Operational Guideline for Implementing Modular Assembly Robots in an Engine Manufacturing Line including an Examination of Economical Potential

Master Thesis

by

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In Cooperation with:

AUDI HUNGARIA MOTOR Kft.

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Kurzfassung

Bei der Implementierung neuartiger Technologien hat die Automobilindustrie schon in der Vergangenheit eine Vorreiterrolle eingenommen. So wurden die ersten Industrieroboter in Produktionsprozessen in der Fahrzeugfertigung eingesetzt. Heute sind diese ein fixer Bestandteil des gesamten Fertigungsprozesses und übernehmen immer umfassendere Aufgaben. Bereiche wie der Karosseriebau und auch die Lackiererei sind bei AUDI HUNGARIA MOTOR Kft. nahezu vollständig automatisiert. Der in dieser Arbeit behandelte Bereich der Motorenproduktion, ins besondere die Motormontage, weist hingegen einen deutlich geringeren Automatisierungsgrad auf. Dies ist Großteils den komplexen auszuführenden Tätigkeiten und der damit verbundenen Notwendigkeit für einzigartige menschliche Fähigkeiten geschuldet. Neue technologische Entwicklungen in der Robotertechnik, wie die Konstruktion feinfühliger Leichtbauroboter, ermöglichen nun den Einsatz des Roboters in unmittelbarer Nähe zum Menschen somit scheint ein Einsatz des Roboters als direkter Partner des Menschen möglich zu sein.

Eine Analyse der betrachteten Linie und Interviews mit den betroffenen Personen in der Produktion sowie im Management ergaben die Notwendigkeit für die Vereinheitlichung und strukturierte Herangehensweise im Umgang mit der Umsetzung dieser neuartigen Technologien im Produktionsprozess. Durch eine Benchmarking Analyse vergangener Automatisierungsprojekte in anderen Segmenten, konnten die wichtigsten Kriterien und Herausforderungen für Automatisierungsprojekte eruiert werden. Diese Erkenntnisse dienen als Grundlage für die Erstellung eines einheitlichen Handlungsleitfadens für zukünftige Automatisierungsprojekte.

In der vorliegenden Arbeit wird zunächst der Hintergrund der verstärkten Automatisierung in der Produktion beleuchtet. Des Weiteren wird auf die wichtigsten zu beachtenden Aspekte von Automatisierung für menschliche Arbeitskräfte und wirtschaftliche Bestrebungen einer Unternehmung eingegangen. Zuletzt werden aktuelle Herausforderungen für das betrachtete Segment aufgezeigt, da die Motormontagelinie des Segments P3 in den Jahren 2016-2018 eine Umstellung auf eine Evolution des bisherigen Motors erfahren wird.

Unter diesen Prämissen wird ein Handlungsleitfaden vorgestellt der sich zum Ziel setzt Automatisierungspotentiale in der Motorfertigung des Segments P3 bei AUDI HUNGARIA MOTOR Kft. aufdecken zu können, diese zu vergleichen, die Umsetzung zu unterstützen und wirtschaftlich zu bewerten. Der Handlungsleitfaden stellt eine einheitliche, nachvollziehbare Methode zur Umsetzung und Bewertung von möglichen Automatisierungsprojekten dar und beinhaltet die für den betrachteten Bereich wichtigsten Entscheidungskriterien.

Schlussendlich wird der Leitfaden an einem praktischen Projekt getestet um dessen Aussagekraft und Durchführbarkeit zu beweisen. Durch die Umsetzung dieses Vorzeigeprojekts konnte die Gültigkeit des Handlungsleitfadens bewiesen werden und zukünftige Automatisierungsprojekte sollen sich an diesem orientieren.

Abstract

The automotive industry, historically, has a tradition of implementing technological innovations in the production processes as one of the first. Especially industrial robots were widely used from the start for different manufacturing tasks, supporting humans at work-intense production steps and assuring repeatable quality in the process. Their field of application has spread broader over time, for example, the car body shop or the paint-spray line at AUDI HUNGARIA MOTOR Kft. is almost fully automated. At final assembly lines, like the regarded engine assembly line, on the other hand, the degree of automation is still on the low-end side. This is owed to the very complex tasks at final assembly, requiring fine dexterity and other abilities only humans can provide. Recent technological innovations in the field of robotics and innovative new safety applications, however seem to allow for a new field of application for robots. Special lightweight robots are being developed, created for work in close proximity to humans. This might pave the way for true human robot collaboration where strengths of both can be capitalized on.

By analyzing the lines of the regarded segment and interviewing involved stakeholders the importance of a structured approach for handling these new technologies came to light. A benchmarking analysis involving other segments in the plant helped deriving the most important criteria and challenges for any new automation project. These findings are used to establish an operational guideline for future automation projects involving new technologies.

This thesis shines a light on the historic development of automation in production processes all the way to recent technologies and ways of production summarized under the term Industry 4.0. Further-on the most important impacts of automation on the human workforce are described taking demographic change and labor costs into consideration. Finally, challenges and opportunities for further automation at the regarded engine assembly line at AUDI HUNGARIA MOTOR Kft. are explained and pending changes of the production portfolio analyzed. This line will face major restructuring in the years 2016-2018, since the next generation successor of the current engine type will be introduced.

As a result, the described operational guideline for automation opportunities at the line is introduced, assessing all major criterions these types of projects hold. The guideline helps evaluating different stations, comparing them and economically judging them for their potential for automation. The aim is to achieve a uniform and holistic standard for dealing with.- and assessing individual assembling stations in terms of automation.

Ultimately, the operational guideline is tested on a practical example in order to test and validate its functionality. By establishing this trailblazer project, the guideline’s validity could be proven and further application could be decided on.

Preface

Diese Arbeit ist während meiner Tätigkeit als externer Mitarbeiter in der Abteilung G/P3 bei AUDI HUNGARIA MOTOR Kft. in Györ, Ungarn, entstanden.

Ich möchte mich sehr herzlich bei allen Personen bedanken die mich bei der Entstehung der vorliegenden Arbeit unterstützt haben und ohne die ein erfolgreiches Abschließen nicht möglich gewesen wäre.

Ein besonderer Dank gilt dem gesamten Segment P3 und dessen Leiter Herrn Tibor Czingráber für die Unterstützung nicht nur im Themenfeld der Masterarbeit sondern auch für die Einblicke in AHM und die gesamte Motorenproduktion. Herzlichen Dank auch an Szablocs Kudomrák, dem Leiter der Rumpfmotormontage und Herrn Zsolt Heszler, der mir wichtige Informationen im Bereich des Controlling so einer großen Firma näher gebracht hat.

Besonders möchte Ich mich bei Herrn Dipl.-Ing. Dr.techn. Jochen Kerschenbauer bedanken durch dessen kompetente Betreuung diese Arbeit überhaupt erst möglich war.

Abschließend möchte Ich mich bei meinen Eltern, meiner Tante, meinen Großeltern und meinen Schwestern bedanken die mich das gesamte Studium hinweg unterstützt und gefördert haben.

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1 Introduction

This chapter includes the corporate presentation of AUDI HUNGARIA MOTOR Kft. and the background of the area of focus this master's thesis is dealing with. Further, it describes the research methods used to answer formulated research questions as well as the scope, objectives and a brief outline of the thesis.

1.1 About AUDI HUNGARIA MOTOR Kft.

The history of AUDI HUNGARIA MOTOR Kft. (hereafter AHM) starts with the foundation of a 100-percent subsidiary of the AUDI Aktiengesellschaft (AUDI AG) in 1993 in Györ, Hungary. The main focus was the engine production for both the AUDI AG and other companies within the Volkswagen Group. Continuous investments and expansion led to the fact that today (as of 2014) AUDI HUNGARIA MOTOR Kft. is one of the most important foreign investors in Hungary and one of the biggest employers of the region, currently employing over 11.000 people on an area of approximately 4.000.000 m2 (Gábor, 2014, pp. 9-10). The facility can be seen in figure 1.

Figure 1: AUDI HUNGARIA MOTOR Kft. facility (Gábor, 2014, p. 10)

The fields of work and competencies were simultaneously increased with investments, now including four main activities which are engine production, car production, tool shop and technical development. By adding these fields to the plant, AHM became a full automobile production plant. Annually over 160.000 automobiles are completely produced in Györ by types Audi TT Coupe, the TT Roadster, the Audi A3 Sedan and the A3 Cabriolet (Gábor, 2014, p. 16 & passim).

1.2 Background – Engine production

The area of focus of this master's thesis lies within the field of engine production. Starting in 1994 with only one type, nowadays almost the entire range of AUDI engines comes from Györ, supplying 30 different sites of the Volkswagen group worldwide. Annually about 2 million engines are produced at this plant, making AHM the largest engine factory in the world (Gábor, 2014, pp. 18-19). The most important facts about engine production in Györ are summarized in table 1.

Facts (as of 2014)	Data
Production capacity engines per day	8.850
Number of engine variants	216
Number of engine parts	14.400
Customers (production sites of the VW group)	30
Direct employees	4.464
Indirect employees	1.483

Table 1: Overview Engine Production (2014) (Gábor, 2014, p. 18)

These impressive numbers of variation require a clear segmentation within the production. Each engine type has its own production and assembly line. A basic structure of the different departments can be seen in figure 2.

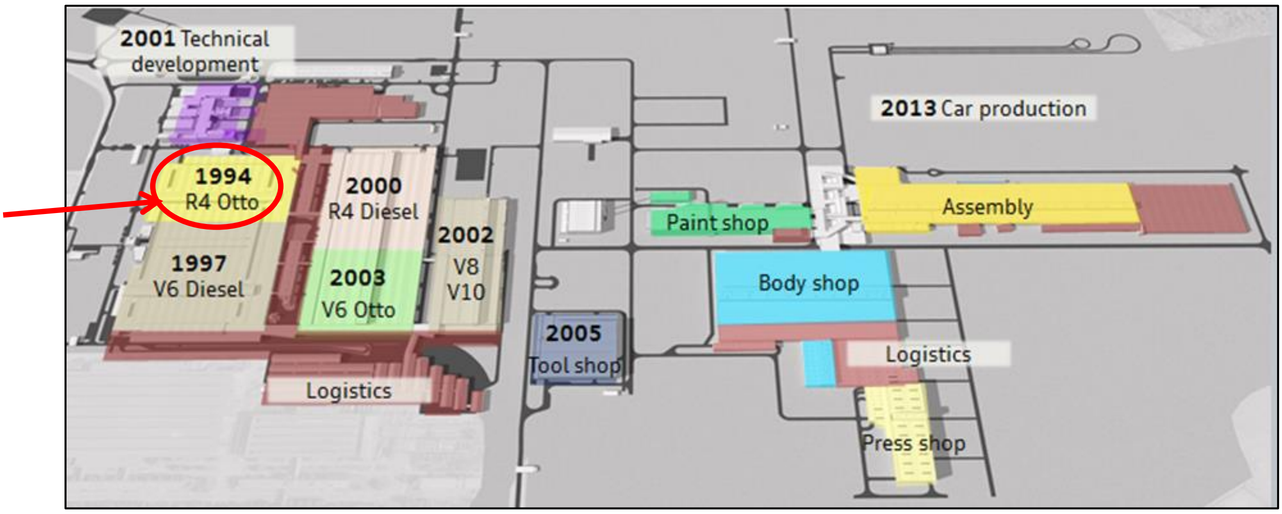

Figure 2: Structure of the company (adapted from: Czingráber, 2015, p. 3)

For further discussion of the production flow, manufacturing and finally the engine assembly line, this work deals with the department G/P3, currently responsible for the product segment of R4 Otto EA211 engines, marked red in figure 2. A detailed analysis of the assembly line will be conducted and pending changes and plans for the production line will be discussed in this thesis.

1.3 Introducing Segment P3

Production line EA211 R4 Otto engine is managed by segment P3, headed by Tibor Czingráber. Currently the P3 department manufactures and assembles three variations of the EA211 R4 Otto engine family, which is planned to be replaced over time by its successors, the EA211 EVO family. The starting point will be the introduction of a 1,5 liter 4 cylinder engine in 2017, followed by a 1,0 liter 3 cylinder engine in 2018. Altogether 671 people are working for this production line, of which 623 are directly involved in the manufacturing or assembling process. The depth of production goes as deep as in-house manufacturing of the engine block, the cylinder head, the connecting rod as well as the crankshaft (Czingráber, 2015, p. 7 & passim). Depicted in figure 3, is the basic setup of the manufacturing and assembly line.

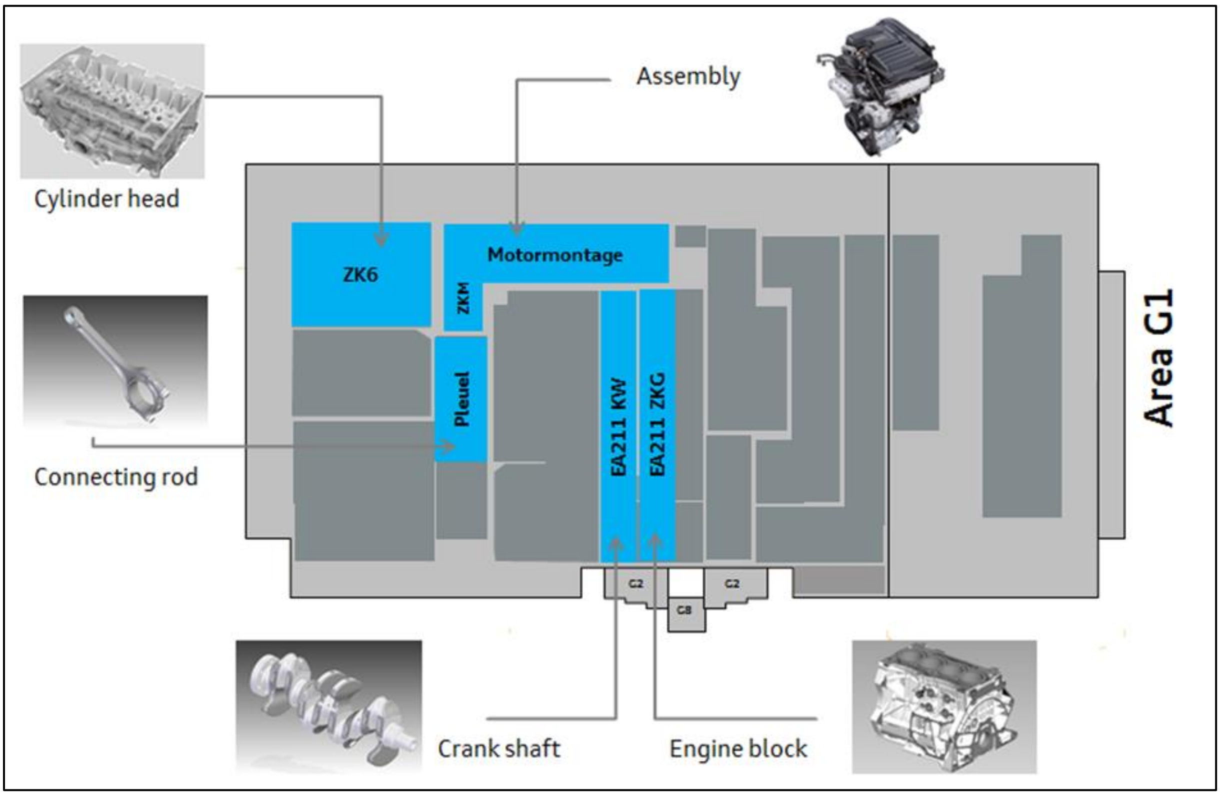

Figure 3: Layout of the construction and assembly line EA211 R4 Otto (adapted from: Czingráber, 2015, p. 14)

It can be seen that logistics of manufacturing for the in-house manufactured parts is process-chain oriented. Each manufacturing line runs inward towards the assembly line of the engine. This layout ensures the avoidance of long routes of transportation of required parts. Another important goal is the elimination of wasteful interim storage, for only those parts are available at the end of the line that are further processed in the engine assembly (Audi MediaInfo, 2015, p. 9).

1.4 Scope

The production lines of the EA211 R4 Otto engine will undergo massive restructuring in the next few years. These include the rearrangement from production of the existing engine to its next generation successor, so called *EA211 R4 Otto EVO,* as well as the introduction of a completely new three-cylinder engine at the same line, the *EA211 R3 EU6ZD*. Currently this segment produces just over 350.000 engines per year. The restructuring of the production line, especially the planned introduction of the new engines comes with challenges for both planning and construction, in the fields of personnel, machines, layout and automation. Pending changes to the current engine assembly line of EA211 R4 Otto require a thorough analysis of the existing line, in order to detect challenges for implementing the changes in late 2017. By using both theoretical and empirical data, differences will be pointed out and possible difficulties will be brought to attention at this stage of the project. Further on prerequisites for further automation in the assembly line will be identified, taking into consideration the location of the plant and demographic development in industrial countries. For this part of the project, costs and socio-economic effects will be discussed. Finally, methods and solutions for handling the challenges will be presented in more detail and an operational guideline for further automation projects will be generated.

