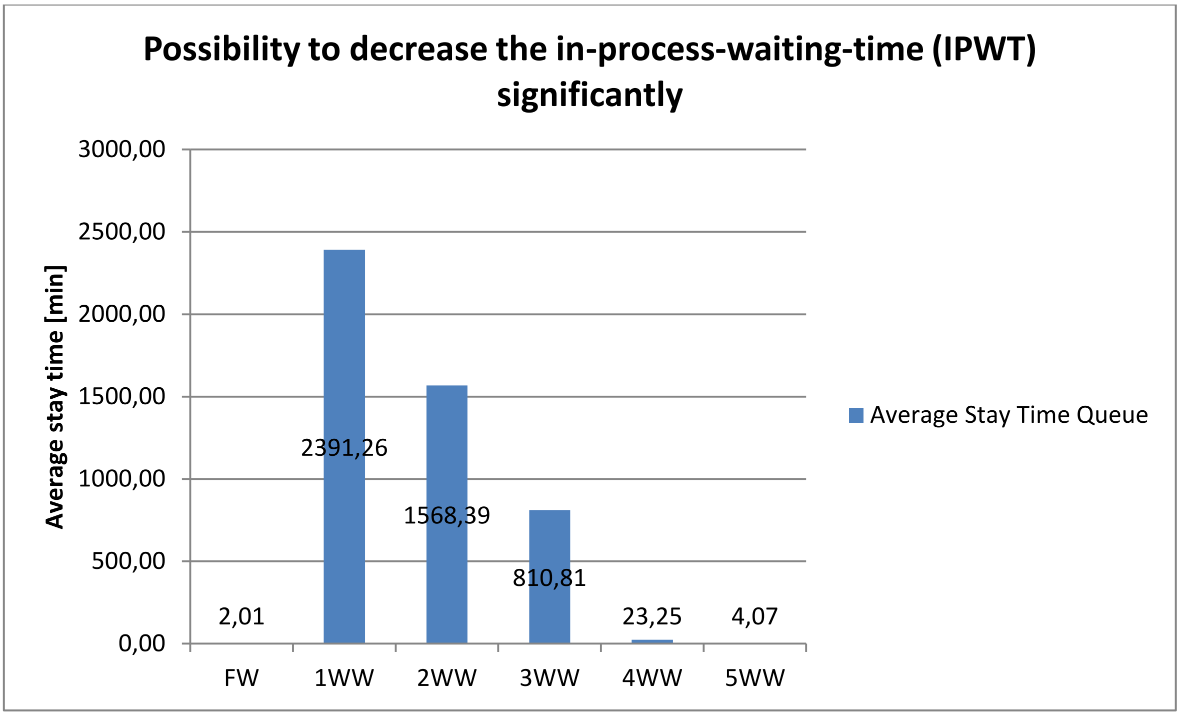

Figure 23 - Average Stay Time in the Queue

The workers have a different utilization at the different lines. Figure 24 shows that the one, two and three walking workers have no waiting time. Their utilization is by 100%. They are occupied with working for almost 90% at the work stations and assembling products and the rest of the time they are moving to their job.

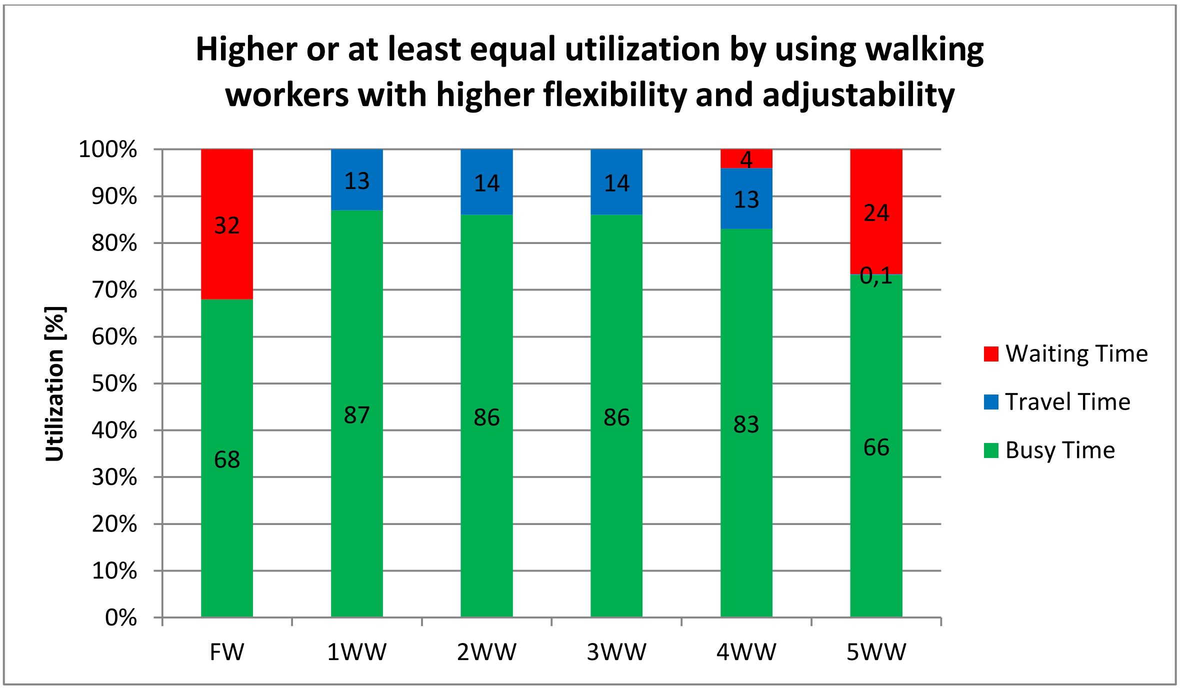

Figure 24 - Labour Utilization

The fixed and the five walking worker have a utilization of over 60%. The utilization of the four walking workers is nearly 100%. They are waiting for 4% of their working time. The rest of the time they are occupied for 83% with assembling products and for 13% with moving to their job.

The different number of workers cause a different output per shift, see figure 25. The output per shift is stable for the line with one, two and three workers. One walking worker produces 50 parts per shift. When an additional worker is added the output per shift is nearly 50 parts higher. So the output per shift of three walking workers is nearly by 150 parts. By using four walking workers or more the output is not increased in the same way anymore. The output per shift is impeded for the three other lines. The output of the four walking workers fluctuates less than the lines for the five and fixed workers and is nearly stable. It goes down a bit in shift number nine. The output for these three lines is between 150 and 210 parts.

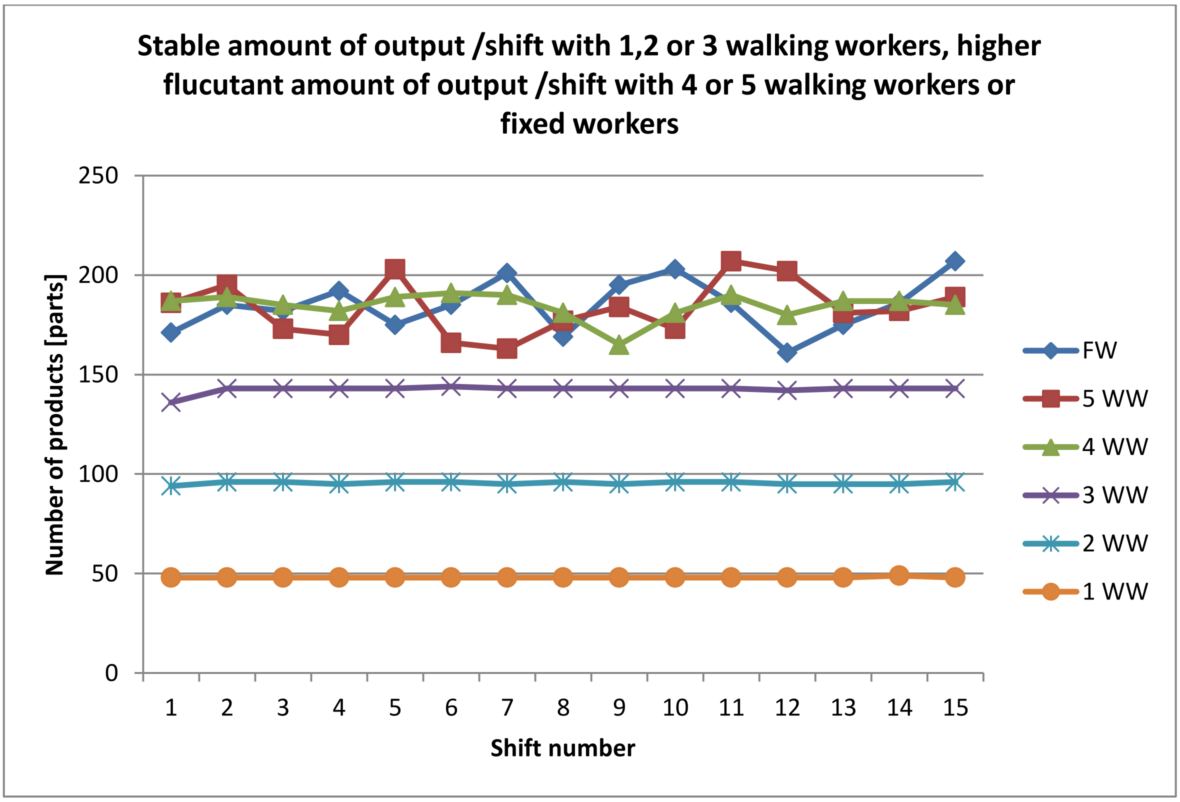

Figure 25 - Output per Shift

The different utilization results in a different output per worker per shift. Figure 26 illustrates the different number of products which every single worker assembles every shift.

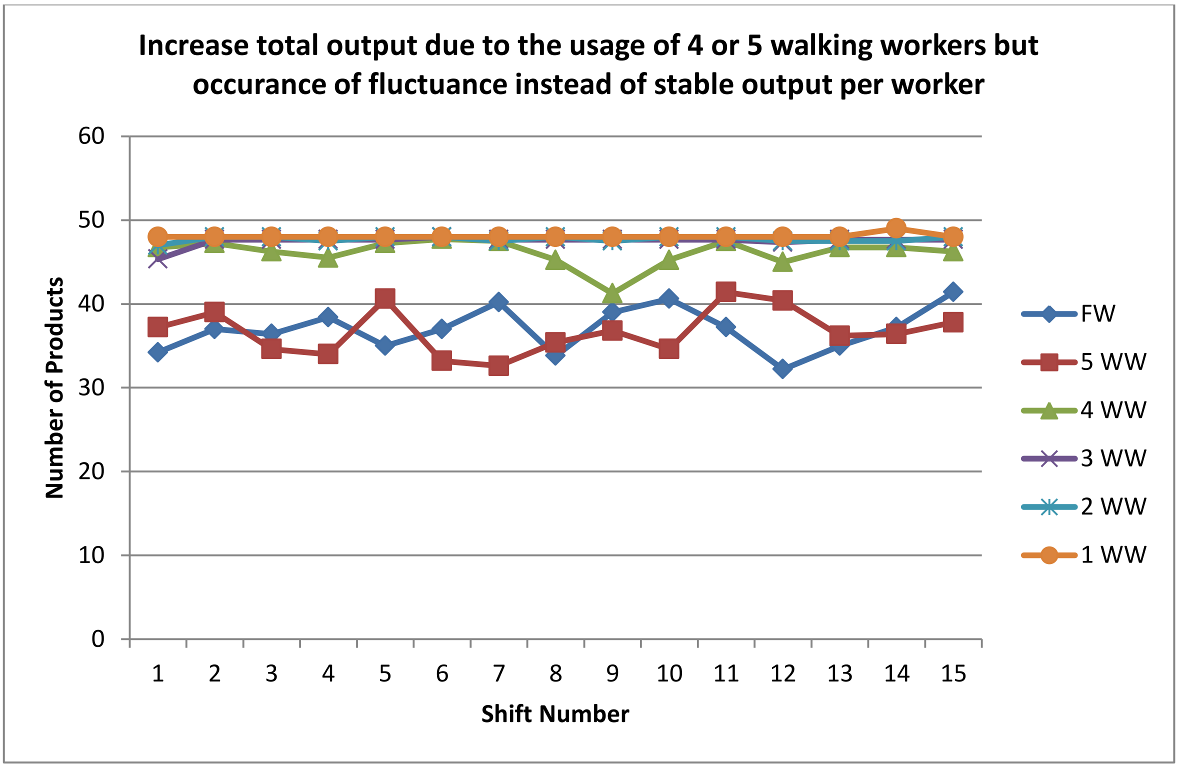

Figure 26 - Output per Worker per Shift

The lines with one, two and three walking workers produce constant nearly 50 products per seven hour shift. The four walking workers are almost stable by 48 parts and have their lowest output in shift number nine with 41 parts. The other worker's output per shift is between 30 and 45 products.

3.1.5 Analysis of the Simulation Results

The results shown and described in chapter 3.1.4 are caused in different reasons and will be explained and analysed in this chapter.

The total output of the assembly line can be increased by a higher number of walking workers. Each worker, which is added to the line, increases the total output by more than 700 parts. So the lines with four and five walking workers has an output of nearly 2800 parts in a week, which is four times of the output of one walking worker. See figure 27 to see the dependency of the number of walking workers and the increase of the total output.

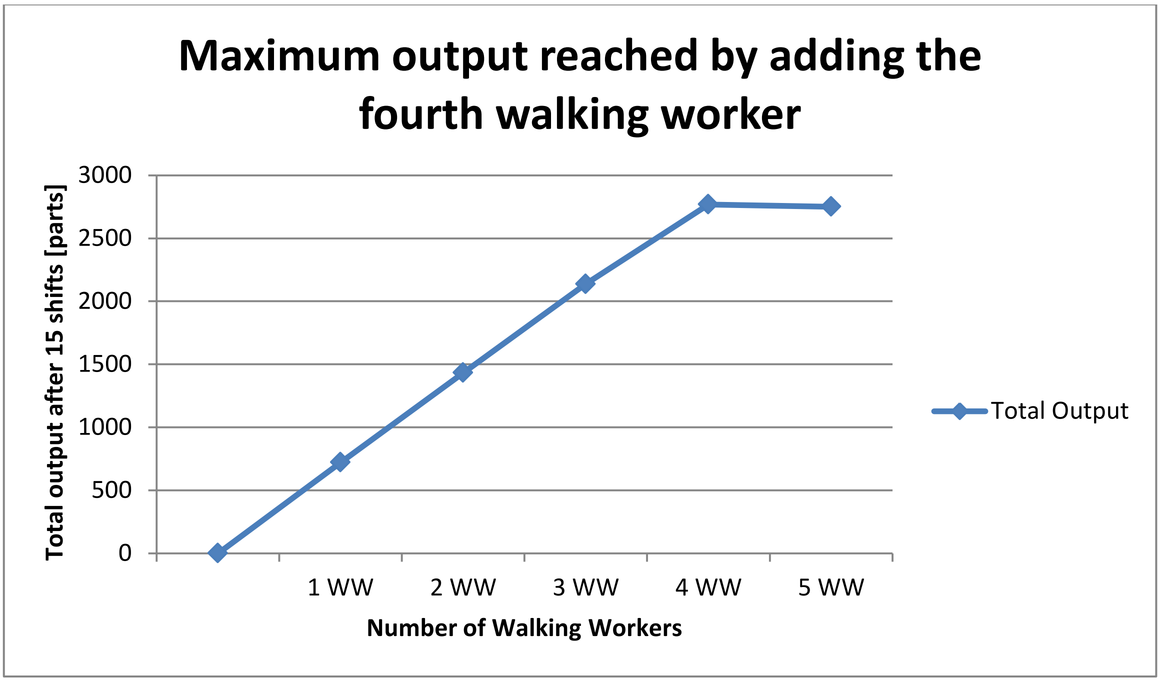

Figure 27 - Output in Relation to the Number of Workers

The scenario with four walking workers has the highest output. This is caused by a higher input over the week. As described in the chapter 3.1.3 the input fluctuates caused by the negative exponential distribution of the inter-arrival-time. The input of the five walking workers line is not that high, so the total output falls down by adding the fifth worker. The increase of the output to a multiple times of the output of one walking worker stops after adding the fourth walking worker. Adding the fifth worker guarantees that the total input will be handled and all parts will be assembled, but the output does not increase in the linear way as it has increased before. Adding more than five workers would not increase the output anymore. The output would go down because the workers would block each other more often.