1.5 Area of Focus

The focus is narrowed down to the engine assembly line of segment P3, however the results presented in this thesis will be universally applicable to different lines. Segment P3, responsible for the engine production of the EA211 R4 engine, has been shortly presented in subitem 1.3 Details about the existing and future plans for the assembly line will be discussed in chapter 3.1.

1.6 Objective Target

In order to handle the topic of this thesis, research questions have been constructed. The aim of the research questions is to structure the topics of this thesis to fulfill its ultimate purpose. The research questions are:

a. What is the structure of the existing manufacturing line and how can changes be implemented smoothly?
b. Are costs for further automation justified in low wage countries, considering demographic developments?
c. How can new automation technologies, such as lightweight robots, assist humans effectively at a workplace?

In the first part of this thesis the question “Why?” shall be answered. What is the background of further engine downsizing? What are the drivers behind further automation in engine manufacturing, including an analysis of industrial revolutions up until Industry 4.0, and how it will affect future workplaces? Using the case study of AUDI HUNGARIA MOTOR Kft., the second part will deal with the "How?". How is the engine assembly line affected, and how to implement changes? Is it feasible to conduct further automation at AHM?

1.7 Methodology

To find feasible answers to the overall research questions both primary and secondary data were collected for this thesis. Secondary data includes sources like statistics, scientific papers, databases, books and the internet. The gained knowledge has been carefully evaluated and assessed for its relevance for the challenges described in this thesis. Primary data was mainly collected by semi-structured qualitative interviews and company literature resulting from personal contacts and access to the company's internal database. Another important source for data was a benchmarking analysis of current projects within the AHM plant, this method is also known as internal benchmarking.

1.7.1 Semi-Structured Interviews

Literature often distinguishes three different types of interviews, open, structured and semi-structured interviews. Open interviews are characterized by a simple initiatory question followed by an elaboration of the interviewee without too much interference of the interviewer. These types of interviews have a preferred application in psychological fields for they allow a completely open narration of the interview partner. The structured interview on the other hand can be regarded as inflexible concerning the course of the interview. A fixed set of questions is being worked through according to a prepared catalogue, deviation is usually not desired (Weßel, 2010, p. 929). The semi-structured interview style is characterized by an overall outline, as to where the interview is supposed to be headed. This is supported by preparation of a key outline and some key questions. Depending on how the interview is developing some topics can be addressed in more detail and an open discussion can evolve (Bryman & Bell, 2011, p. 467). According to Christa Weßel (2010, p. 930) a typical setup for such an interview consists of eight steps:

1. Identification of the interview partner
2. Setting up a date
3. Preparation
4. Conduction of the interview
5. Additional notes
6. Documentation
7. Data evaluation
8. Report

Due to the above mentioned reasons the semi-structured interview style has been chosen to obtain qualitative information on the project. For the interviews conducted in this thesis a checklist of topics that needed addressing was prepared for each of the different interview partners and later on was revised by transcribing a minutes of the meeting. This showed as especially useful for comparing different information gained from different departments, since the interview style encourages interviewees to freely discuss opinions, interesting inputs from the diverse departments to all topics could be gained. Departments involved were planning, controlling and production, each of which have their own approach and viewpoint when the realization of a new project is handled. Later the collected information has to be checked for relevance and the individual minutes of the meeting were compared.

1.7.2 Internal Benchmarking

Benchmarking, according to literature, has many different definitions depending on the purpose it should fulfill. Gabler's dictionary of economics (2016) defines it as an instrument for competitor analysis to be able to make products, processes, services or methods comparable. Further, it is seen as a tool for learning which differences exist and in where room for improvement can be found. The five steps of the benchmarking process listed in the dictionary of economics (2016) are:

1. Selection of the object (product, process, method) that shall be compared
2. Selection of the comparing institution (comparability needs to be ensured)
3. Collection of data
4. Identification of distinguishable characteristics
5. Definition of measures to be taken

The benchmark can be seen as the "what", or the subject that should be analyzed and benchmarking as a tool should describe the "how", or the way the issue is tackled (Stroud, n.d.). Internal benchmarking can be seen as a special type in the definition of benchmarking as a whole and is a vital source for data in a big plant like AHM and. Due to the size of the company, different lines individually work on different solutions for common problems. The flow of information however can be non-transparent and often, good solutions stay within the boundaries of each organizational unit. That is the reason why internal benchmarking was chosen as an appropriate method for gaining important information existent solutions within the plant. One of the liberties of writing this thesis was to have the opportunity to collect data from several lines and examine them for best-practice concepts. Other departments share the issue of implementing more than one engine model on an existing engine manufacturing line, as well as the challenge of reaching a higher level of automation at an engine assembly line. For research purposes, internal benchmarking at the engine assembly line of segment P4 Global Engine was conducted in this thesis. The data collected will be presented in chapter 3.3 of this thesis. The ultimate goal of this benchmarking study was to deduct decision variables as of what are the most important points to take into consideration before implementing an automation project at the line, and profit from the experiences that were made at other lines. Segment P4 was chosen for their variety of existing and planned automation projects as well as their cooperation with the renowned research institution *Fraunhofer Institute for Manufacturing Engineering and Automation (IPA)*.

2 Theoretical Basics

This chapter includes a definition of the terminology and theoretical framework of this thesis. In the first part of the theoretical background of this thesis the development of industrial revolutions leading to Industry 4.0, the so-called fourth industrial revolution will be discussed briefly. This shall provide an understanding as of why technological advancements in production systems are necessary and indispensable and how they have affected societies in the past. Next, a study of industrial robots and new technologies, like lightweight robots is performed including important safety aspects and existing work safety standards. Then the impact of ongoing automation on the workforce will be reviewed, including the demographic development in industrial countries. Further on a cost comparison of labor costs in Hungary and investment costs for automation robots will be presented. Finally, the underlying reasons for engine downsizing will be carved out to better understand the agenda behind the ongoing changes in segment P3.

2.1 Stages of the Industrial Revolution

A retrospection at previous stages of the industrial revolution can give a deeper understanding of how the everlasting intention to raise productivity, and the technological developments it is accompanied by, will inevitably lead to a next so-called industrial revolution (Bauernhansl, ten Hompel, & Vogel-Heuser (eds.), 2014, pp. 5-9).

- The first stage of industrial revolution occurred during the second half of the 18th century with the development of the steam engine. For the first time mechanical production facilities could be realized and huge factories arose because energy supply became independent in terms of quantity, time and place. The steam-power driven machines allowed a rise in productivity and mobility, therefore impacting both industry and society at the same pace, turning society from agriculture to industry based.

- The second stage of industrial revolution took place approximately 100 years later, impacted by two major developments. One of them was the concept of mass-production facilitated by electrically powered conveyor belts, the other one was an organizational development, best known as Scientific Management or Taylorism, defined by aspects like separating blue.- and white collar work or division of labor.

"Any customer can have a car painted any colour that he wants so long as it is black."

Henry Ford

(Remark about the Model T in 1909)

This quote by Henry Ford suitably describes the concept of mass production during the second stage of the industrial revolution.

- The so-called Digital Revolution, or third industrial revolution started in the 1970's and was driven by developments in electronics, information- and communication technologies. Production processes were further automated and a shift in market orientation took place from producer oriented.- to consumer based markets. The demand for individual customization had surged and the idea of mass production was slowly replaced by the concept of mass customization. At this time industrial robots became relevant for the first time in a large scale in the field of manufacturing.

Recent technological developments paved the way for a completely new understanding of industrial production and production systems. Trying to describe all these advancements and possibilities in one term, a group of German experts initiated the term Industry 4.0 in 2011. Nowadays it is widely accepted, defining a new era in industrial production. It is irrelevant whether or not we call it the fourth industrial revolution as some adversaries may dispute, the progress and technologies have entered not only everyday life, but also production plants like AHM (Bauernhansl, ten Hompel, & Vogel-Heuser (eds.), 2014, p. 5). The four stages of industrial revolution are illustrated in figure 4.

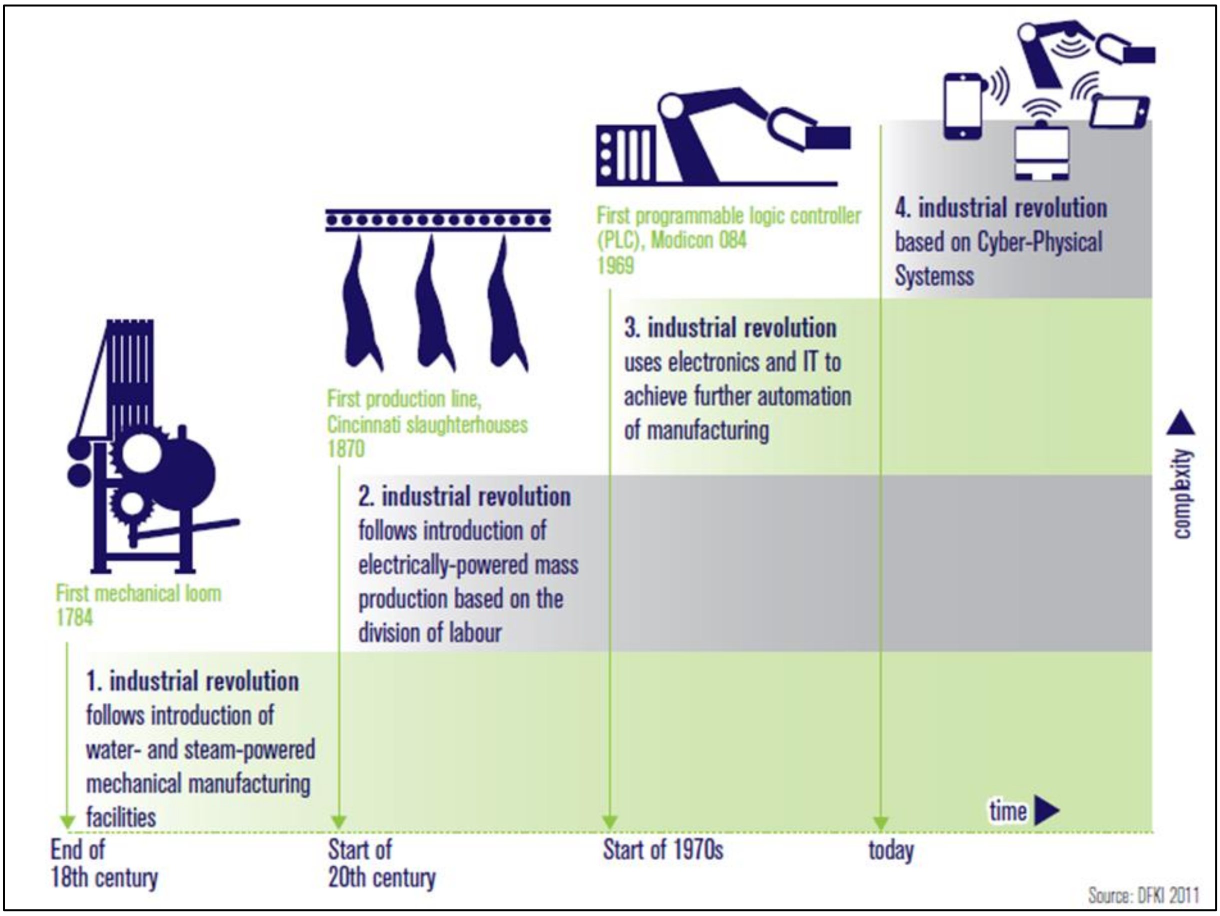

Figure 4: Four stages of Industrial Revolution (Kagerman, Wahlster, & Helbig, 2013, p. 13)

This timeline appropriately shows the impact of technical innovations on our understanding of production systems. Each of the four steps is accompanied by a major technical invention of its time. What can be further deducted is that complexity is ever rising and at the same time the time passed between new systems is shortening between each revolution. This indicates the importance for companies to adapt to new systems fast so they don't fall behind, as well as the fact that an accelerated rise in complexity makes it all the more important to be able to handle the opportunities provided by technology.

2.2 Fourth Industrial Revolution

As indicated earlier, in order to characterize the impact of technological progress of our time, like the internet or smart communication devices on manufacturing systems, eventually the demand to create a new term, Industry 4.0, existed. Key components of this alleged fourth stage of the industrial revolution are, *Cyber Physical Systems (CPS)*, *Internet of Things, Internet of Services* and *Smart Factory*. These four terms are closely interlinked and make up the idea of a completely new way of production. Incorporated in the Smart Factory is the Cyber Physical System, which can be seen as the hub to outside influences, while Internet of Services and Internet of Things, intelligently provide information and a connection to customers and products (Kagerman, Wahlster, & Helbig, 2013, p. 14). Illustrated in figure 5 is a possible future scenario for production systems.

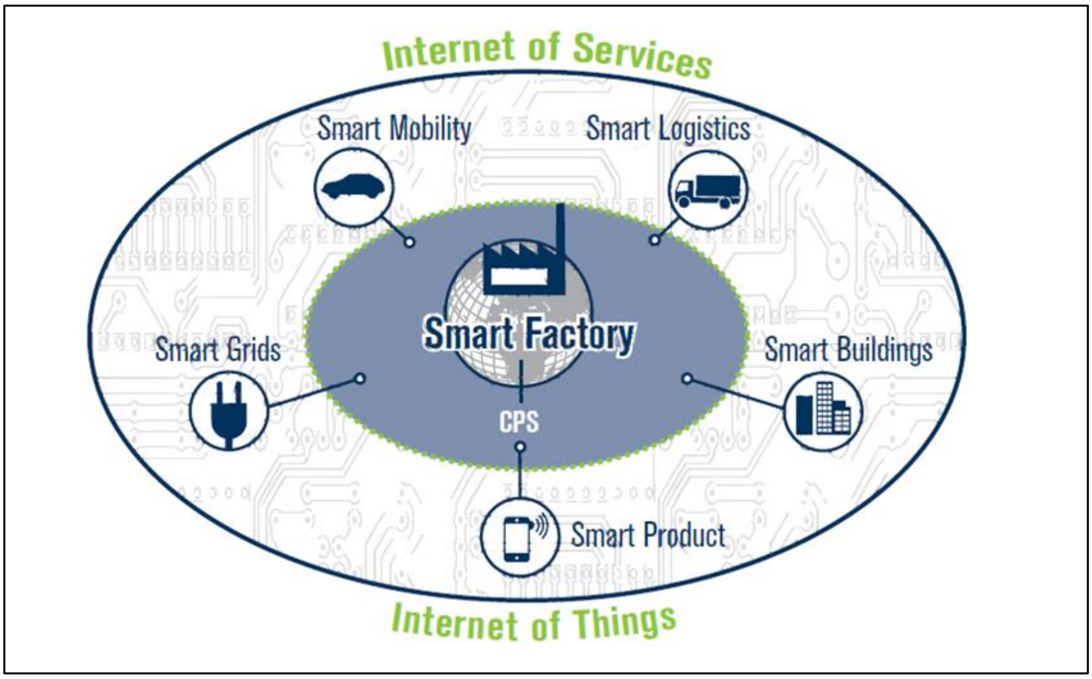

Figure 5: Cyber Physical Systems and Smart Factory (Kagerman, Wahlster, & Helbig, 2013, p. 19)

Cyber Physical Systems are per definition the integration of processes of the virtual and physical world. Simultaneously they can influence one another through feedback loops in real time and are communicating through platforms like the internet. Eventually there is no more clear segmentation of embedded and IT systems. The realization of CPS in the manufacturing industry is called Cyber Physical Production Systems (CPPS). Aspects of the so-called smart factory of CPPS include everything from inbound logistics, smart machines, warehouses to suppliers and finally the customer. Using a fully integrated Cyber Physical System in production may help accomplish a greater flexibility in regard for customer wishes and production planning. With its help, customer requirements like design and configuration can be involved in several operational stages, and last-minute changes can be incorporated. This real-time communication and reaction of the entire process chain could ultimately lead to a desired profitable batch size one. However, at this time, integrating CPS into manufacturing industries is a great challenge for both the industry and logistic systems behind it. Connecting former isolated systems like production.- and mechanical engineering, automation engineering, IT and the internet, to one homogenous union will take huge effort and time. Finally, one must not forget the security issue, such an interactive system is vulnerable to any sorts of hacker attacks or system outages (Kagerman, Wahlster, & Helbig, 2013, p. 14).