In figure 19 - Input/Output a different input for the different lines can be seen. The reason is explained above with the negative exponential inter-arrival-time which is set in the simulation. By using walking workers in the assembly line it is possible to react very flexible to different demands. If the demand would fall to around 700 parts a week, just one walking worker would be needed. Two walking workers could handle a demand up to over 1400 parts. With three walking workers it would be possible to react to an increased demand up to 2100 parts in a week. The maximum is reached by nearly 2800 parts. To handle a higher demand than 2800 parts in a week the structure of the assembly line would have to be changed. The change of the number of workers to react very flexible to different demands is not possible in a line with fixed workers, because one or more workstation would not be in use.

The input for the one, two and three walking workers is too high, hence a queue is built in front of their lines. In these cases the input should be decreased to reduce the in-progress-inventory. Inventory is one of the seven wastes which are described in chapter 2.3. By implementing the walking worker as a Lean project it should be one of the main objectives to reduce the inventory significantly. This can be done by adding additional workers. The line of four walking workers build up a queue content in front of them, but they are able to handle the queue content and reduce it to zero. That inventory built up depends on the cycle times at each work stations. The cycle time is set to a normal distribution explained in chapter 3.1.3. So it is impeded around the ideal value. The fixed and the five walking workers have the lowest queue content and so a very low in-progress-inventory.

Like the queue content also the in-process-waiting time can be reduced by using the right number of workers. The usage of fixed or five workers guarantees a low waiting time for the products in the queue. But at the other hand this causes that the single workers have to wait for new products.

The labour utilization is an important measure that reflects the system performance. The workers of the first three lines with one, two or three walking workers do not have to wait for new products. Also they can work in a flow, because they are not delayed by occupied workstations. So they are not blocked at any time. They are only working or moving. The fixed workers have to wait for the products at their workstation and the walking workers, when they are four or five, have to wait for new products or are delayed by occupied workstations caused by slower workers. The difference between the waiting time of the four and the five walking workers is 20%. The utilization of four walking workers is nearly perfect it can be increased to 96% by losing just 2% of productivity. The control of the utilization of every worker is given by using walking workers instead of fixed workers.

The figures 25 and 26 with the output per shift and the output per worker per shift show that the workers in the line with one, two or three walking workers are not blocked by slower workers in front of them and they don't have to wait for new products. Their output is stable. The four walking workers nearly have a stable output per shift, except shift nine, where the output decreases. That shows that it takes a bit time to rebalance the line, when a worker is blocked or has to wait for parts. The workers with the highest utilization have the highest output per worker shift. The lines with the fixed and five walking workers are not so balanced, so their output per worker fluctuates, but they are able to assemble all parts, which come into the line. But it has to be taken in account that the utilization is less and more workers are required, which block each other at several times and would affect higher labour costs.

3.1.6 Summary of the Walking Worker Simulation

The main benefit of using walking workers instead of fixed workers is the high flexibility. For different demands different numbers of workers can be used in the line. The crossed-trained workers can handle every assembly step and when they are not needed they can be added to other parts of the line or in other areas.

Due to the high flexibility it is possible to increase the labour utilization by keeping a high output.

The walking workers on the assembly line enable to improve the line by reducing Ohno's seven wastes. The in-progress-inventory can be reduced. The overproduction can be avoided, when just the number of workers is added to the line which is needed for the actual demand. The waiting of the single workers is reduced to a minimum.

For the simulated line five walking workers have the highest output with the highest effectiveness and very low queue content. But their utilization is lower than the one of the fixed workers.

The reduction of one worker to four walking workers increases the utilization from 66% to 83%. The line is much more balanced and the output per worker per shift is nearly stable. The output is a bit less, but the four workers are still able to handle the input. It should be the best way to work with four walking workers on the line and economize on one worker by taking in account that a little queue in front of the line can be built but a high utilization and the stable output per worker is guaranteed.

The main barrier of implementing the walking worker is the high costs to train these workers for every single task in the assembly line. Due to statutory requirements it can be really expensive to use crossed-trained workers to carry out every different work step. If a certificate for single work steps is required it would be too expensive to train every worker to get the certificates. Instead of walking workers and the cross-trained workforces a waterfall-system would be better to save costs in this case.

3.2 Industrial Case Study: The Lean Approach by Herose GmbH Armaturen und Metalle

The medium-sized German company which is considered in this case study is Herose GmbH Armaturen und Metalle. The company is situated in Bad Oldesloe, Schleswig Holstein in North Germany. Herose works in the development, design, production, manufacturing and sales of valve systems. There are about 215 employees in the company and Herose operates with its own production department. The annual sales in year 2012 were nearly 44 million euros. The export rate is 75%. In 2012 400,000 valve systems were produced and sold. The in-house production depth is nearly 90%.

Herose started to implement Lean Management in 2008. The implementation was decided and introduced by the directors of the company, hence the top management gave their commitment for Lean Management, this made the whole implementation much easier.

Today three people are mainly assigned to handle the Lean projects and implement a Lean culture. In the first years Herose worked together with a Lean consultancy firm. But currently they carry out their projects on their own.

They started to implement 5S in their assembly lines and tried to implement Kaizen and a Lean culture in their whole company. But after a short period of time they realized that the implementation of Lean tools in single areas or workplaces does not increase the whole output or productivity. They set themselves four main objectives to reach. The most important objective is to get a very high adherence to delivery dates. Herose also wants to increase the productivity and the total output and stabilize the output by implementing Lean Management and a Lean culture in the company.

The projection was carried out with more than just single Lean tools in single workplaces or cells. To get the most benefits from this a value stream analysis had to be done. After that the whole value stream could be analysed. The conclusion was that Herose decided to change their order assignment in the assembly lines and the main production area. A constant work in progress (conwip) control system was implemented to create a smooth production.

One of the main problems was a low material and part availability. Several times a costumer request could not be shipped, because one or two positions in the order were not ready. Herose reduced this number of finished and not shippable valves in the inventory. Due to the high export rate, 75%, it is not possible to ship single positions of the requested order. The customer would have to pay for every single delivery new taxes and border fees, so Herose has to do an order combination.

An ABC-Analysis was carried out to identify the highest selling products with a high number of parts. It was found out that 14 valve-systems are responsible for 80% of the whole sales. These 14 different valve-systems are now produced in a consistent and continuous way. Herose does not wait for a customer request anymore for these valve-systems. That results in a high availability and a reduction of finished valves in the inventory which could not be shipped, because the high requested valves have a high availability now.

To guarantee this high availability the mentioned conwip-system was implemented. The number of orders which are handled in the single assembly lines have been limited. The assembly of the valve-systems is handled after product types. Herose has six different assembly areas for the different valve-types.

Before installing conwip the foreman confirmed right to use for every order for which all necessary parts were available. This ensured an average number of parts in the system which could be produced of 4000. The capacity of the assembly lines is 400 parts a day. Hence the theoretical total cycle time was ten days. The workers could decide on their own which order they wanted to work on. Urgent orders could be given a higher priority, which causes that other orders had to wait and the cycle time was increased further. Due to the usage of the conwip-system the maximum amount of parts which could be assembled were reduced to 1600 parts. The workers have to handle the orders in order they are given into the assembly line. The result was that the cycle time is supposed to be reduced to four days by 1600 parts and a capacity of 400 parts per day for all assembly lines. At the assembly area of the armatures with big nominal bores the total cycle time could be reduced from over 14 days to 7 days. The cycle time for armatures with a small nominal bore was reduced from 8 to 4 1/2 days. At another assembly area for safety relief valves the cycle time was reduced from 11 days to 7 1/2 days. The new cycle times are stable and not effected by priority changes or the random adaptation by the workers.

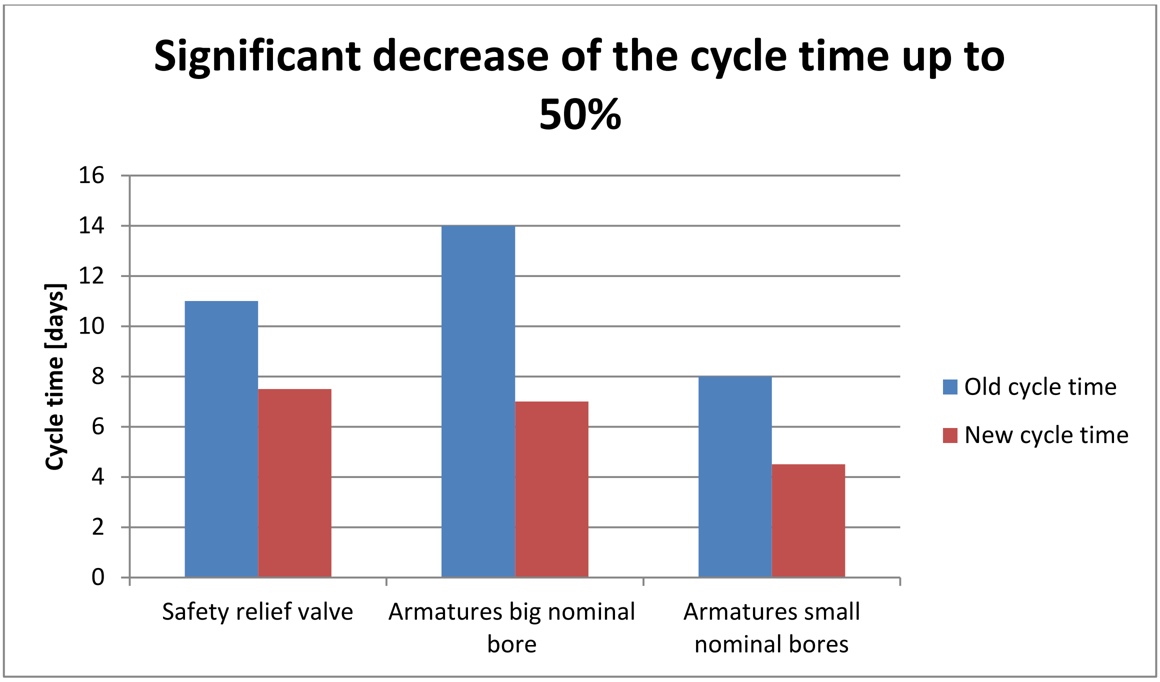

Figure 28 - Cycle Times of the Different Assembly Areas

The average of all cycle times could be reduced from 7.38 days in 2012 to 6.11 days, for further information see appendix F.

The lower cycle time causes a higher predictability for every order. This increases and stabilizes the output. A higher productivity is reached and the adherence to the delivery dates could be increased. The sales department can promise the customer exactly how long their orders are going to take once they are in the assembly line.

It is also planned to implement Lean in the actual assembly lines by reorganizing the cells. But a higher benefit was seen in the restructuring of the order assignment. In the next one or two years the cells should be restructured to increase the production flow. Also a walking worker system, as indicated in the simulation in chapter 3.1 is possible. The requirements are given. Every worker in the assembly area is able to handle nearly all steps of assembling a valve-system. They are very flexible and can act at different lines or valve-systems. These well crossed trained workers are perfectly eligible to being set in a walking worker assembly line.

Besides the improvement of the cycle time and the material availability, by using new production control systems and the smoother production with the heijunkaprinciple, Herose tries to implement a Lean culture in the whole company. A new manager- and foreman-leadership should be implemented. Every foreman or manager has to arrange the Lean thinking for his labour. The different changes and Lean-projection are carried out at the level of the employees and workers. The single department chiefs are not involved in every single step. They are updated at regular meetings.

Every employee should develop “Lean thinking” in relation to everything he/she does. They should consider problem solving and create sustainable solutions themselves. But to create such a culture takes a long time. Not every employee is willing to accept that he/she has to think according to Lean-principles and that the changes are positive. After the world economic crisis shorter hours of work were implemented in the company, because of a low number of customer requests. When the new conwip-systems reduced the number of parts in the assembly lines the workers thought at the first stage that the reduction is something negative until they realized that the changes are needed and have positive results.

One of the main barriers was that mistakes were not solved immediately or addressed to the person who is responsible. In respect to the person who made the mistake and not to blame this person the problem resolved. In the last few years this culture and thinking changed. The employees are not afraid anymore to make mistakes or finding a solution for problems they discover together with the person who is responsible.

Herose themselves are of the opinion that the implementation of Lean in their company relates to 30% of all their processes. Since the start of implementing Lean in 2008 the productivity was increased by 8% per year, for further information see appendix G. To implement the Lean thinking and culture in the whole company and involving every employee may take up to two generations.

4 Conclusion

The dissertation covers the main topics of Lean Management and its techniques through a literature review. The study of the literature review shows the general aspects of Lean Management from the basic definitions, the historical development to the main Lean tools, six sigma, pull-principle, 5S, TPM, Kaizen and Value Stream Analysis. Lean Production is discussed and presented in relation to its application in assembly lines. The application of using walking workers in an assembly system as a case study is described in the report.

In the first case study in this dissertation there is a summary of an investigation into the conventional fixed worker assembly line. It is reconfigured by using cross-trained walking workers at six instead of five workstations with fixed workers. The comparison between the original line with fixed workers and the re-balanced line with walking workers is presented in this report. The case study was conducted with the computer simulation software Enterprise Dynamics.

The results of the simulation show the great flexibility of the walking worker instead of fixed workers. Due to the high flexibility a different number of demands can be easily covered by using a different number of flexible walking workers, which is not possible with fixed workers. The labour utilization could be improved from 68% to 83% by no negative effects to efficiency or productivity. Using a walking worker increases the job flexibility and the labour satisfaction as the worker will work in different areas doing different tasks. The application of job rotation, job enlargement and job enrichment is also possible. Significant changes of the main assembly layout are not required and no additional costs occur and the valorisation could be achieved when using walking workers instead of the traditional fixed worker system.

On the other hand the main barriers like costs of special certifications for single work-tasks can block the implementation of a walking worker system. Another barrier is that slower workers are not allowed to be overtaken by faster workers along a linear line as it might cause production chaos. So workers can be blocked and the cycle time and the output per worker per shift are not stable anymore.

Slow walking workers can become a bottleneck that affects the whole performance of the assembly line.

In case study two the report discusses about implementing Lean in a company, it showes the different aspects which have to be covered and which benefits can be gained or which barriers can occur. The different projection of Herose, by reordering the assembly orders and not just adjusting single Lean tools in the assembly lines and recreating the cells, shows that the companies should know exactly which Lean approach brings the most benefits at the single stage of Lean implementation.

In further dissertations or projects different aspects can be covered. These aspects are described in the following section.

The results of the utilization in the simulation show for the five walking workers a travel-time of only 0.1%, see figure 24. This value should be tested in another model. It seems to be too small. The travel-times for the other walking workers are at nearly 15% much higher.

Furthermore the simulation could run with different inter-arrival times to simulate different demands. The possibility of breakdowns at the single workstations could be simulated to create more realistic results.

Another model of the assembly line can be created with another layout, e.g. the U-Shape-Layout, in which different products with different priorities and cycle times come into the line for assembly.

Also some calculations and equations for the proposed IPWT or total output can be carried out in further reports.

The results of the case study at Herose GmbH Armaturen und Metalle should be compared with other companies. These other companies may have chosen a different approach and gained different benefits and other barriers occurred by implementing Lean.

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Appendices

Appendix A – Project Proposal Form

Project Proposal – Individual Project 2012 / 2013

STUDENT NAME Torben Schaft **REGISTRATION NUMBER** 674068

COURSE Mechanical Engineering **DATE** 25.09.2012

PROJECT TITLE	Lean Approach to Operations Management
BACKGROUND A brief introduction to the topic.	The project is based on an application of the Lean Prinicples which are applied on a real-life productions environment. It is the aim to identify sources of waste, thus improvements for the manufacturing systems can be developed. The project is done in collaboration with a small-sized manufacturing company.
AIM Describe the general aim of your project (e.g. investigate ways of catching mice).	The aim is to describe, explain and constitute the "Lean Management". The project should solve a problem of waste or optimize a production line of a company, using lean management.
OBJECTIVES Describe how you hope to achieve the aim of the project (e.g. literature review; feasibility study, conduct interviews, write a questionnaire, working prototype, experimental plans etc....)	There will be literature review to achieve the aim of the project. Hence, the focus is put on the Lean Management in a production line. Therefore I describe and analyse the main tools of this topic: Six Sigma, Kanban, 5S, TPM, Kaizen Furthermore there will be an analysis of the data from the company.
PLAN (provisional) Breakdown of the objectives in a timescale.	1. Literature review of Lean Management 2. Study the Lean Management theory 3. Data analysis 4. Report writing & conclusion of the project
ETHICS/ Health and Safety Are there any ethical issues raised on this project? Have you completed the fast track web review: http://ethicsreview.port.ac.uk	**No** If yes 1. please read and fill in the form at: K:\Student\Technology\Eng\MDE\TewkesbG\Ethics 2. Please attach this form to this proposal and submit it to the Department Rep on the Faculty Ethics Committee (currently Dr Giles Tewkesbury) for approval to continue with the project.