2.3 Motivation for further Automation

Evidently, development in technologies have influenced the way societies interact and therefore how production processes are organized. It is human nature to search for new ways to facilitate manual labor and to best allocate resources, this is where automation is getting involved. Historically automation derives from the Greek word *automatos*, which means acting by itself or by its own will. For this thesis deals with engine manufacturing, the focus will lie on industrial robots and automation stations in automated lines who's task of right now is to perform certain activities, or chains of activities without human interference (Y. Nof (ed.), 2009, p. 14). Springer Handbook of Automation (2009, p. 24) lists the seven most important motivations for automation:

1. Feasibility- Tasks a human worker cannot perform
2. Productivity- Mostly repetitive tasks can be performed at much higher speeds
3. Safety- In unsafe environments robots can substitute humans and prevent them from dangerous exposures
4. Quality and economy- Quality can be improved by having low deviation in production, thus saving costs for errors
5. Importance to organization- Reduced need for human "middle-man", savings on bureaucracy, taking tasks from human so that they can focus on more challenging tasks
6. Accessibility- Help for humans with disability to interact in society
7. Additional motivations- conveniences and life quality improvement

These seven reasons speak for increasing automation in general, since the underlying purpose of automation is to make life easier for humans, increase working conditions and quality of life, while at the same time performing high precision tasks. Besides all this, more automation has an interesting side effect, the attempt to eliminate humans from an automated system actually increases their significance in control processes. Therefore, the fear of robots or machines taking human labor is only justified partly. In fact, humans and automated machines can complement each other in an excellent way (Bengler, 2012, p. 28). The following chapters will shine a light on how this could be achieved.

2.3.1 The Field of Robotics

According to Springer Handbook of Automation (2009, p. 17) modern automation can further be split into three basic groups, being computers, automation including robots and classical robotics. Therefore robotics can be seen as a sub-group of automation. Although they are also programmed to execute predefined tasks automatically, their field of application lies in more flexible and precise operations mostly aiming to automate motions.

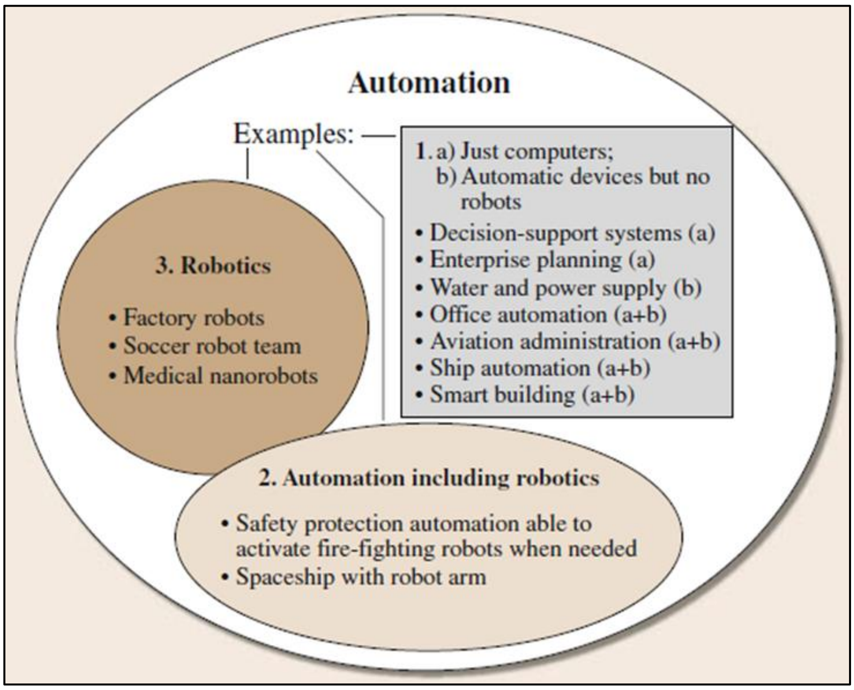

Figure 6: Correlation of Robotics and Automation (Y. Nof (ed.), 2009, p. 17)

As seen in figure 6, general robotics per definition still includes a broad spectrum of different applications, from factory robots to medical nanorobots. Therefore, robots especially for manufacturing purposes were defined as so-called industrial robots. Their tasks in engine manufacturing typically include drilling, welding, screwing and picking and placing of work pieces. Their big advantage lies within flexibility, simply by changing the programming by the operator a new task can be performed (Y. Nof (ed.), 2009, p. 17). For further discussion in this thesis the focus will be narrowed down to industrial robots and lightweight robots.

2.3.2 Industrial Robots

Industrial robots are defined by ISO Norm 8373:2012 as:

“automatically controlled, reprogrammable (2.4), multipurpose (2.5)manipulator (2.1), programmable in three or more axes (4.3), which can be either fixed in place or mobile for use

in industrial automation applications" (ISO, International Organization for Standardization, 2012)

This definition includes the main advantages of industrial robots and their importance for production systems. They are reprogrammable and therefore applicable in more than one way, making them a powerful partner for certain production steps. The specific characteristics of industrial robots described in this definition are achieved by splitting it up in several partial systems being:

- power unit
- measuring system
- tools and/or gripper
- control unit
- sensors
- kinematics

The power unit is responsible for transferring energy for movement to the diverse axis. To determine the right amount of energy the measuring system assigns speed and necessary movements to the power unit. Depending on the task, diverse tools or grippers can be used to fulfill the actual main work of the robot, which are monitored by the control unit. The control unit is furthermore responsible for communication between the host system and the robot and implementing a smooth program sequence. Sensors are used to identify and localize work pieces and measure dimensions and conditions of them. Kinematics for industrial robots establishes spatial allocation of the tool, the work piece and the production facility as well as the guidance of the tool (Gevatter & Grünhaupt (eds.), 2006, p. 743). The allocation of joints and chain-link elements are primarily responsible for the setup of kinematics of industrial robots and their possible feasible movements. According to the different kinematics, robots can be distinguished from one another. Some of the main groups are cartesian robots, SCARA robots, delta robots and articulated arm robots, each differing in the number of axes and degrees of freedom. (United States Department of Labor, n.d.) Cartesian robots are able to move along three linear axes and therefore are able to operate in a prismatic workspace. SCARA robots (selective compliance assembly robot arm) can operate in four distinct axes allowing a cylindrical operating space. Delta robots are a special form of parallel robots, where, between 3 and 6 axis, are fixed parallel to one another, providing them with high stiffness but at the same time limiting the workspace significantly (Bouchard, 2014). However, when speaking about industrial robots in manufacturing, most commonly a robot arm comes to mind. Their setup can be described as a verticulary-articulated arm with six or more degrees of freedom, allowing both rotatory and translatory movement along the axis (Gevatter & Grünhaupt (eds.), 2006, pp. 743-746). A standard 6-axis industrial robot in engine manufacturing typically follows a setup of six main components, the wrist, the arm, a link arm, a horizontal rotating system, electric installations and a base frame. The axes provide additional ranges of movement which in turn can be described as degrees of freedom, so a six-axis articulated robot arm consists of six individual joints providing twisting and rotatory movements (KUKA Roboter GmbH, 2015, p. 14).

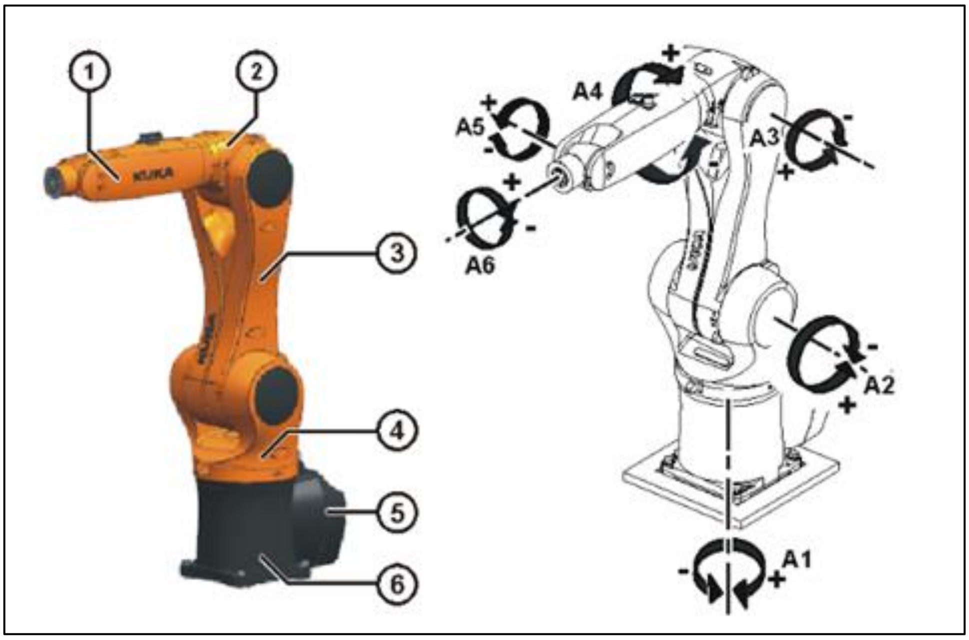

Figure 7: Main Components including Directions of Rotation of a Robotic Arm (KUKA Roboter GmbH, 2015, p. 10 & 17)

Illustrated in figure 7, KUKA Roboter GmbH further defines the specifications of such a robot and the allocation of the axes for a *KUKA “KR Agilus sixx”* robot in their specifications which can be seen as an accurate representation of these types of robots (2015, pp. 10-11):

1. Wrist: The wrist includes axes A5 and A6 where A5 can raise or lower the wrist up and down and A6 can rotate it circular.
2. Upper Arm: The upper arm can be rotated circular by axis A4 and moved up and down by axis A3.
3. Lower arm: The forward or backward movement is performed by axis A2 at the end of the lower arm of the robot.
4. Horizontal rotating system: Here the rotational movement of axis A1 can be performed.
5. Electric installations
6. Base frame

The motivations for using industrial robots are similar to the ones mentioned in subitem 2.3. Most important to mention are economic aspects such as, reduction of labor costs, increased productivity & quality and higher efficiency, and humanitarian reasons like, unacceptable operation processes and unbearable working conditions (Y. Nof (ed.), 2009, p. 24). The influencing factors of industrial robots on process automation can be categorized in four major groups, technical effects, economic effects, ecologic effects and social effects (figure 8).

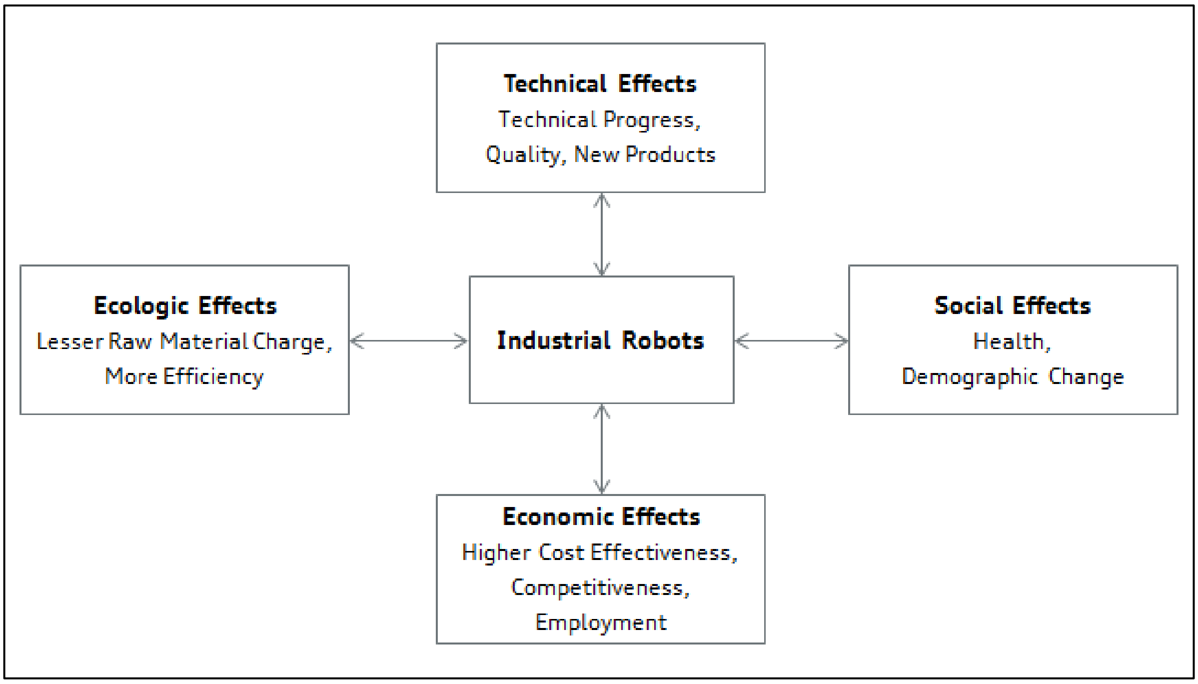

Figure 8: Industrial Robots - Influencing factors (own illustration: Y. Nof (ed.), 2009, p. 23)

Due to the numerous advantages industrial robots offer, the automotive industry was one of the first industries to implement them on a large scale in production processes. The first industrial robot used in automotive industry was the *Unimate* developed by George Devol and Joseph Engelberger and was sold to General Motors in 1961. Following decisive progress in mechanical construction and electronics, robots quickly became faster, more precise and more flexible. They especially helped to increase productivity and manufacture stable quality products. With these developments a quick expansion took place and automotive sector is still a pioneer when it comes to application of automation in production processes (Haun, 2007, pp. 11-12). This fact can be best seen in an illustration of the robot density in the automotive sector compared to general industry (figure 9).

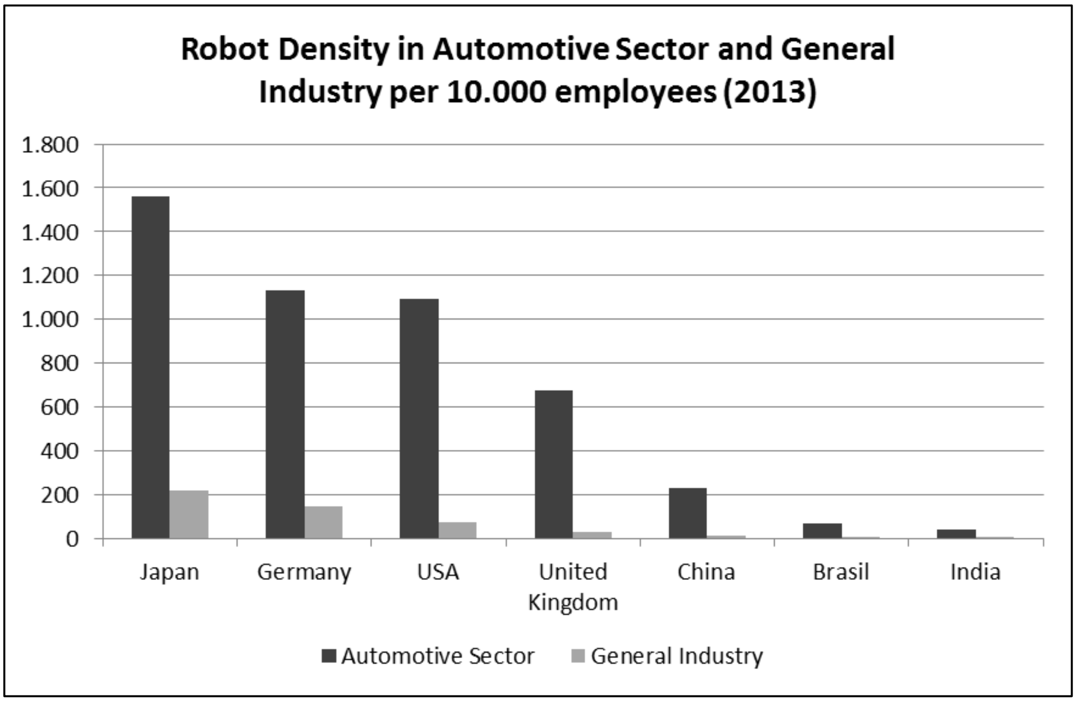

Figure 9: Robot Density in Automotive Sector and General Industry (2013) per 10.000 employees (adapted from: KUKA, n.d.)

Correlating to labor costs, described in subitem 2.4.2, the density of industrial robots is highest in western industries like Japan, Germany and the United States. In Germany for example per 10.000 employees in the automotive industry 1.133 Robots are carrying out construction tasks. This number is only surpassed by Japan where traditionally the highest usage of robots is established. Figure 9 also illustrates the gap between robot-usage in general industries and the automotive sector, although 147 robots per 10.000 employees in general industries in Germany is still a comparably high value, no other industry comes close to the automotive sector. Since the introduction of the *Unimate* in 1961 industrial robots have been widely applied in automotive industry and their abilities have vastly increased in the past decades. Main sectors of application remain however heavy duty work in the car body production such as welding, spray painting and material handling. Current developments in robotics involve a lighter constructional structure and will be described in the following subitem.