PROJECT SUPERVISOR NAME:	**STUDENT NAME:**
SIGNATURE Radulovic	**SIGNATURE**

Appendix B – Interim Report Form

Interim Report Form

Please use block letters

NAME OF STUDENT: Torben Schaft..
Student Number: 574068...

NAME OF SUPERVISOR: Dr. Qian Wang..

DATE: 09/01/2013.................... **AWARD:** MMB..............................

PROJECT TITLE: Lean Approach to Operations Management – Assembly Lines

REVIEW OF PROGRESS:

- Research: Lean Management, Lean Production, Historical Development, Assembly Lines, Enterprise Dynamics Simulation
- Literature Review: containing the research
- Complete structure of the report
- Time Plane with Milestones

ACTIONS TO BE COMPLETED BEFORE END OF PROJECT PERIOD

- Literature Review
- Simulation
- Analysis
- Conclusion

TIMESCALE (JANUARY TO APRIL)

- 15/02/13 Literature Review
- 15/03/13 Simulation
- 01/04/13 Analysis
- 15/04/13 Conclusion, refine the report, prepare the poster

Signature of Supervisor:...

Appendix C – Project Monitoring Form

Project Monitoring Form

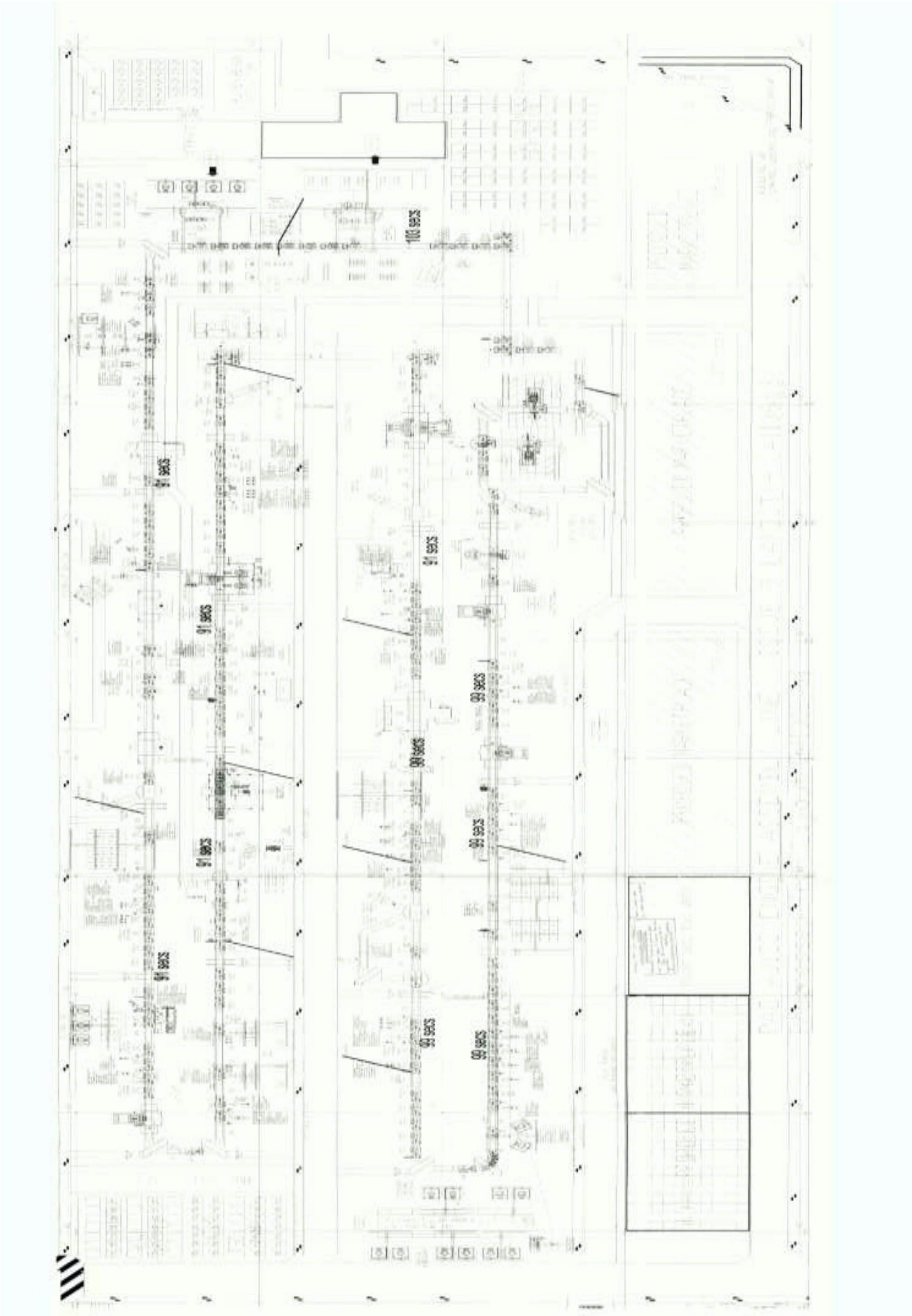
Student: Torben Schaft	Student Number: 674068
Supervisor: Q. Wang	
Title: Lean Approach To Operation Management	
Award:	Year: 2012 - 2013 3rd year

Students should consult their supervisors and keep them informed about the progress of their work.

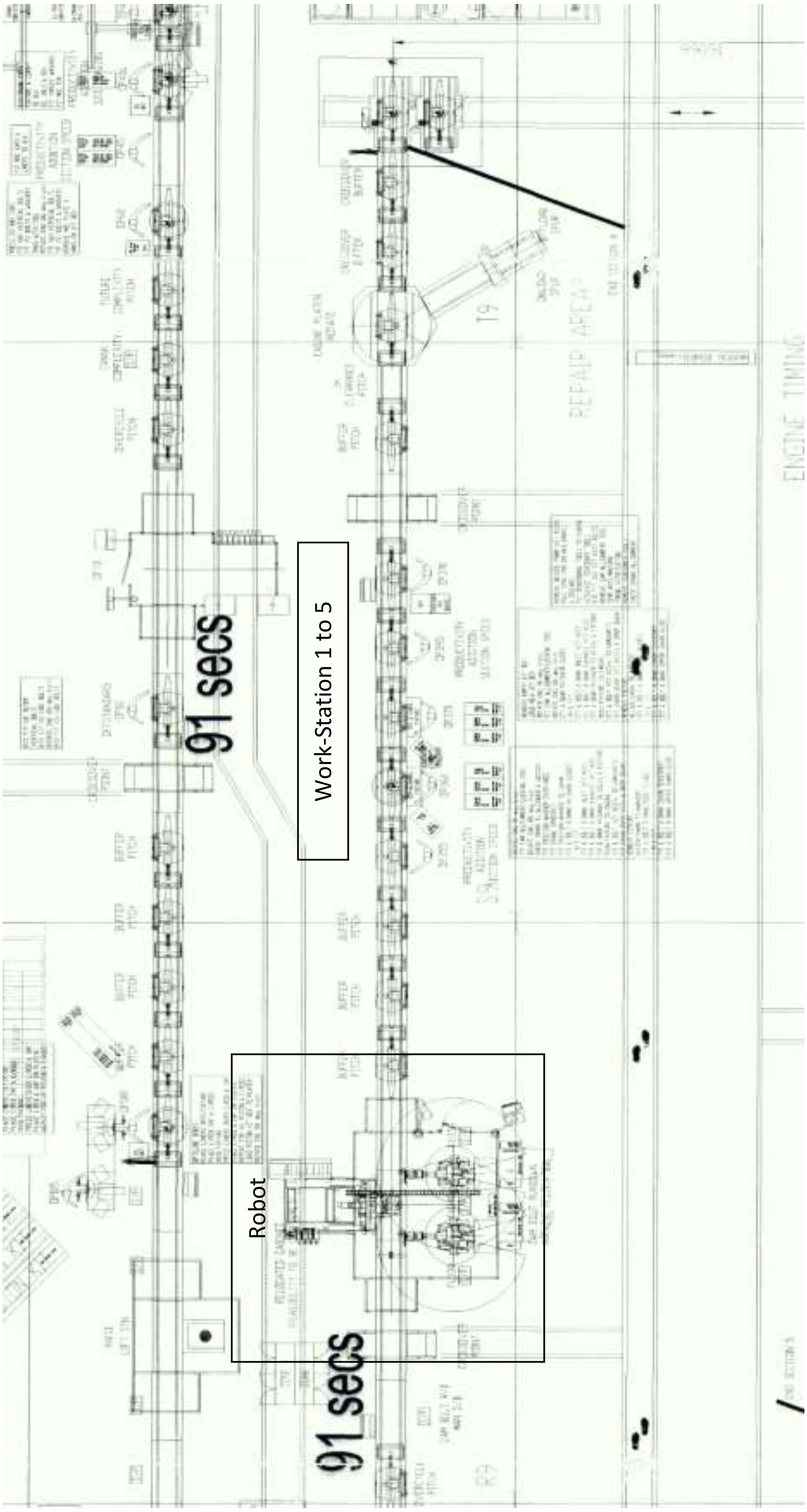
Date	Deliverable	Comments	Supervisors Initials
Mid October	**Project Proposal including Plan**	Project Title is defined Time Plan with Milestones	QW
End October	Progress Review	First Research started	QW
Mid November	Progress Review	rough structure of the report is set	QW
End November	Progress Review	Start of Literature Review	QW
Early December	Progress Review	fine structure is defined	QW
Mid January	**Interim/Progress Report**	see Interim Report Form	QW
End January	Progress Review	Literature Review almost done	QW
Mid February	Progress Review	Start of Simulation - Literature Review done	QW
End February	Progress Review	Building of Model in Enterprise Dynamics	QW
Mid March	**Project Monitoring Form**	Model done Results of Simulation	QW
End March	Progress Review	~~[illegible]~~ Final write-up	QW
Mid April	Progress Review	case Study in Germany Final Write-Up	QW
Early May	**Full Report**		