2.3.3 Lightweight Robots

Strengths of conventional industrial robots are high resilience, constant speed and high precision. Due to these characteristics the construction needs to be robust and therefore rather massive and bulky influencing the necessary features of the environment they are applied in. Safety regulations require such robots to be protected from interaction with co-workers to avoid collision and injuries. Lightweight robots on the other hand are constructed in a way that their mass is reduced vastly opening new possibilities for implementation in the working environment. By reducing the mass and providing the robot arm with intuitive sensors an application without safety fences is possible even in close proximity to human beings at an assembly line (Bauernhansl, ten Hompel, & Vogel-Heuser (eds.), 2014, pp. 110-111).

Lightweight robots are relatively new on the market, however all major robot manufacturers are putting immense efforts into the development of this new technology hoping to reach a broad spectrum of new customers and opening completely new doors for production systems (Frutig, 2013, p. 44). According to *technica magazine* (2013, p. 44) finding an adequate definition for lightweight robots is not easy, but producers agree on several characteristics:

- Light enough for one person to carry (max. 30 kg)
- Easy to use operating interface
- Simple programming via touchscreens (even smartphones or tablets)
- High degree of safety systems (sensors, collision control) to ensure operation without fences
- Meet EN ISO 10218-1:2006 requirements to enable safe human-robot-collaboration

An overview over the current market situation in robotics gives an idea how leading manufacturers see the future of robots in production systems (table 2).

Manufacturer (Source/Catalogues)	Type	Illustration	Load [kg]	Weight [kg]	Reach [mm]	Price [€]
KUKA (KUKA Roboter GmbH, 2016)	LBR iiwa		14	29,5	820	60.000
Fanuc (Fanuc America Corporation, 2015)	CR-35iA		35	990	1813	75.000
ABB (ABB Automation GmbH, 2015)	YuMi (IRB 14000)		0,5/arm	38	559	40.000
Universal Robots (Universal Robots, 2015)	UR10		10	28,9	1300	25.000

Table 2: Lightweight Robots - Market Overview

Regarded manufacturers are *KUKA*, *Fanuc*, *ABB* and *Universal Robots* each of which recently introduced their individual solutions to best meet the market requirements for lightweight robotics. It can be seen that when regarding the four characteristics load, weight, reach and price, big differences show. This concurs with the difficulty of finding a common definition for what such a robot shall represent. While KUKA and Universal Robots strictly stick to the 30-kilogram mark concerning weight, Fanuc's solution attempts to reach higher loads and reach, accepting a higher weight. ABB's YuMi on the other hand has two individual arms at disposal to perform precise, small part operations. Prices also vary dramatically from 25.000 Euros for the basic UR10 model, to 75.000 Euros for the Fanuc robot which according to the manufacturer is additionally a full industrial robot, already suggested by its high weight. The one thing all of them have in common is the high degree of safety implementation. Sensors are able to detect any contact with their surrounding immediately initiating an emergency stop as well as a rounded design avoiding sharp edges and potential sources for harm to humans. This suggests that what the producers aim for is a user-friendly robot able to interact with humans as a coworker, rather than a bulky robot protected by a cage. The trend definitely leads towards a higher degree of human-robot-collaboration, introducing robots as partners in production systems. The advantages and fields of application of such robots are collected in table 3.

Lightweight Robots	
Advantages	• Remote investment • Low space requirements • Lightweight construction • Collision Monitoring • Safe interaction (human-robot) • Flexibility (Movability) • High accessibility • Intuitive operation • Simple operating interface • Easy integration (plug & play)
Range of Application	• Pick & Place operations • Screwing tasks • Palletizing jobs • Profitable for small series • Jumper assignments (due to the high mobility and transportability)

Table 3: Lightweight Robots – Attributes

2.3.4 Human-Robot-Collaboration

The distinct abilities of described lightweight robots combined with technological advancements and a new way of understanding production processes (Industry 4.0) have opened the door for an even broader spectrum of application for robots in the automotive sector. This is furthermore facilitated by a shift in safety systems, away from traditional fences, towards motion and contact sensors controlling the entire spectrum of movement of the robot which allows an installation in close proximity to humans. The robot is viewed as a coworker, rather than a machine carrying out repetitive tasks, this development is regarded as human-robot-collaboration (VDMA, Verband Deutscher Maschinen- und Anlagenbau, 2014, p. 1). According to DIN EN ISO 10218-1:2006 clause 3.4 human robot collaboration is defined as*: "state in which purposely designed robots work in direct cooperation with a human within a defined workspace".* Stefan Thiemermann (2005, p. 43) describes and illustrates (figure 10) a truly collaborative mode of operation as a situation where no spatial or temporal separation is the case.

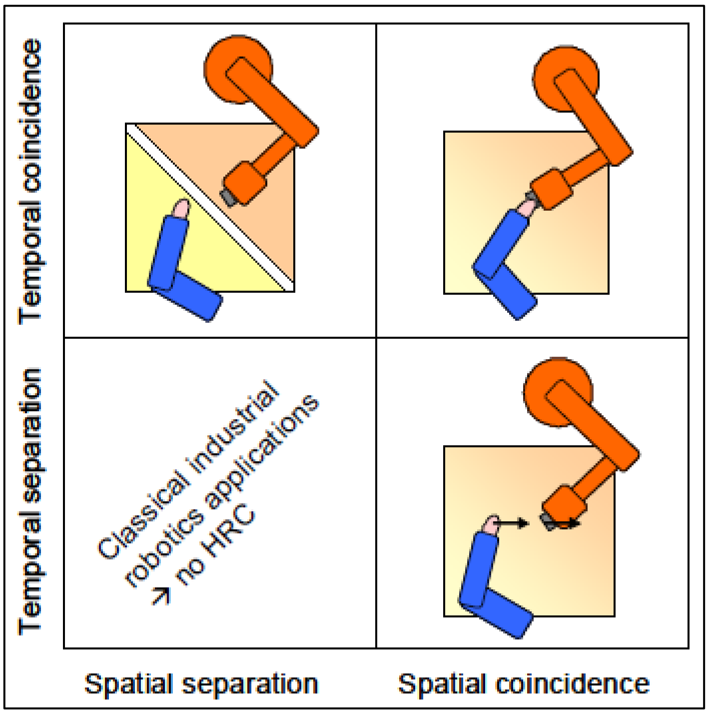

Figure 10: Definition of Collaborative Operation (Matthias, 2015, p. 4)[1]

The state of the art robotic system is defined by a clear separation of workspace and time for humans and robots. In such a system no human-robot-collaboration is allowed. In case the spatial separation is not given and both human and robot are working in the same area, a clear segmentation between the operating ranges needs to be made. If human and robot work at the same time but are still separated in terms of workspace, no restrictions are to be expected but a complementing working rhythm needs to be implemented. Full human-robot-

[1] Adapted from Thiemermann, S.: Direkte Mensch-Roboter-Kooperation in der Kleinteilemontage mit einem SCARA-Roboter, Dissertation, Stuttgart 2005

collaboration is only the case when humans and robots work in the same area at the same time preferably on the same work piece. In this scenario humans and robots are able to complement each other according to their strengths. Keeping in mind that both human and robot possess unique capabilities in their essence, a type of co-existence in the workplace can combine the strengths of both. These unique capabilities are listed in figure 11, by overlapping them, big advantages for production systems can be achieved (Thiemermann, 2005, pp. 43-44).

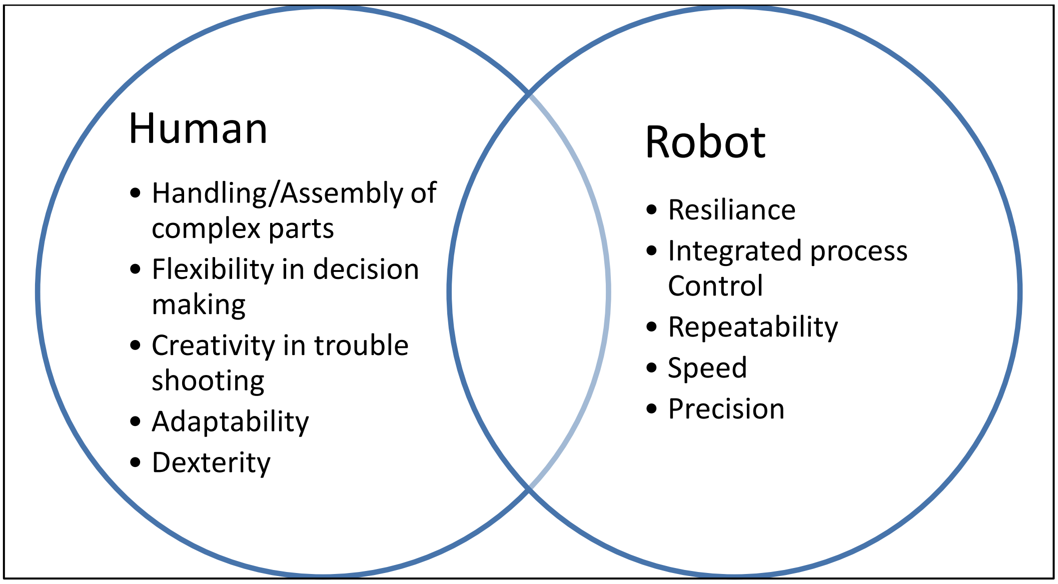

Figure 11: Strengths - Human/Robot (own illustration: Kossmann, 2014, p. 6)

Human's main advantages lie within our cognitive abilities enabling us to react to difficult situations and improvise to find new solutions for unforeseeable problems. In addition, our precise dexterity allows us to handle unshaped parts of all compositions. We lack however, abilities concerning repetitive tasks and are limited physically concerning strength and speed of operation. Robots can operate at high speed while at the same time delivering continuous quality and are able to automatically perform process control tasks. From an ergonomical viewpoint robots can assist with all kinds of heavy load work allowing humans to focus on more difficult and precise tasks (Matthias, 2015, p. 32). In order to be able to profit from such a close interaction between humans and robots, certain restrictions have to be made and several guidelines have to be followed. Subitem 2.3.5 elaborates on the current safety regulations for human-robot-collaboration.

2.3.5 Safety Requirements for Human-Robot-Collaboration

The current status of safety requirements for collaborating robot systems is still in the development phase. There are not yet enough precedents from industry to fully understand the risks, therefore human safety has highest priority and safety parameters are strict. Therefore, when in collaborating mode, robots have to work in a mode of power- and force limitation, only then an operation without safeguarding equipment, like gates or fences, is possible (DGUV - Deutsche Gesetzliche Unfallversicherung, 2015, p. 1). Fraunhofer Institute (2012, p. 32) summarizes the basic goals for general robot and machine safety in three points:

- The functionality of the machine needs to be secured
- The conditions for operation and target application need to be clearly defined
- Risks for the operator need to be adequately minimized

The challenge according to these points is, to profit from the usability of such a HRC system without compromising its functionality, while at the same time minimizing the risk of injury for the coworker. Therefore, in order to achieve both, the functionality of the robot and secure a safe working environment for the human worker, the *International Organization for Standardization* has published several norms to achieve a uniform understanding for HRC applications.

2.3.5.1 Legal Basics and Norms

Collaborative robot systems in general are under the law of the European Machinery Directive 2006/42/EC demanding producers to provide a CE-seal (Conformité Européenne) for any robot sold on the market. ISO Norms 10218-1 and 10218-2 are applicable in the same way, if applied it is assumed that the EC directive is complied and therefore redundant. This is called “presumption of conformity”. At this moment (2016) the norms are still being further developed, owed to the fact that the technology is rather new and a recent technical specification (ISO TS 15066) just came on the market in February 2016. In accordance with this technical specification the two mentioned norms will be reworked in the next couple of months (DGUV - Deutsche Gesetzliche Unfallversicherung, 2015, p. 1). When all aspects have been regarded the norms shall provide a standardized understanding for suppliers and integrators to help achieving legal requirements for HRC applications. These different norms and specifications cover the following content:

- EN ISO 10218-1:2008 Robots and robotic devices - Safety requirements for industrial robots - Part 1: Robots: The first part of this norm describes basic hazards associated with implementation of industrial robots and specifies requirements and instructions to help avoid risks related to them (DIN, Deutsches Institut für Normung, 2009, p. 4).
- EN ISO 10218-2:2008 Robots and robotic devices - Safety requirements for industrial robots - Part 2: Robot systems and integration: The second part of this norm specifies hazards occurring for the entire robotic system and differentiates between different types of automation and application of the robot. In contrast to the first part it regards the entire robotic system, which per definition includes tools, work pieces, materials handling and peripheries (DIN, Deutsches Institut für Normung, 2008, pp. 4-5).
- ISO TS 15066:2016 Robots and robotic devices - Collaborative robots: This technical specification is an addition to the earlier described norms. It specifies concrete risks occurring for collaborative industrial robot systems, explains different types of collaboration modes in more detail and provides information on what the focus of a risk assessment of such systems needs to be. Furthermore, it gives detailed information on

injury level data. While the two ISO norms are applicable to all types of industrial robots, this technical specification is only valid for HRC systems (International Organization for Standardization, 2016).

Two especially interesting aspects, described in the regarded norms are the definition of types of collaboration modes and the injury level data. The first one is described in EN ISO 10218-1:2008 and defines the different requirements necessary for human robot collaboration by distinguishing four basic scenarios (figure 12).

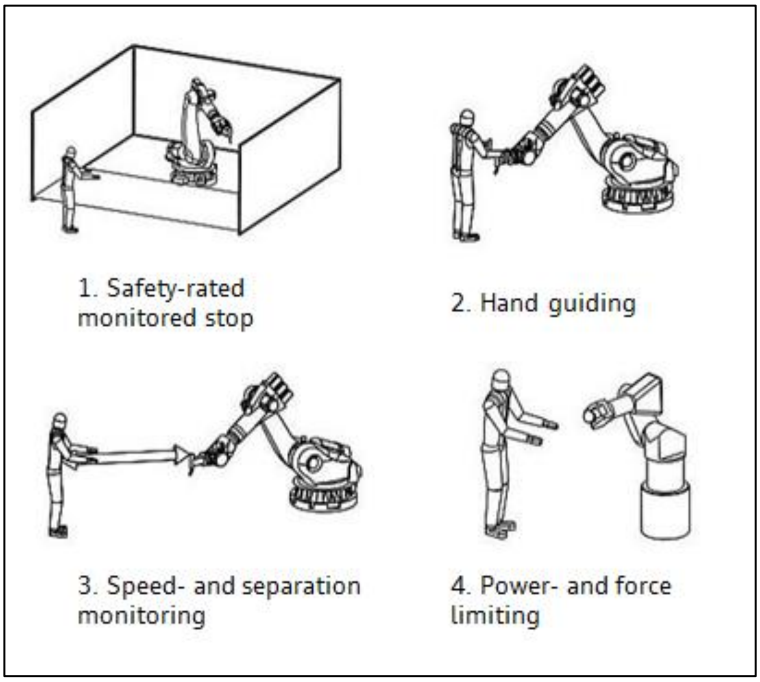

Figure 12: Different Scenarios for Human Robot Collaboration (adapted from: Kossmann, 2014, p. 7) & (DIN, Deutsches Institut für Normung, 2009, p. 19)

According to ISO Norm 10218-1:2008, the four different scenarios of human-robot-collaboration each require different examination in terms of safety features. The first one is a safety-rated monitored stop, meaning a complete stop when a human enters the collaboration area. The robot discontinues their work, resuming their work routine only when the human leaves the area. An example for this would be a manual loading-station. The second scenario is the human guidance of the robot arm. By grabbing a grip the human worker guides the robot through its various tasks, sensors make sure that the robot arms kinetic energy can’t surpass a defined limit. A possible application for this is the operation of the robot as an assisting device. The third scenario is based on speed- and separation monitoring, where sensors consistently measure the distance of the coworker to the robot, as soon as the safety distance is violated an automated mechanism is triggered forcing the robot to operate at reduced velocity under constant surveillance. This scenario can be applied for example when the worker has to perform replenishing tasks. The last described scenario for human robot collaboration at a workstation is based on power- and force limitation. Here the construction of the robot has to be done in such a way, that a maximum power of 80 Watt or a maximum static force of 150 Newton at the flange is not surpassed. In this scenario human and robot can both actively work on the same work piece. (DIN, Deutsches Institut für Normung, 2009, pp. 23-24). This is where the second above mentioned point, a big novelty of ISO TS 15066, injury level data follows up. University of Mainz, Germany, developed a chart analyzing levels of pain for collision scenarios with robots. Each bodily region is treated separately, defining maximum values for force and pressure exposure to the human body regions. Two approaches to influence these values are the design of the robot as such and the regulation of the movement velocity of the robot. The design can be realized so that sharp edges are avoided, the robot arm is capped or the impact surface is enlarged. By regulating the velocity in the programming step, forces can be limited as well, allowing to stay in the defined regulation parameters (Bélanger-Barrette, 2016). Another distinction has to made in terms of the type of contact, either a transient contact, or a quasi-static contact can be the case. Transient contact is characterized by a short collision event where peak forces and pressures can reach high levels, by decreasing the mass or increasing the contact area, harm can be avoided. Quasi-static collision events describe the case, where a body part is trapped by the robot at very small velocities, it is important that the worker can free themselves, peak forces and pressures are limited according to guidelines and contact duration is shortened to avoid injuries (Matthias, 2015, p. 13&18). In conclusion it can be summarized that a lot of research is done in the field of safe human-robot-collaboration, the new ISO technical specification provides adequate help to determine risks of the robot application and to design a safe working environment for the worker. The side effect is the tradeoff between performance characteristics of the robot and achieving an adequately safe working environment and meeting all safety regulations. The competences for a safe HRC can therefore be split among the partners, while robot manufacturers are responsible for sticking to ISO norms and specifications to produce a robot that is capable for collaborating, system integrators must use the ISO norms and specifications for generating the right robotic system for the specific intended use, conducting a thorough risk analysis for the complete application reaching from the robotic arm over the process and the moving paths to the end-effectors like grippers. End-users like AHM must be informed about the norms, but have to rely on the integrator to fulfill the specifications. They always need to make sure a CE marking is provided by the integrators (VDMA, Verband Deutscher Maschinen- und Anlagenbau, 2014, p. 3) & (Matthias, 2014, pp. 23-25).

2.3.5.2 Current HRC Safety Regulations at AHM

Audi Hungaria safety inspector Ferenc Szenftner (2016) describes the process of safety releases for human-robot-collaboration at the regarded plant as very complex due to its novelty and the lack of reference. There exists a general guideline for operation of machines, that is binding for human-robot-collaboration as well, but no specific one has been established as of now. Currently a guideline is being generated based on the strictest possible regulations so no risk of harm for the workforce will be taken. Bases are ISO Norms 10218 part 1 and 2 and the ISO/TS 15066 norm, published earlier this year. Common practice right now is to pass on requirements to suppliers and system integrators who are responsible for adhering norms and achieving a CE-seal so that AHM can rely on the supplied machines. When all regulations are met, the responsible safety inspector for the line checks the automated system according to a checklist and performs a risk assessment regarding function and range of application. The checklist includes the four collaboration scenarios described in subitem 2.3.5.1 and is based on the following characteristics (Beck, 2015, pp. 1-2):

- Documentation: e.g. Risk assessment, CE conformity declaration, certifications for safety functions, instruction manual for a human-robot-collaborative workplace
- Exterior technical properties: e.g. access to emergency stop button, profile of the machine (sharp edges), possibility for the coworker to disengage by themselves, signal to display the collaboration mode
- Inner safety functions: e.g. safe speed regulations, choice of operation mode
- Others: e.g. employee trainings, right equipment

It is important to understand that the checklist serves as an additional help for safety officers for safety-related assessment of human-robot-collaboration applications. The general machine.- and equipment acceptance protocols of each production site are still applicable (Beck, 2015, p. 2). By regarding all these guidelines and implementing the newest ISO Norms a safe collaboration of humans and robots can be achieved.

2.4 Human Workforce in Industrial Countries

When talking about automation, the human aspect must not be forgotten. Therefore this chapter deals with the connection between the situation of the human workforce in industrial countries and the decision for raising the degree of automation. First challenges of demographic development for our society in the next decades, and how automation can impact the labor market in the future, is regarded. Finally, labor costs in different European countries will be displayed to understand the different degrees of automation for different countries.

2.4.1 Demographic Development in Western Industries

It is well known that the average age in industrial countries is rising and therefore moving towards an increasingly older workforce. Depicted in figure 13 is a prognosis for population in Germany for different age groups until 2050. The workforce in this prognosis is split in three age groups, below age 20, between age 20 and 60 and above age 60.

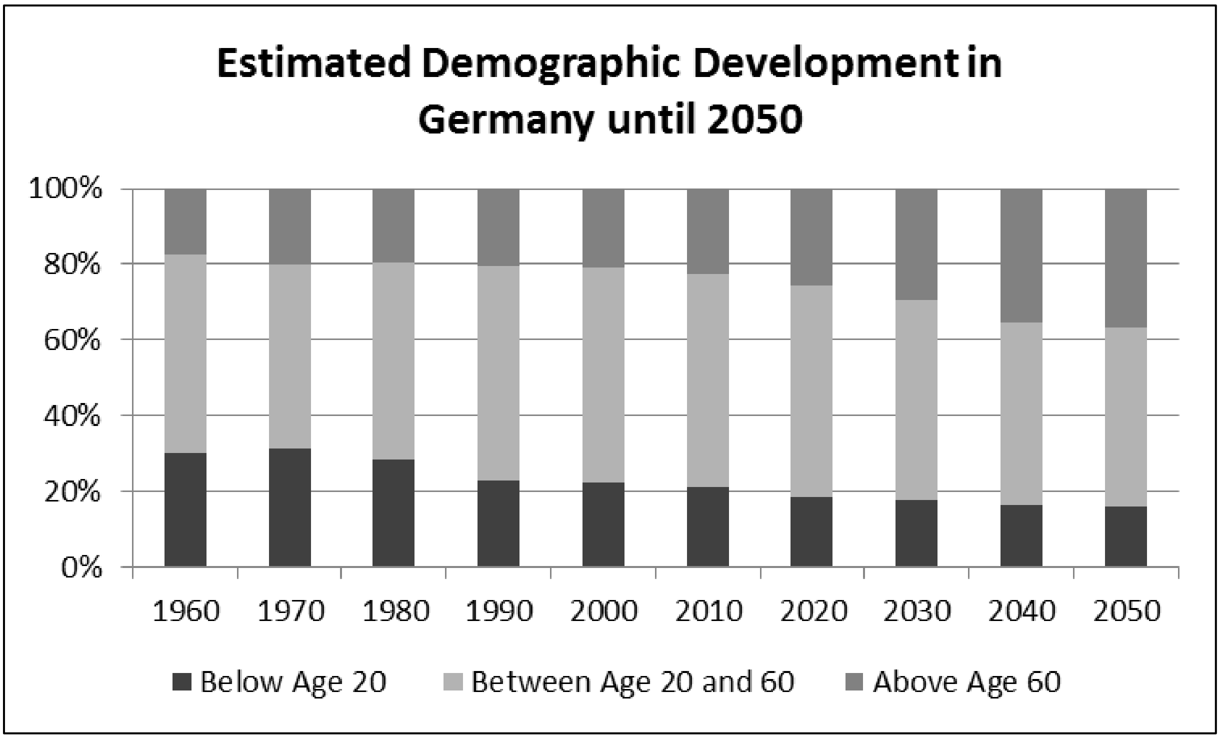

Figure 13: Demographic Development in Germany until 2050 (adapted from: vdek, n.d.)

A definite trend towards a consistently older society can be seen, which will be a test not only for the welfare state but also for the industrial sector including automotive manufacturing. In 2010 roughly 57% percent of the total workforce in Germany was between the age of 20 to 60 years and 22% of 60 and older. These numbers will shift until 2050 to 47% between 20 and 60, and 37% of ages above 60 years. The reasons for this development lie within the continuous rising of general life expectancy, declining birth rates and the aging of the baby-boom generation of the sixties. Results of this progression will have an impact on how the production systems will develop in the future, simply because older personnel have different physical capabilities than younger. In order to avoid a decline in productivity, due to modified physical preconditions, companies cannot afford to ignore these facts. The main issue is, that typically the field of duties shifts within the work life of a worker because declining physical capabilities are compensated by experience, technical understanding and organizational know-how (Niephaus, Kreyenfeld, & Sackmann (eds.), 2015, p. 91 & passim). That is exactly where automation enters labor intense industries such as engine manufacturing. Responding to demographic change, using competences of skilled workers and experience, in combination with technological advancements in fields of automation and industrial robots, this forecasted maturity can be turned to an advantage. The automated assisting robots can take burdens such as routine tasks and heavy duty work off the worker and enable a prolonged productive work life emphasizing adapted capabilities of the worker (Kagerman, Wahlster, & Helbig, 2013, p. 18 & passim). Besides the described challenge of acquiring enough qualified workers due to the aging of society, the issue of ergonomics at the workplace is ever present. Work environment needs to suit to humans physical properties in order to stay productive for a longer period of their work life.

2.4.2 Labor Costs

The final aspect influencing progressing automation in western industries is labor costs. Depicted in figure 14 a comparison of hourly costs of labor in the automotive sector for different European countries can be seen. Total labor costs are composed of a gross income and incidental wage costs. Especially interesting for a German company like AUDI is the cost comparison of German labor costs and labor costs in Eastern European member states of the European Union.

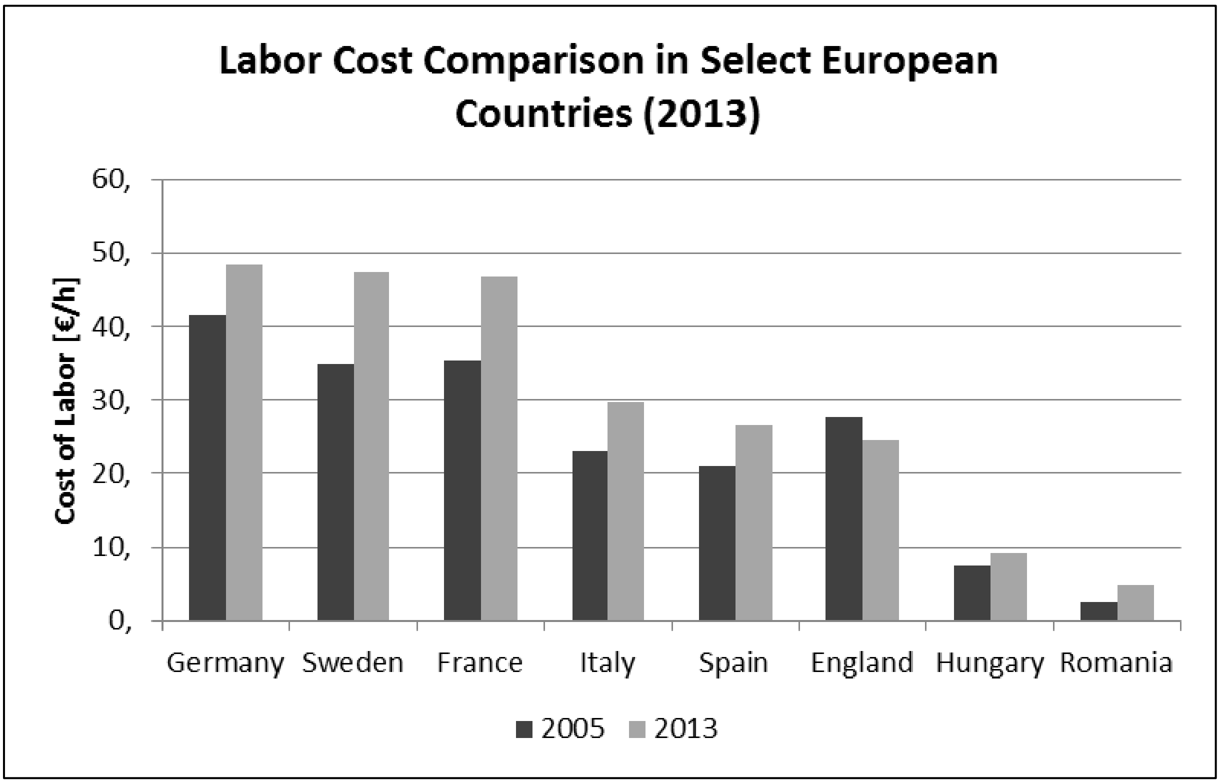

Figure 14: European Wages in the Automotive Sector per Hour (adapted from: CESifo-Gruppe, n.d.)

It can be seen that labor costs for the regarded industry are highest in Germany in international comparison. In average an hour of labor will cost the employer 48,4 Euros per employee in the automotive sector. In Hungary however the same hour will only cost 9,1 Euros which is roughly 19% of what they would have to pay in Germany. This fact makes Hungary as a production location very attractive. Looking a bit deeper there are several other advantages over some of the even cheaper production locations in Eastern Europe. The degree of education, qualification and productivity make Hungary especially interesting for foreign companies (Kaufmann & Panhans, 2006, p. 103). In terms of the level of automation different strategies can evolve out of these differences. While in Germany a high level of automation is desired and profitability of investments in machines is given faster due to the high wages, in Hungary the question whether the degree of automation should be adapted to the labor cost level needs to be addressed in a different way. Most companies that chose Hungary as a production location want to profit in the first place from the low labor costs but opinions differ if that means lowering the degree of automation. The issues of quality, repeatability and high precision work a machine can perform cannot be disregarded, also investments are a commitment into the future. Early adaption of new technologies might give an advantage in terms of flexibility and changing parameters in future production systems (Kaufmann & Panhans, 2006, p. 108). As described in chapter 2.2 the way production systems work is changing continuously therefore the implementation of new technologies even in so-called low cost countries has to be investigated. The next subitem will shine a light on the calculation of investments and the most important parameters for an investment decision in automation machines at Audi Hungaria will be introduced.

2.5 Investment in Automation

When deciding automation of certain production.- or assembly steps in the regarded production sector the initial investment is usually very high. A typical articulated robot arm as introduced in subitem 2.3.3 costs between 25.000 and 100.000 Euros without peripheries and implementation. Such an investment needs to be precisely planned and economic calculations need to be conducted to identify economic feasibility and potentials. The investment needs to be compared to possible savings of labor costs that include more than just the hourly wages but aspects like workers' insurance, vacation times, recruitment and training costs and sick days. Another aspect that must not be forgotten is the transfer of dangerous and monotonic process tasks to machines resulting in a more attractive workplace for the coworker with the side effect of preventing injuries and prolonging the physical work life of a worker (Staff, 2002). In the following subitems general methods for economic calculation of investments will be introduced and later compared to internal methods at AHM.

2.5.1 Economic Calculation for Investments

An investment in the broad sense is the transformation of capital into assets. It is always connected to a long-term engagement of financial resources with the expectation of a certain return in the future (Becker, 2007, p. 37). Literature differentiates between three different types of investment:

- Investments in material assets (e.g. property, real estate, machines)
- Financial investments (e.g. long-term shares and investments)
- Immaterial investments (e.g. patents, research & development, software)

As this thesis deals with investment in automation stations and robots, they can be clearly assigned to the group of investments in material assets. Further distinctions can be made for the type and purpose of an investment like initial-, replacement-, rationalization-, capital-widening- and other investments. Another significant group of investment purposes are influenced by external factors like compulsory environmental directives and social matters like improving quality of work for employees and work-safety related issues. In operational fields a clear segmentation is not always possible as the type of investment can be overlapping and more than one objective can be fulfilled with one investment (Thommen & Achleitner, 2012, pp. 656-657). No matter the motive, an investment is always a highly strategic decision because of the long-term capital commitment and associated fixed costs like depreciations and interest rates and on the other hand the long planning interval that bears risks and requires preparation and detailed planning. An essential part of this planning process is capital budgeting, in order to identify economic feasibility and profitability of an investment. Capital budgeting can be classified in two main groups (figure 15), static- and dynamic capital budgeting, with each using different techniques, depending on available data time and necessary accuracy, to evaluate an investment (Becker, 2007, p. 38).