Supervisor Signature

Appendix D – Factory Layout



Appendix E – Assembly Line



Appendix F – Simulation Results

Input vs Output for the different lines

Input FW	Input 1 WW	Input 2 WW	Input 3 WW	Input 4 WW	Input 5 WW
2775	2709	2694	2809	2798	2754
Output FW	**Output 1 WW**	**Output 2 WW**	**Output 3 WW**	**Output 4 WW**	**Output 5 WW**
2773	721	1432	2138	2769	2751

Queue Content

Shift	Queue FW	Queue 1 WW	Queue 2 WW	Queue 3 WW	Queue 4 WW	Queue 5 WW
1	0	125	69	33	5	3
2	1	250	149	74	12	4
3	0	378	235	121	0	0
4	0	508	316	190	1	5
5	0	637	389	255	4	0
6	0	781	466	302	13	0
7	1	932	563	341	0	0
8	0	1058	653	398	0	2
9	1	1199	759	428	14	6
10	2	1339	835	467	4	0
11	4	1469	935	502	7	8
12	0	1592	1030	547	1	0
13	0	1717	1101	577	7	1
14	1	1854	1204	629	0	0
15	0	1987	1260	668	25	0

Total Output

Shift	Output FW	Output 1 WW	Output 2 WW	Output 3 WW	Output 4 WW	Output 5 WW
1	171	48	94	136	187	186
2	356	96	190	279	376	381
3	538	144	286	422	561	554
4	730	192	381	565	743	724
5	905	240	477	708	932	927
6	1090	288	573	852	1123	1093
7	1291	336	668	995	1313	1256
8	1460	384	764	1138	1494	1433
9	1655	432	859	1281	1659	1617
10	1858	480	955	1424	1840	1790
11	2044	528	1051	1567	2030	1997
12	2205	576	1146	1709	2210	2199
13	2380	624	1241	1852	2397	2380
14	2566	673	1336	1995	2584	2562
15	2773	721	1432	2138	2769	2751

Output per Shift and Output per Worker per Shift

Shift	Output/Shift FW	Output/Shift 1 WW	Output/Shift 2 WW	Output/Shift 3 WW	Output/Shift 4 WW	Output/Shift 5 WW
1	171	48	94	136	187	186
2	185	48	96	143	189	195
3	182	48	96	143	185	173
4	192	48	95	143	182	170
5	175	48	96	143	189	203
6	185	48	96	144	191	166
7	201	48	95	143	190	163
8	169	48	96	143	181	177
9	195	48	95	143	165	184
10	203	48	96	143	181	173
11	186	48	96	143	190	207
12	161	48	95	142	180	202
13	175	48	95	143	187	181
14	186	49	95	143	187	182
15	207	48	96	143	185	189

Shift	Output/Worker /Shift FW	Output/Worker /Shift 1 WW	Output/Worker /Shift 2 WW	Output/Worker /Shift 3 WW	Output/Worker /Shift 4 WW	Output/Worker /Shift5 WW
1	34,2	48	47	45,33333333	46,75	37,2
2	37	48	48	47,66666667	47,25	39
3	36,4	48	48	47,66666667	46,25	34,6
4	38,4	48	47,5	47,66666667	45,5	34
5	35	48	48	47,66666667	47,25	40,6
6	37	48	48	48	47,75	33,2
7	40,2	48	47,5	47,66666667	47,5	32,6
8	33,8	48	48	47,66666667	45,25	35,4
9	39	48	47,5	47,66666667	41,25	36,8
10	40,6	48	48	47,66666667	45,25	34,6
11	37,2	48	48	47,66666667	47,5	41,4
12	32,2	48	47,5	47,33333333	45	40,4
13	35	48	47,5	47,66666667	46,75	36,2
14	37,2	49	47,5	47,66666667	46,75	36,4
15	41,4	48	48	47,66666667	46,25	37,8

Utilization

Observation period :	378000						
Warmup period :	0						
Number of observations :	1						
Simulation method :	Separate runs						
Description :							
Group :	FW						
Elements :	Operator2	Operator3	Operator4	Operator5	Operator6		
		Average	St.Deviation	Lower bound (95%)	Upper bound (95%)	Minimum	Maximum
Status Idle		0,32	0	n.a.	n.a.	0,32	0,32
Status Busy		0,68	0	n.a.	n.a.	0,68	0,68
Atom :	1 WW						
		Average	St.Deviation	Lower bound (95%)	Upper bound (95%)	Minimum	Maximum
Status Busy		0,87	0	n.a.	n.a.	0,87	0,87
Status Travel to Job		0,13	0	n.a.	n.a.	0,13	0,13
Group :	2WW						
Elements :	Operator47	Operator48					
		Average	St.Deviation	Lower bound (95%)	Upper bound (95%)	Minimum	Maximum
Status Idle		0	0	n.a.	n.a.	0	0
Status Busy		0,86	0	n.a.	n.a.	0,86	0,86
Status Travel to Job		0,14	0	n.a.	n.a.	0,14	0,14
Group :	3WW						
Elements :	Operator57	Operator58	Operator59				
		Average	St.Deviation	Lower bound (95%)	Upper bound (95%)	Minimum	Maximum
Status Idle		0	0	n.a.	n.a.	0	0
Status Busy		0,86	0	n.a.	n.a.	0,86	0,86
Status Travel to Job		0,14	0	n.a.	n.a.	0,14	0,14
Group :	4WW						
Elements :	Operator85	Operator86	Operator87	Operator88			
		Average	St.Deviation	Lower bound (95%)	Upper bound (95%)	Minimum	Maximum
Status Idle		0,04	0	n.a.	n.a.	0,04	0,04
Status Busy		0,83	0	n.a.	n.a.	0,83	0,83
Status Travel to Job		0,13	0	n.a.	n.a.	0,13	0,13
Group :	5WW						
Elements :	Operator119	Operator120	Operator121	Operator122	Operator123		
		Average	St.Deviation	Lower bound (95%)	Upper bound (95%)	Minimum	Maximum
Status Idle		0,24	0	n.a.	n.a.	0,24	0,24
Status Busy		0,66	0	n.a.	n.a.	0,66	0,66
Status Travel to Job		0,1	0	n.a.	n.a.	0,1	0,1