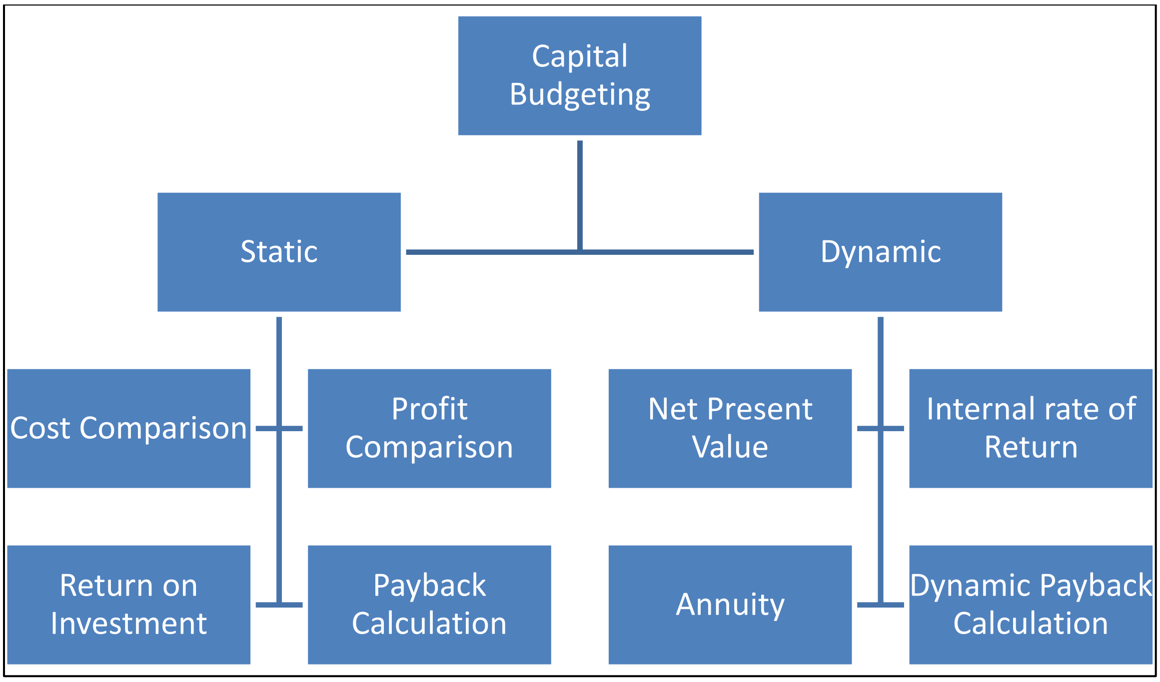

Figure 15: Methods for Capital Budgeting (own illustration: Heesen, 2012, p. 5)

Static capital budgeting methods usually can be conducted rather simply and a lot faster than dynamic ones. Their distinct property is that they do not regard temporal differences of cash outflows and cash inflows that is why average values are taken and usually only one period is considered for calculation purposes. By making such a simplification, results are rather inaccurate and often differ in reality. Therefore using static methods should only be considered when needing quick estimations or when the investment is small (Thommen & Achleitner, 2012, p. 667). In comparison to static methods, dynamic methods regard the entire lifecycle of the investment including cashflows of all periods. The big advantage of this method is the inclusion of temporal aspects into the calculation. In order to make values of different periods comparable they are discounted back to a certain time (Thommen & Achleitner, 2012, pp. 667-668). Both, static.- and dynamic capital budgeting groups, have distinct properties but in order to achieve an accurate calculation this thesis will specify on aspects of the dynamic capital budgeting methods as they are used in the regarded plant. The controlling department at AHM uses dynamic capital budgeting methods to determine profitability of investment projects. The three methods being used are, the net present value method, internal rate of return method and the dynamic payback period calculation.

2.5.1.1 Net Present Value

The net present value calculation (NPV) uses a required rate of return, also called discount rate to make all expected cash inflows and cash outflows that are triggered by an investment of future periods comparable by discounting them to the present date (Thommen & Achleitner, 2012, p. 683). The basic formula for calculating the net present value of an investment is:

$$K_0 = -A_0 + \sum_{t=1}^{n} \frac{CF_t}{(1+i)^t} \qquad (1)$$

K_0	Net Present Value (€) at the time of initial investment
A_0	Cash outflow of the investment
CF	Cash Flows (difference of cash out.- and inflows)
i	discount rate
t	years
n	period

Looking at equation (1)[2] first of all it can be seen that the amount and the temporal occurrence of cash in.- and outflows are relevant, and second of all the discount rate has a major impact on the net present value of an investment. Therefore choosing the right discount rate is of big importance. It is not always easy to define the right number for the discount rate but basically it should be made up of a customary market interest rate for low risk investments plus an additional risk surcharge appropriate for the type of investment. Together it makes up the interest rate an investor expects to receive for their investment. The estimation of cash inflows and outflows of all the periods is another challenge because achieving a good accuracy for these values in the future is afflicted with several insecurities. However one can conclude that the net present value can give a good picture whether or not an investment is profitable for the investor (Heesen, 2012, p. 28):

- If the NPV > 0 that means that the initial investment is completely reclaimed, the desired rate of return is achieved and a final positive cash inflow remains
- If the NPV = 0 that means that the desired rate of return is achieved and the initial investment can be totally retrieved. However, if more than one project is evaluated with this method, the investment with the highest NPV should be realized.
- If the NPV < 0 an investment should be avoided

Besides some limitations and insecurities in estimations, the net present value has the big advantage of defining a total success for an investment over its entire lifecycle including all

[2] A full depreciation assumed. No liquidation proceeds regarded.

cash in.- and outflows calculated to their present worth, however no information about profitability is given (Becker, 2007, p. 61).

2.5.1.2 Internal Rate of Return

Internal rate of return (IRR) is used for describing the profitability of the tied-up capital of investments, before deduction of the desired interest rate, on a yearly basis. An investment can be seen as profitable when the IRR is bigger or equal to the expected rate of return. The calculation of internal rate of return can be seen as an alteration of the formula for net present value. It is defined as the value of return for the case that the net present value, after all in.- and outgoing cashflows have been discounted, is exactly zero. Equation (2)[3] has to be solved for i (Becker, 2007, p. 63):

$$K_0 = 0 = -A_0 + \sum_{t=1}^{n} \frac{CF_t}{(1+i)^t} \qquad (2)$$

Solving this equation is done with the help of interpolation because investments planned longer than two periods would require extremely long calculation loops. The course of action for this is to choose two required rate of returns, both should result in a net present value as close as possible to zero with one of them being just positive and one of them slightly negative. The next step is to perform an interpolation according to Becker (2007, p. 63):

$$r = p_1 - K_{01} * \frac{p_2 - p_1}{K_{02} - K_{01}} \qquad (3)$$

r	Internal Rate of Return
p_1	experimental interest rate 1
p_2	experimental interest rate 2
K_{01}	Net Present Value (p_1)
K_{02}	Net Present Value (p_2)

Limitations of this method are similar to the ones of the net present value, the long term estimations for cashflows might be inaccurate and investments with big differences of initial costs have to be regarded under a different light. The biggest advantage of this method is the statement about profitability and therefore it is complementing the NPV method ideally (Becker, 2007, p. 64).

2.5.1.3 Payback Period – Dynamic Calculation

The definition for the payback period is described as the time it takes for the incoming cashflows to level the entire initial investment including the required internal rate of return. The

[3] A full depreciation assumed. No liquidation proceeds regarded.

moment this is achieved is called the Break Even point, any incoming cashflows after this point contribute to a positive NPV. In figure 15 it can be seen that a payback period calculation can also be found in the static methods of capital budgeting. The difference between the two is that in the dynamic calculation the interest rate is also regarded (Heesen, 2012, p. 42). Calculating the time of payback period is done with equation (4):

$$Payback\ Period = period(C_1) - \frac{C_1}{C_2 - C_1} \qquad (4)$$

C_1 last negative periodic NPV
C_2 first positive periodic NPV

The equation requires accumulating the net present values periodically for each period. At one point the NPV's will turn positive meaning that somewhere between this and the prior period the point had been reached where our initial investment was completely matched by the difference of incoming and outgoing cashflows. Since the result will be a period followed by a decimal point, the exact day, if required, needs to be calculated by multiplying the percentual share with 365 (days/year). In practice this is usually not executed because a deviation due to the estimation of all the cashflows is already part of the calculation and therefore an exact day is redundant (Heesen, 2012, pp. 44-45).

2.5.2 Economic Calculation for Investments at AHM

In the previous three subitems the most important calculation methods for dynamic capital budgeting are described. At Audi Hungaria Motor Kft. these are also the methods used to decide whether or not an investment project should be pursued. However more data is needed for the calculation of all the cashflows. The following information was retrieved during several interviews with the controlling department at AHM for a typical calculation of a small sized investment. The individual positions used in the internal economic calculation at AHM are (Heszler, 2016a):

- The initial investment
- Material
- Direct Labor Costs
- Indirect Wages
- Maintenance
- Contracted Services
- General Expenses
- Other Savings
- Tax Impact on Costs
- Tax Impact on Depreciation

For the purpose of implementing industrial robots or lightweight robots at the line some simplifications can be made according to the controlling department. The initial investment is the sum of the entire investment including the machine, peripheries, installation and programming tasks (sum is provided by the planning department). Material costs will not occur and can therefore be neglected. The direct labor costs are considered as an average value of 25.000€/a for one worker at the line. Indirect wages are disregarded because they do not have an impact on the decision. Maintenance costs do not need to be considered because the new machine will be integrated in the weekly maintenance shift. Contracted services are negotiated in the initial investment and will be part of that point. General expenses for the lines are distributed according to their percentage shares of consumption, they do not have an impact on the decision of an investment of this size. Tax impact on costs and depreciation are calculated with a corporate tax of 35%. These impacts are calculated for each period, if less costs occur due to savings of labor costs and others, while earnings stay the same (as expected) the sum of corporate tax will rise. On the other hand more costs occur due to depreciation which will have to be deducted of the sum of corporate tax (Heszler, 2016a) & (Heszler, 2016b). Data used for the internal economic calculation and depreciation calculation in accordance with the topic of this thesis is described in table 4.

Data	Value
Asset Category	5000 (technical equipment and machines)
Depreciation Period	8 years
Depreciation Method	Declining & Linear[4]
Rate of depreciation	20%
Discount rate	9%
Corporate tax	35%
Required payback period	2 years

Table 4: Values for Internal Economic Calculation (Heszler, 2016a) & (Heszler, 2016b)

Table 4 defines specific data for economic calculation tasks within the regarded plant. Industrial robots, automation machines and lightweight robots fall under the internal asset category 5000 (technical equipment and machines). The depreciation period for such assets is given with eight years until a complete depreciation is achieved. Internal standards require a mix of declining depreciation (20% depreciation rate), which is applied in the first three periods, and later, until the end of the assets write-off, a linear depreciation with constant depreciation values. Liquidation proceeds are disregarded because machines usually stay within the plant after depreciation is complete. Therefore the prior introduced capital budgeting formulas can be applied as described. The discount rate, introduced in subitem 2.5.1.1, is given with 9%,

[4] A specification has been set that a declining depreciation method is applied for the first three periods, the final five periods are calculated with the linear depreciation method.

meaning this is the companies required rate of return. Corporate tax is given with 35%. The final number, required payback period, is given for the introduced kind of investments (new technologies, human-robot-collaboration) with 2 years. The payback period is also the main criterion for the actual implementation of a project (Heszler, 2016a) & (Heszler, 2016b). With the help of Mr. Heszler, the internal numbers and the capital budgeting methods, an excel tool has been created and will be introduced in the practical problem solution later in this thesis.

2.6 Engine Downsizing

This chapter gives an overview over the fundamentals of the trend towards construction of ever smaller engines in the automotive industry and the rising demand for them, which in turn is one of the driving forces behind the fact that segment P3 was chosen to produce a share of 1,0 liter cars for the Volkswagen group. Automotive manufacturers are currently facing big challenges. While the market in North America and Europe is saturated and growth can only be achieved through crowding out of competitors, there is still big potential in emerging markets for increase of sales. However all major OEM's are aware of this situation, creating additional pressure to prevail in these regions. These high levels of competition, challenging customer requests as well as strict legal requirements are big drivers of technological innovation (Brünglinghaus, 2013).

Engine Downsizing, currently being the trend for almost all major OEM's, principally has two main goals:

- Cut carbon dioxide emissions
- Boost fuel efficiency

These targets are not only required by legislative guidelines such as the mandatory *2020 emission reduction target*, passed by European Council and Parliament in 2008, but are also easily communicable to the customers buying a car. In fact, with environmental awareness climbing and constant high gas prices, the end customer demands more efficient and "greener" cars (THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION, 2009).

The automotive industry has a consensus that engine downsizing, in combination with other technological innovations, could be the answer to those issues. That is the reason why a considerable amount of research effort is put in this field and new engines meeting these specifications are being developed. Figure 16 shows the ambitious road towards CO2 reduction for diesel, gasoline and alternative fuel vehicles (AFV) in grams CO2 per kilometer.

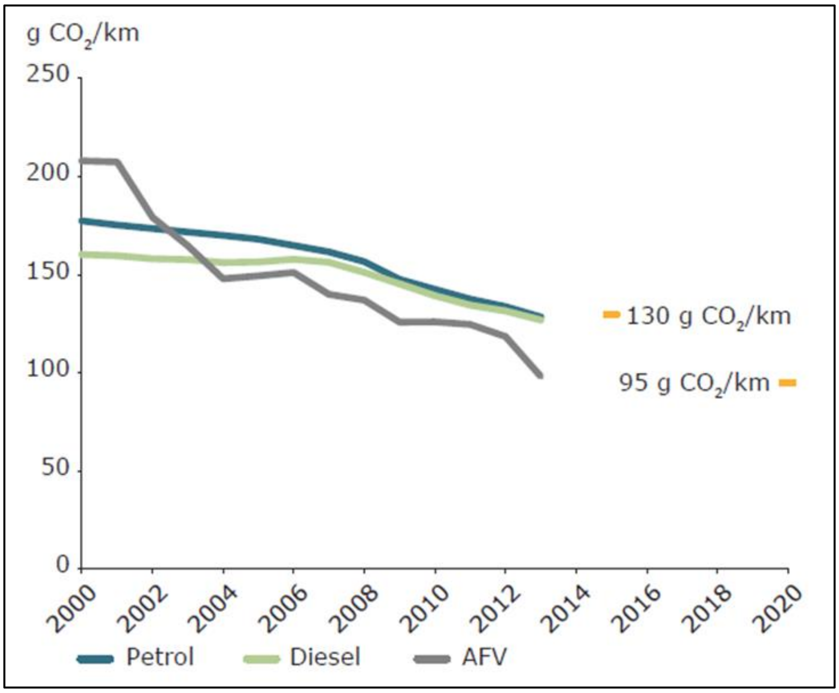

Figure 16: Evolution of CO2 emissions from new passenger cars by fuel type (EU 27) (European Environment Agency, 2014, p. 19)

European Environment Agency (EEA) was able to announce in 2013, two years early that the required emission values for 2015 had been reached. In average every newly sold car in 2013 had a value of 127 grams of CO2-emission per kilometer, staying well below the required 130 g/km. Still it will not be easy to keep the pace up to reach the aspiring goal of 95 g/km for the fleet average in 2020. This will require the trend line to continue falling at the same grade making alternative fuel engines and downsized engines all the more vital (European Environment Agency, 2014, p. 19 & passim).

2.6.1 Principles of Engine Downsizing

The basic approach for engine downsizing is very straightforward, bigger engines are substituted by smaller ones, likewise a decreased displacement is implemented. Taking a look at equation (5) for calculating displacement, it can be seen that total displacement depends on two parameters, the number of cylinders and the displacement geometries.

$$\mathrm{V}_H = \mathrm{z} * V_H = \mathrm{z} * \frac{D^2 * \pi * s}{4} \tag{5}$$

V_H engine displacement [m^3]
z number of cylinders
D bore hole [m]
s displacement [m]

Consequently there are two possibilities for decreasing engine displacement. First, simply reducing the amount of cylinders in the engine, for example from six to four cylinders. This can be achieved relatively easily without too much engineering effort but has the major downside of struggling with customer acceptance. The second possibility, as seen in equation (5), is the reduction of the displacement. The concept behind this is that if fewer or more compact cylinders are in place, less losses will occur due to friction and thermal losses. With these measures for more efficiency fuel economy can be increased and with it CO2 emissions decreased. However, inconveniences, feared by sceptics of this approach include the perception of the end customer of an inferior car or the loss of engine power. One has to question whether clients purchasing the car are willing to pay the same amount for a downsized engine (Golloch, 2005, p. 67 & passim). The connection of performance to engine displacement can be seen in equation (6).

$$\frac{P_e}{V_H} = \mathrm{i} * \mathrm{n} * p_{me} \qquad (6)$$

P_e effective performance [kW]
i amount of working cycles per crankshaft rotation (i = 0,5 for four stroke engines)
n engine speed [1/min]
p_{me} effective mean pressure [bar]

If engine displacement (V_H) is reduced, and all other parameters stay the same, a loss of performance would be the result. To avoid this imminent loss of power of downsized engines, certain counter measures have to be taken. Either the engine speed, or the effective mean pressure have to be increased. Two resulting concepts are the high-performance concept and the high-speed concept. Therefore downsizing can be further referred to as reduction of engine displacement with simultaneous increase of effective performance. This means huge amounts of energy in a very small space, or in other terms a lot of air and fuel have to be brought into the combustion chambers. Therefore technological innovations, such as turbocharging or direct fuel injection, are crucially interlinked with downsizing. Most prominently turbocharging is used to provide extra air in the combustion chamber and therefore more fuel can be burned with higher efficiency (Golloch, 2005, p. 67 & passim). To visualize the efforts that have been taken in engine downsizing figure 17 and figure 18 show statistics of the most recent developments in engine production. Underlining a clear trend, towards higher performance and at the same time reduction of displacement.

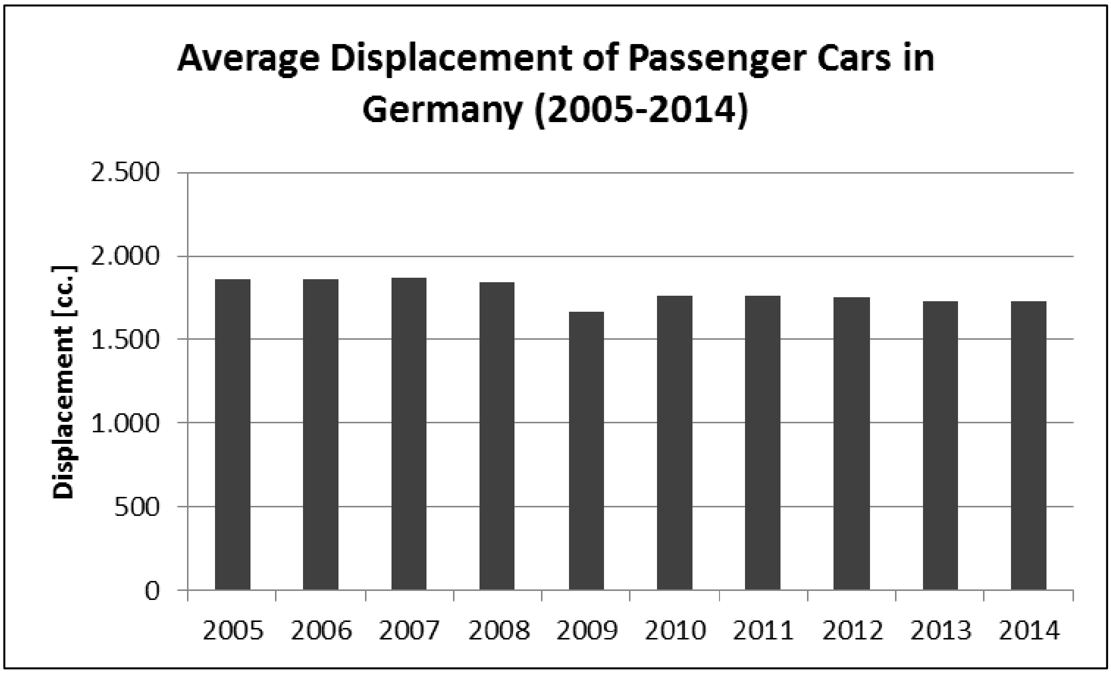

Figure 17: Average displacement of new passenger cars in Germany until 2014 (adapted from: KBA, n.d.)

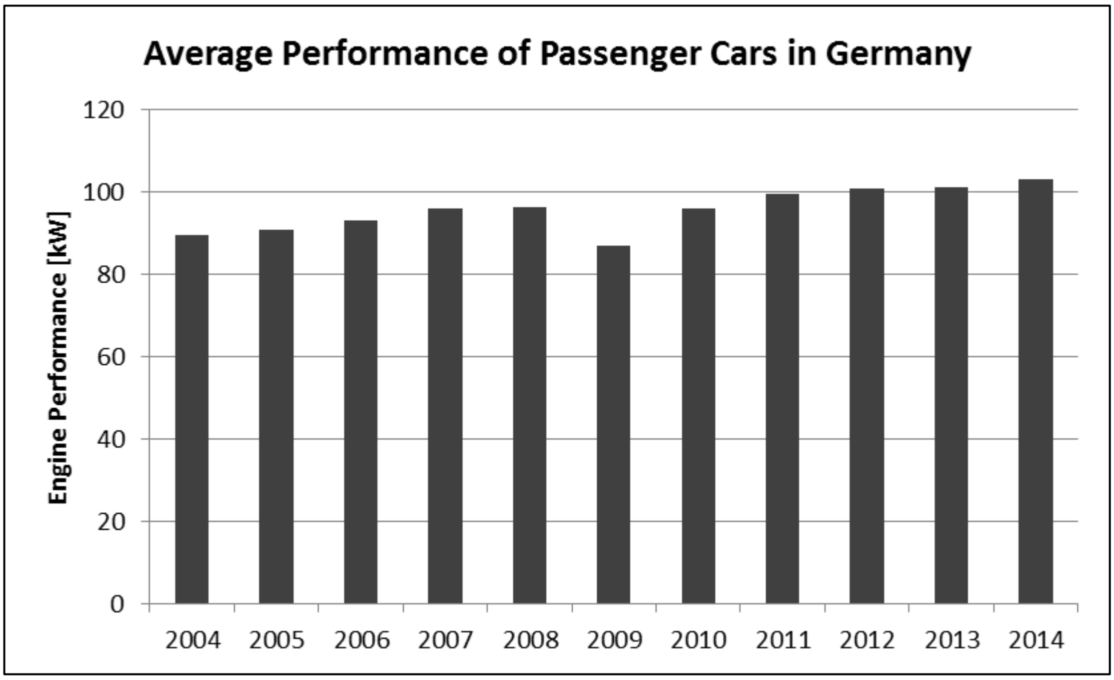

Figure 18: Average performance of new passenger cars in Germany until 2014 (adapted from: KBA, & Die Welt, n.d.)

The two statistics (figure 17 and figure 18) precisely demonstrate the ongoing development of engine downsizing. While the average engine displacement of passenger cars in Germany has significantly decreased from 2004 to 2014, average performance has heavily increased in the same time frame. This displays the successful implementation of downsizing concepts in the automotive sector. Another area of research in engine downsizing is the so-called dynamic-downsizing. Compared to earlier mentioned concepts of reduced amount of cylinders or reduction of displacement, this segment goes into the area of variable displacements. Different car manufacturers have different concepts as of how to realize this, here Audi's patented Audi Valvelift system (AVS) shall be discussed to get a deeper understanding of the principles (Knopf, 2011, pp. 36-39) & (Golloch, 2005, p. 67 & passim).

2.6.2 Audi Valvelift System (AVS)

Audi's approach to increasing fuel efficiency is the dynamic differentiation of engine requirements at different load cases. With normal driving behavior, engines will mainly operate at partial loads only requiring full load calibration for short periods of time. To optimize all cases for the full operating range AVS was first introduced in 2008. In principle the system uses different cam sizes for different load scenarios that can be variably switched. The reason is to be able to open and close the valves in a way that the right amount of air is provided in the cylinders at the right time. A small cam for a shorter opening of the valve and a big cam for full opening. These can be switched within two rotations of the crankshaft thus avoiding any delay. With this approach the engine can be seen as down-sized for partial loads, still having the power for handling any full load scenarios with full displacement. The next step is total cylinder cut-off at partial loads which can be realized by implementing a zero-profile cam, where certain cylinders are completely deactivated for partial loads. The main advantages of this concept are the increase of efficiency by reducing friction losses inside the cylinders and by avoiding losses in the throttle of charge-cycle exchanges (Huber, Klumpp, & Ulbrich, 2010, pp. 839-840). A sketch of the principle of different cam sizes of the Audi Valvelift System can be seen in figure 19.

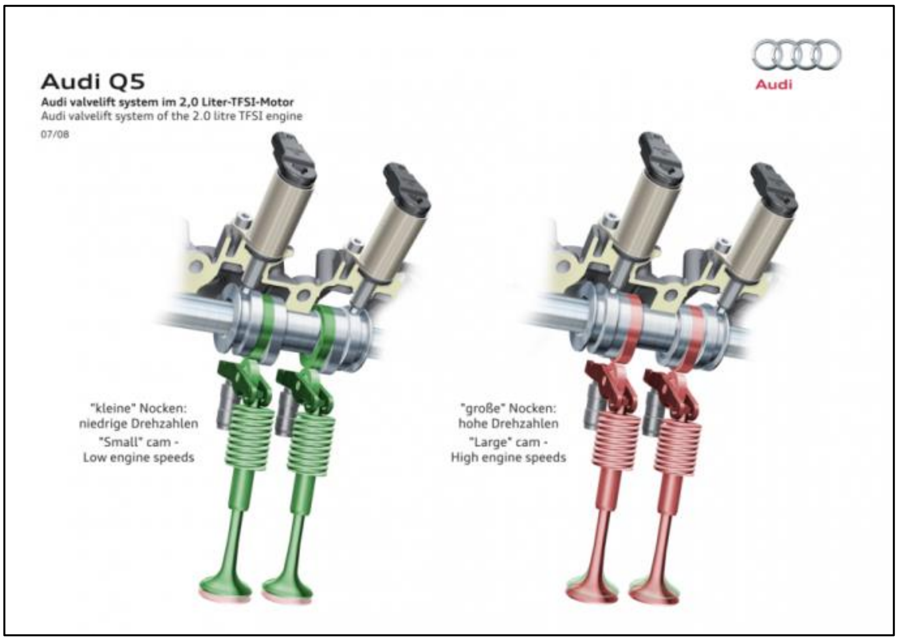

Figure 19: Audi Valvelift System (AUDI AG, 2011)

3 Analytical Examination

In this chapter first the imminent changes to the assembly line of segment P3 will be thoroughly analyzed. Plans and changes for this segment will be discussed and later a benchmarking analysis of automation projects at other segments will be conducted. This shall first of all emphasize the necessity for raising the degree of automation also in the engine assembly line and secondly, the benchmarking analysis shall carve out the major criterions for an operational guideline to implement future automation projects.

3.1 Analysis of the current state assembly line

In order to detect the changes that are coming to assembly line EA211 R4 Otto, first some details of the existing line have to be regarded. This line has been running successfully since 1994, today having a capacity of 1512 engines/day. In table 5 the most important facts about the engine assembly are summarized.

Facts	Data
Start of production	1994
Investment	69,3 Mio. €
Area size	5360 m2
Length of line	570 m
Cycle time	52,02 sec
Engines per shift	456 eng./shift
Number of fully automated machines	9
Number of half-automated machines	38
Work/Shift plan	5/3; 6/3
Capacity	1512 engines/day
Throughput time	4,56 hours

Table 5: Basic Data EA211 R4 Otto assembly (Czingráber, 2015)

The EA211 R4 Otto assembly line is the oldest still running line at AHM plant, changes have been gradually implemented over time, but with 9 fully automated and 38 half-automated machines the degree of automation is still on the low end side. Depending on demand and production numbers either a 5/3 or 6/3 shift system is implemented. 5/3 meaning five days and three shifts a day, 6/3 six days and 3 shifts. The engine family currently assembled at this line is described in the next subitem 3.1.1.

3.1.1 The EA211 engine family

The EA211 type series at Volkswagen AG includes small three and four cylinder Otto-engines, which are being produced at several plants worldwide. Additionally to reasons mentioned in chapter 2.6, impressive advancements in technology have led the entire VW group to formulate a strategic goal to increase EA211 share significantly. This engine embodies the efforts towards downsizing and innovation at once, leading to high customer demand. In 2020 this product family is supposed to hold fifty percent of the total production volume (Czingráber, 2015, p. 6). To get a deeper understanding of the commitment taken in engine production at AHM and the entire Volkswagen group, a study of current and planned production volumes of engines will be conducted hereafter. This will shine a light on the changes segment P3 will undergo in the coming years and the underlying reasons for it. In 2015 the overall output of engines at AHM plant was increased by 2,47% in comparison to 2014 to a total of 2.022.520 engines. Detailed output numbers per segment are illustrated in figure 20.

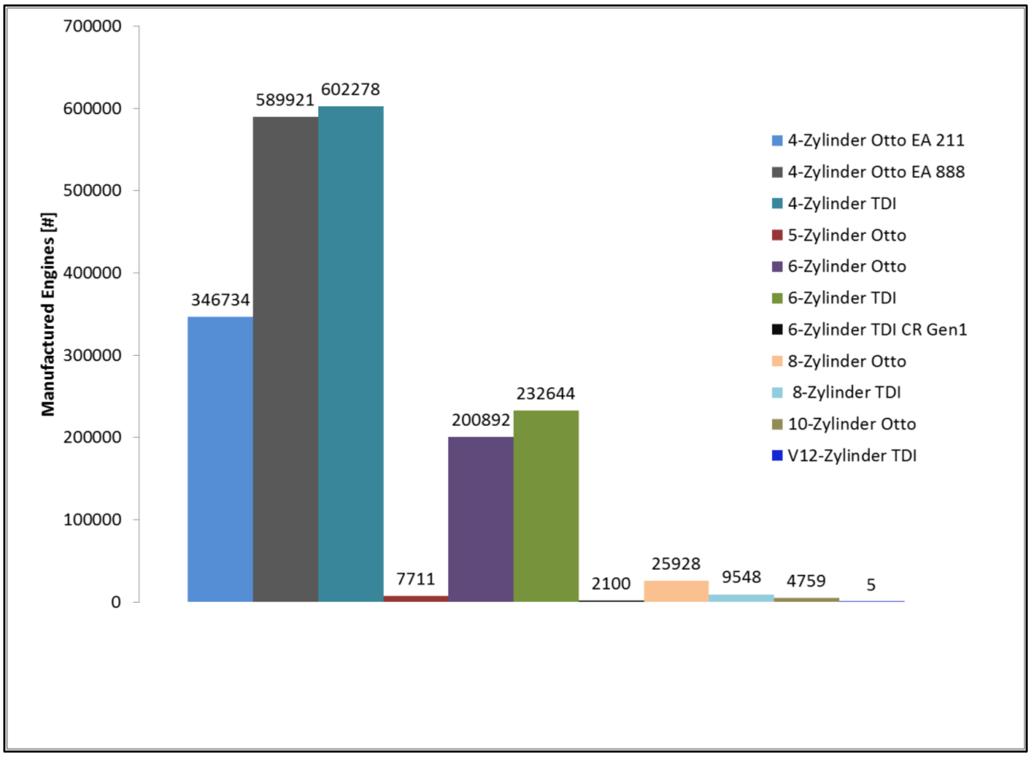

Figure 20: Production Volume of Engines at AHM (own illustration: AUDI HUNGARIA MOTOR Kft., 2015)

As indicated by the numbers, segment P3 was a huge player in the overall production of AHM in 2015, having manufactured 346.734 engines of the type EA211, the share was 17,14% of the total production volume. This makes the segment third largest in the plant only surpassed by the four cylinder global engine (EA 888) with approximately 590.000 engines produced in 2015 (29,17%) and the four cylinder turbo diesel being responsible for a production volume of roughly 600.00 engines in 2015 (29,78%). The entire percentual distribution of engines can be regarded in figure 21.

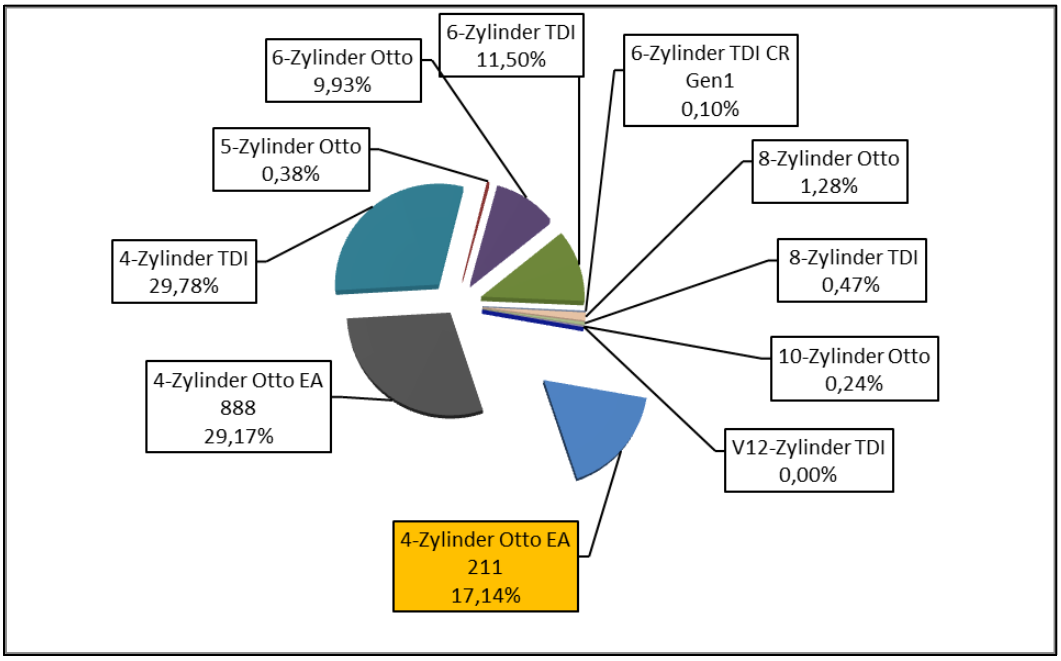

Figure 21: Percentage share per engine type (own illustration: AUDI HUNGARIA MOTOR Kft., 2015)

The three engine families, 4-cylinder diesel, 4-cylinder Otto EA888 and the regarded 4-cylinder EA211, are absolute volume engines found in almost all small and mid-sized car types of the Volkswagen group. Consequently the manufacturing and assembly lines share several similarities. Due to recent developments on the global car market and customer demand the EA211 family will strategically receive an even higher significance for Volkswagen. Customer demands for low fuel consumption cars and engine downsizing efforts being as advanced as described in point 2.6, this share shall continuously rise at AHM. As mentioned above, Volkswagen group's corporate goal for the EA211 product family until 2020 is a portion of 50% of the entire engine manufacturing. Market prognosis for this engine go as far as 2025, suggesting a steady rise in demand, peaking in 2024 with a worldwide demand of about seven million engines annually. Segment P3 will simultaneously grow, with a planned production of 480.000 engines of this type in 2020. The numbers and AHM's share of EA211 until 2020 are illustrated in figure 22.