Average Stay Time of the Products in the Queue

Observation period :	378000						
Warmup period :	0						
Number of observations :	1						
Simulation method :	Separate runs						
Description :							
Atom :	Queue - FW						
		Average	St.Deviation	Lower bound (95%)	Upper bound (95%)	Minimum	Maximum
ipwt		120,31	0	n.a.	n.a.	120,31	120,31
Atom :	Queue - 1WW						
		Average	St.Deviation	Lower bound (95%)	Upper bound (95%)	Minimum	Maximum
ipwt		143475,72	0	n.a.	n.a.	143475,72	143475,72
Atom :	Queue - 2WW						
		Average	St.Deviation	Lower bound (95%)	Upper bound (95%)	Minimum	Maximum
ipwt		94103,53	0	n.a.	n.a.	94103,53	94103,53
Atom :	Queue - 3WW						
		Average	St.Deviation	Lower bound (95%)	Upper bound (95%)	Minimum	Maximum
ipwt		48648,76	0	n.a.	n.a.	48648,76	48648,76
Atom :	Queue - 4WW						
		Average	St.Deviation	Lower bound (95%)	Upper bound (95%)	Minimum	Maximum
ipwt		1395,12	0	n.a.	n.a.	1395,12	1395,12
Atom :	Queue - 5WW						
		Average	St.Deviation	Lower bound (95%)	Upper bound (95%)	Minimum	Maximum
ipwt		243,97	0	n.a.	n.a.	243,97	243,97

Appendix G – Cycle Times Herose GmbH Armturen und Metalle

HEROSE Cycle Times 2012

HEROSE - Fertigung / Lean

HANS 3-In-1 Report für Durchlaufzeit nach ConWIP-Kreisen

Tage

Strategische Zielgrößen = SZG's	2012 YTD	12	Jan	Feb	Mär	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez
ConWIP_01 (Ind-SV)	7.50	SZG	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50
	7.25	Aktuell	9.53	7.76	8.33	7.26	8.03	7.43	6.73	6.60	6.16	6.77	6.68	5.73
ConWIP_02A (TTSV 060ff)	9.00	SZG	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
	9.21	Aktuell	11.27	8.01	9.74	9.22	10.68	8.84	9.92	9.02	9.72	8.64	8.04	7.40
ConWIP_02B (TTSV 063FF)	8.00	SZG	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
	8.03	Aktuell	9.62	7.44	7.97	9.46	9.95	7.50	8.57	8.18	7.11	6.57	6.86	7.15
ConWIP_03 (TT-Wechsel)	9.00	SZG	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
	8.68	Aktuell	8.77	7.56	7.22	8.86	8.21	8.42	9.92	12.08	7.46	7.78	9.70	8.21
ConWIP_04A (TTV oben)	7.00	SZG	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
	6.49	Aktuell	9.56	7.33	6.95	6.65	7.90	6.13	6.11	6.49	4.99	5.47	5.12	5.18
ConWIP_04B (TTV unten)	7.00	SZG	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
	6.86	Aktuell	8.61	5.69	7.10	7.70	5.72	6.61	6.40	8.21	8.74	6.92	5.68	4.99
Ø Durchlaufzeit	8.00	SZG	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
	7.38	Aktuell	9.57	7.43	7.80	7.78	8.62	7.14	7.34	7.38	6.56	6.47	6.38	6.07

HEROSE Cycle Times 2013

HEROSE - Fertigung / Lean

HANS 3-In-1 Report für Durchlaufzeit nach ConWIP-Kreisen

Tage

Strategische Zielgrößen = SZG's	Basis 2012	2013 YTD	3	Jan	Feb	Mär	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez
ConWIP_01 (Ind-SV)	7.25	6.50	SZG	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50
		6.69	Aktuell	6.16	7.04	6.86									
ConWIP_02A (TTSV 060ff)	9.21	8.75	SZG	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75
		7.99	Aktuell	8.69	7.04	8.22									
ConWIP_02B (TTSV 063FF)	8.03	7.50	SZG	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50
		6.91	Aktuell	7.19	6.56	6.98									
ConWIP_03 (TT-Wechsel)	8.68	8.50	SZG	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50
		6.58	Aktuell	7.71	5.89	6.16									
ConWIP_04A (TTV oben)	6.49	5.60	SZG	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60	5.60
		4.84	Aktuell	5.41	4.39	4.73									
ConWIP_04B (TTV unten)	6.86	6.75	SZG	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75
		6.53	Aktuell	8.92	5.92	4.73									
Ø Durchlaufzeit	7.38	6.75	SZG	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75
		6.11	Aktuell	6.28	5.94	6.11									

Appendix H – Productivity Herose GmbH Aarmaturen und Metalle

HEROSE Productivity 2010

HEROSE - M+F

HANS 3-In-1 Report für Ausbringungsproduktivität
[Stück pro Stunde]

	Basis 2009	2010 YTD	12	Jan	Feb	Mär	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez
Ausbringungsproduktivität nach zugebuchter Menge (MB51; Bewegungsart: 101)															
TT Armaturen (141)	3.01	3.23	SZG	3.15	3.15	3.15	3.15	3.15	3.15	3.30	3.30	3.30	3.30	3.30	3.30
		3.48	Aktuell	3.15	3.73	3.18	3.21	3.26	3.41	3.66	3.72	3.46	3.53	3.76	3.67
TT Sicherheitsventile (142)	6.45	6.88	SZG	6.75	6.75	6.75	6.75	6.75	6.75	7.00	7.00	7.00	7.00	7.00	7.00
		7.11	Aktuell	6.28	6.63	7.17	7.03	7.34	7.29	6.73	7.21	7.58	7.43	7.31	7.27
Industrie Sicherheitsventile (143)	7.60	8.00	SZG	7.80	7.80	7.80	7.80	7.80	7.80	8.20	8.20	8.20	8.20	8.20	8.20
		7.84	Aktuell	7.24	7.63	8.31	8.70	8.28	7.91	7.80	8.93	7.40	6.27	8.27	7.36
TT Wechselarmaturen (144)	1.86	1.98	SZG	1.85	1.85	1.85	1.85	1.85	1.85	2.10	2.10	2.10	2.10	2.10	2.10
		2.16	Aktuell	1.86	2.19	1.98	2.02	2.39	2.19	1.30	2.12	2.14	2.13	3.04	2.52
Total	4.96	5.30	SZG	5.20	5.20	5.20	5.20	5.20	5.20	5.40	5.40	5.40	5.40	5.40	5.40
		5.25	Aktuell	4.75	5.26	5.26	5.42	5.20	5.27	5.20	5.49	5.27	5.01	5.59	5.33

HEROSE Productivity 2011

HEROSE - M+F

HANS 3-In-1 Report für Ausbringungsproduktivität
[Stück pro Stunde]

	Basis 2010	2011 YTD	12	Jan	Feb	Mär	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez
Ausbringungsproduktivität nach zugebuchter Menge (MB51; Bewegungsart: 101)															
TT Armaturen (141)	3.48	3.23	SZG	3.15	3.15	3.15	3.15	3.15	3.15	3.30	3.30	3.30	3.30	3.30	3.30
		3.69	Aktuell	3.00	4.02	3.40	3.71	3.56	3.44	3.88	4.08	4.14	3.37	4.29	3.44
TT Sicherheitsventile (142)	7.11	6.88	SZG	6.75	6.75	6.75	6.75	6.75	6.75	7.00	7.00	7.00	7.00	7.00	7.00
		7.22	Aktuell	6.14	6.74	7.15	8.31	7.89	6.90	7.79	7.01	7.15	6.46	7.91	7.18
Industrie Sicherheitsventile (143)	7.84	8.00	SZG	7.80	7.80	7.80	7.80	7.80	7.80	8.20	8.20	8.20	8.20	8.20	8.20
		7.82	Aktuell	8.61	8.54	8.24	7.09	7.29	6.79	7.39	7.69	8.02	6.53	8.18	9.41
TT Wechselarmaturen (144)	2.16	1.98	SZG	1.85	1.85	1.85	1.85	1.85	1.85	2.10	2.10	2.10	2.10	2.10	2.10
		2.22	Aktuell	2.51	2.04	2.11	2.41	2.34	1.41	3.00	2.01	2.31	2.12	2.13	2.23
Total	5.25	5.30	SZG	5.20	5.20	5.20	5.20	5.20	5.20	5.40	5.40	5.40	5.40	5.40	5.40
		5.22	Aktuell	4.69	5.32	5.22	5.42	5.22	4.75	5.46	5.25	5.40	4.85	5.66	5.42

HEROSE Productivity 2012

HEROSE - M+F

HANS 3-In-1 Report für Ausbringungsproduktivität
[Stück pro Stunde]

	Basis 2011	2012 YTD	12	Jan	Feb	Mär	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez
TT Armaturen (141)	3.69	3.30	SZG	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30
		3.85	Aktuell	3.96	3.78	4.00	3.59	3.17	3.39	3.93	4.09	3.97	4.13	4.28	3.95
TT Sicherheitsventile (142)	7.22	7.08	SZG	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.20	7.20	7.20	7.20	7.20
		7.98	Aktuell	6.77	7.44	7.67	7.86	7.97	9.01	8.66	8.61	7.45	8.51	8.37	7.41
Industrie Sicherheitsventile (143)	7.82	8.20	SZG	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20
		7.41	Aktuell	7.21	7.09	7.30	7.79	6.60	8.60	7.76	7.66	8.82	7.32	6.22	6.57
TT Wechselarmaturen (144)	2.22	2.10	SZG	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10
		2.30	Aktuell	1.94	2.20	2.49	1.87	2.09	2.03	2.58	2.50	2.44	2.44	2.37	2.69
Total	5.22	5.34	SZG	5.30	5.30	5.30	5.30	5.30	5.30	5.30	5.40	5.40	5.40	5.40	5.40
		5.38	Aktuell	5.15	5.27	5.31	5.36	4.75	5.34	5.56	5.66	5.74	5.64	5.51	5.22

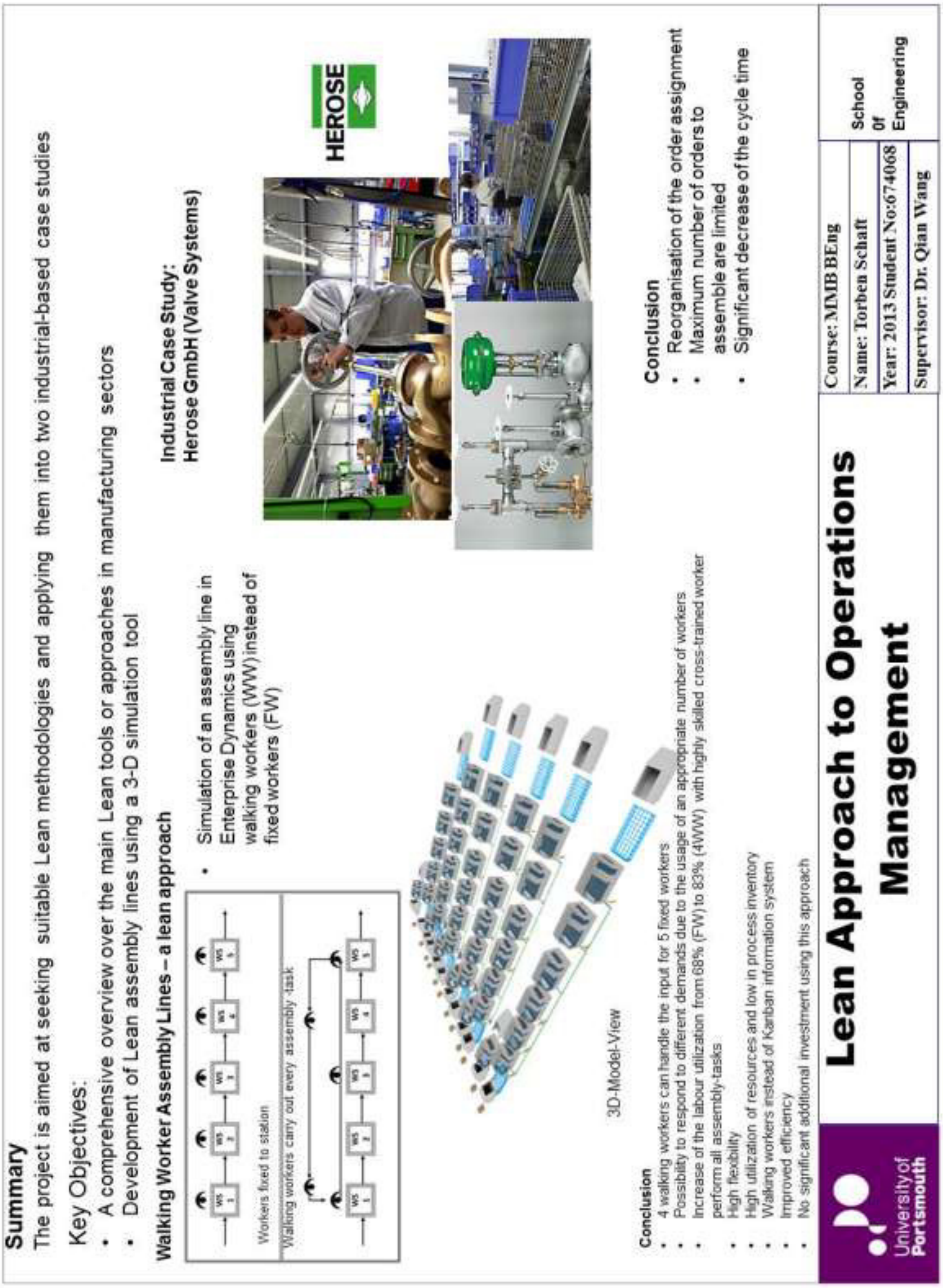
Appendix I - Questionnaire, Interview with Stefan Gil (Lean Manager, Herose)

<u>Questionnaire: Lean Approach to Operations Management -</u>

<u>Herose GmbH & Co. KG</u>

1. In which departments and areas did you implement Lean Management?
2. How many employees are involved in the Lean Management process?
3. Which Lean tools did you implement in your company?
4. How many Lean projects are carried out at the moment?
5. In which way is Lean implemented in your company? (Top-down, bottom-up, central, decentral)
6. In which steps is the implementation scheduled?
7. What are the main benefits of the implemented Lean Tools?
8. What were the main problems during implementing Lean Tools?
9. What are the main barriers to implement Lean tools in your company?
10. How is the Kaizen-process (continuous improvement) carried out?
11. What kind of assembly lines are used in the company (shape,size,etc.)
12. Which Lean Tools are implemented in the assembly lines?
13. Would it be possible to implement the walking worker in your assembly line?
14. What are the barriers to implement the walking worker?

Appendix J – Project Poster



Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Erklärung zur selbstständigen Bearbeitung einer Abschlussarbeit

Gemäß der Allgemeinen Prüfungs- und Studienordnung ist zusammen mit der Abschlussarbeit eine schriftliche Erklärung abzugeben, in der der Studierende bestätigt, dass die Abschlussarbeit „– bei einer Gruppenarbeit die entsprechend gekennzeichneten Teile der Arbeit [(§ 18 Abs. 1 APSO-TI-BM bzw. § 21 Abs. 1 APSO-INGI)] – ohne fremde Hilfe selbständig verfasst und nur die angegebenen Quellen und Hilfsmittel benutzt wurden. Wörtlich oder dem Sinn nach aus anderen Werken entnommene Stellen sind unter Angabe der Quellen kenntlich zu machen.“

Quelle: § 16 Abs. 5 APSO-TI-BM bzw. § 15 Abs. 6 APSO-INGI

Dieses Blatt, mit der folgenden Erklärung, ist nach Fertigstellung der Abschlussarbeit durch den Studierenden auszufüllen und jeweils mit Originalunterschrift als letztes Blatt in das Prüfungsexemplar der Abschlussarbeit einzubinden.
Eine unrichtig abgegebene Erklärung kann -auch nachträglich- zur Ungültigkeit des Studienabschlusses führen.

Erklärung zur selbstständigen Bearbeitung der Arbeit

Hiermit versichere ich,

Name: Schaft

Vorname: Torben

dass ich die vorliegende Bachelorarbeit bzw. bei einer Gruppenarbeit die entsprechend gekennzeichneten Teile der Arbeit – mit dem Thema:

Lean Approach to Operations Management

ohne fremde Hilfe selbständig verfasst und nur die angegebenen Quellen und Hilfsmittel benutzt habe. Wörtlich oder dem Sinn nach aus anderen Werken entnommene Stellen sind unter Angabe der Quellen kenntlich gemacht.

- die folgende Aussage ist bei Gruppenarbeiten auszufüllen und entfällt bei Einzelarbeiten -

Die Kennzeichnung der von mir erstellten und verantworteten Teile der -bitte auswählen- ist erfolgt durch:

Hamburg	27.06.2013	
Ort	Datum	Unterschrift im Original