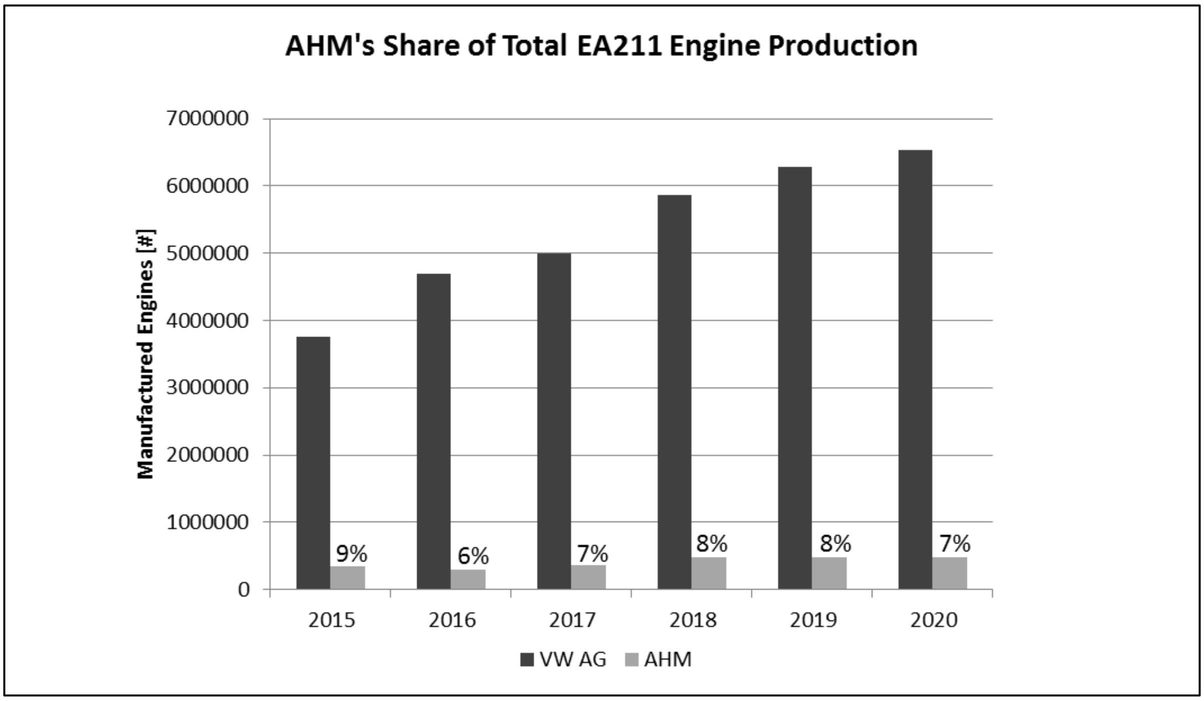

Figure 22: AHM's share of EA211 production in the Volkswagen Group (own illustration: AUDI HUNGARIA MOTOR Kft., 2015) & (Czingráber, 2015)

The numbers show one of the challenges segment P3 is facing in the upcoming years, the planned 25% rise of production volume until 2018 with the goal being increasing numbers from 346.000 engines in 2015 to 476.000 in 2018. The other one being the transition of the lines during that time, which will be explained in subitem 3.1.2.

3.1.2 Implementation of Changes in Segment P3

The project for the new EA211 engine at AHM, EA211 EVO, was initiated in 2015 with the set goal of start of production (SOP) in mid-2017. The core project goals are:

- Achieving the legislative CO2 – fleet specifications 2020
- Improved performance (maximum 118kW) without raising individual unit costs
- Displacement optimization, Reduction of variations

It can be seen that once again the focus lays on reducing CO2 emissions without compromising the performance and driving comfort for the customers. This can be achieved through technological innovations and optimizing the engine further. Technological key aspects besides a redesign are, introducing a new combustion system the “Miller-Brennverfahren” and optimizing the turbocharger. These steps in combination with the patented “Audi Valvelift System” (AVS) will help achieve the ambitious goals (Czingráber, 2015, p. 27).

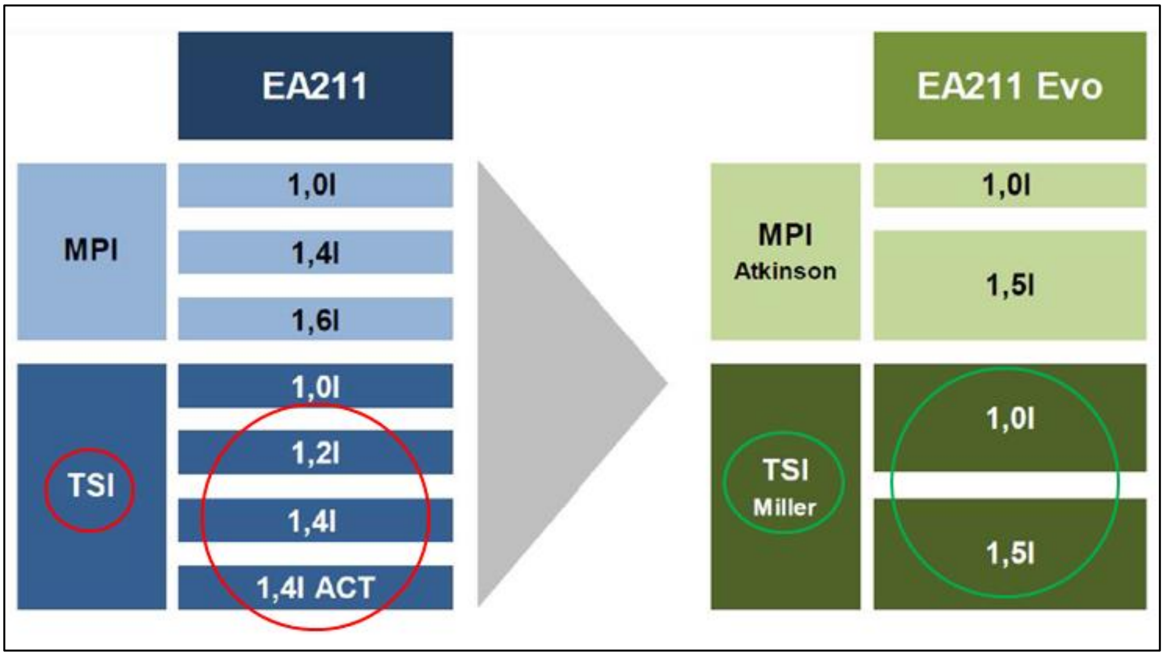

Figure 23: Transition of the EA211 engine family (adapted from: Istvan, 2015, p. 2)

On the left hand side of figure 23 the entire variations of the EA211 engine family can be seen. Framed in red are the types that are currently being produced in segment P3 at AHM. The product portfolio of this line currently includes two 1,2 liter transverse engines with a performance of 63 respectively 77 kilowatts and four 1,4 liter engines, three of which are transverse and one is a longitudinal engine. The performance of the 1,4 liter engines reaches from 90 to 110 kilowatts. All variations are 4 cylinder inline engines. These so-called volume engines can be found in a broad spectrum of cars of both the AUDI AG and the entire Volkswagen group, for example the Audi A1, Audi A3, Audi A3 Limousine, Audi Q3, VW Golf, Skoda Octavia, Seat Leon and Seat Ibiza. The long-term aim is to discontinue the 1,2l, the 1,4l and the 1,6l engine altogether and in future only manufacture two different displacement sizes of the EA211 engine, a three cylinder 1,0l and a four cylinder 1,5l. For the regarded segment that means the disappearance of the red-framed engine types and in future the production of the new EA211 EVO 1,0l and 1,5l TSI engine with Miller combustion cycle, framed in green. Since this change cannot be implemented over night and there is still demand for the other engines, for the time being all five engines have to be produced at the same line. The first engine to disappear will be the 1,2l R4 TSI in 2018 when the new EU emission standard (EU6ZD) will be implemented and further development of the 1,2l engine is discontinued. There is no specific end of production date for the 1,4l engine formulated yet but estimations suggest that it will continue longer than 2020. This means that the production and assembly lines of segment P3 need to be capable of producing these types including the new three cylinder 1,0l and the four cylinder 1,5l EVO for the time being.

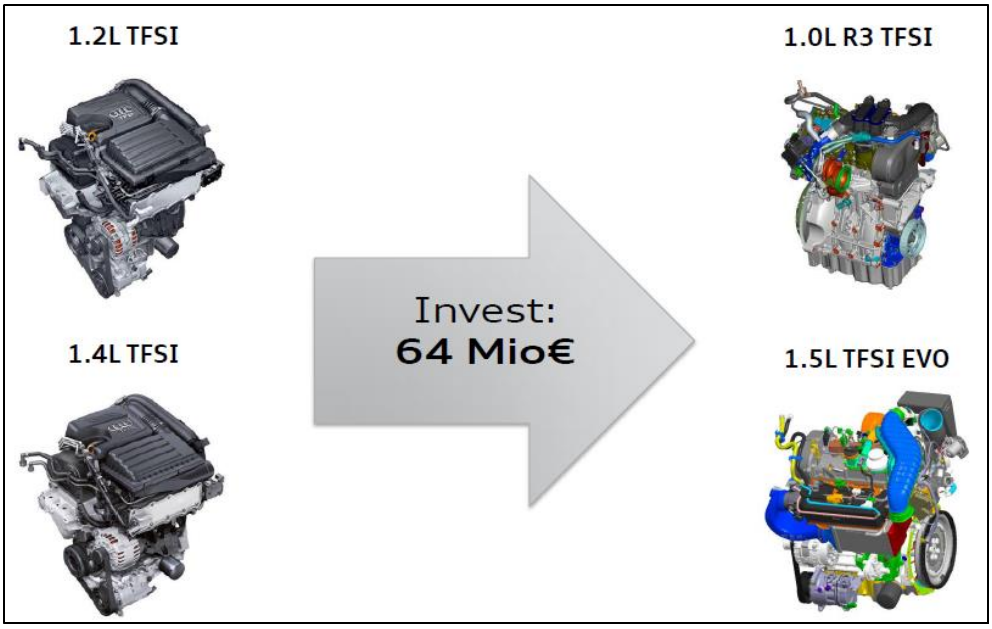

Figure 24: Engine transition in segment P3 (Horvath, 2016, p. 6)

A significant investment of 64 million Euros will be made to support the transition and reconstruction of the manufacturing lines (figure 24) at the same time however, the goal has been set, to further reduce manual workstations in order to raise the degree of automation at the lines. The process of optimizing these manual workstations is described in the next subitem.

3.2 Manual Workstation Analysis for the Assembly Line

Such a transition of the product portfolio in a running line effects all workstations and requires rebuilding, new construction, reprogramming of machines and training of employees. The planning department also realized this change of workstations would require more coworkers according to the complexity of the new operations. The basic assumption is that the smaller three cylinder engine will not require an increase in number of employees, the more complex four cylinder EA211 EVO will however need additional work steps. Simultaneously, the capacity of the line shall be increased from 1500 to 1700 assembled engines/day. Consequently more employees will be necessary to achieve these goals. An analysis of actual numbers proves this statement and reveals some challenges with current numbers. Basic input data for this study is provided in table 6.

Manual Workstation Analysis Engine Assembly R4 Otto EA211						
Date	Type	Capacity	Short Engine	Test Bay	Complete Engine	Sum R4 Otto EA211
04/2015	As-is	1500	30	16	37	**83**
04/2015	KAN Draft: 1,5 EVO	1500	32	18	40	**90**
02/2016	As-is	1500	27 (-8,4%)	14	35	**76**
02/2016	Estimation: 1,5 EVO	1500	29 (-8,4%)	16	38	**83**
02/2016	Estimation: Capacity increase	1700	33	18	43	**94**
10/2015	KAN proposal	1500	28	16	35	**79**
10/2015	KAN proposal	1700	32	18	40	**90**

Table 6: Manual Workstations in the Assembly Line (Tamas, n.d.)

The starting point are numbers of employees from April 2015, these are divided into short engine, test bay and complete engine, with thirty, sixteen and thirty-seven employees respectively. Therefore the total sum of employees in the engine assembly line was 83. At this time planning proposed to increase numbers to 90 employees for the introduction of the new engine type to the so-called "KAN" (Konzern Ausschuss Neuprojekte), whose clearance is required for any new projects involving high investments. The number was justified by the assumption that the increased complexity of the EA211 EVO engine will lead to additional work stations at the line. Due to progressing efforts for efficiency increases, the number of employees could be reduced in all areas by February 2016 to 76 (as of Feb. 2016). This means a reduction by 8,4% in total visualized in figure 25.

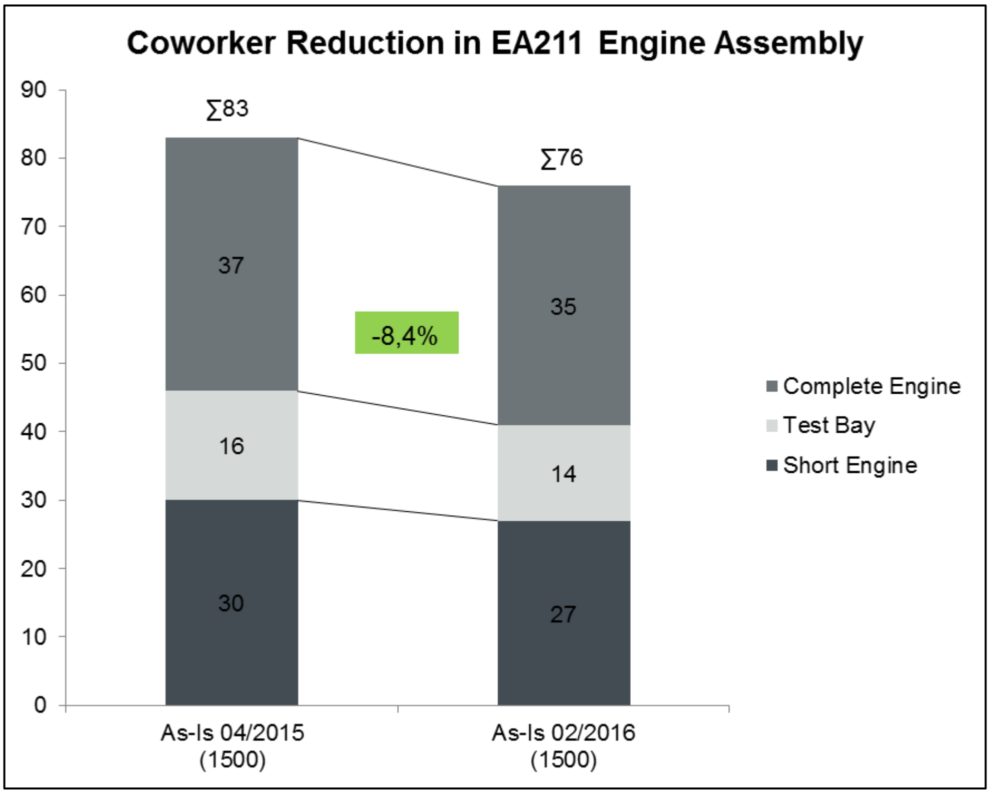

Figure 25: Development of Manual Workstations at the Assembly Line

Planning again took this number as a basis for a new proposal for the EVO project, proportionally deducting 8,4% from the originally proposed 90 employees, now suggesting 83 employees in total. So far these numbers relate to the current capacity of 1500 engines/day. The requirement of raising capacity to 1700 engines/day linearly lead to the result of increasing number of employees by 13%. The new situation was 83 employees for a capacity of 1500 engines/day and 94 employees for a capacity of 1700 engines/day.

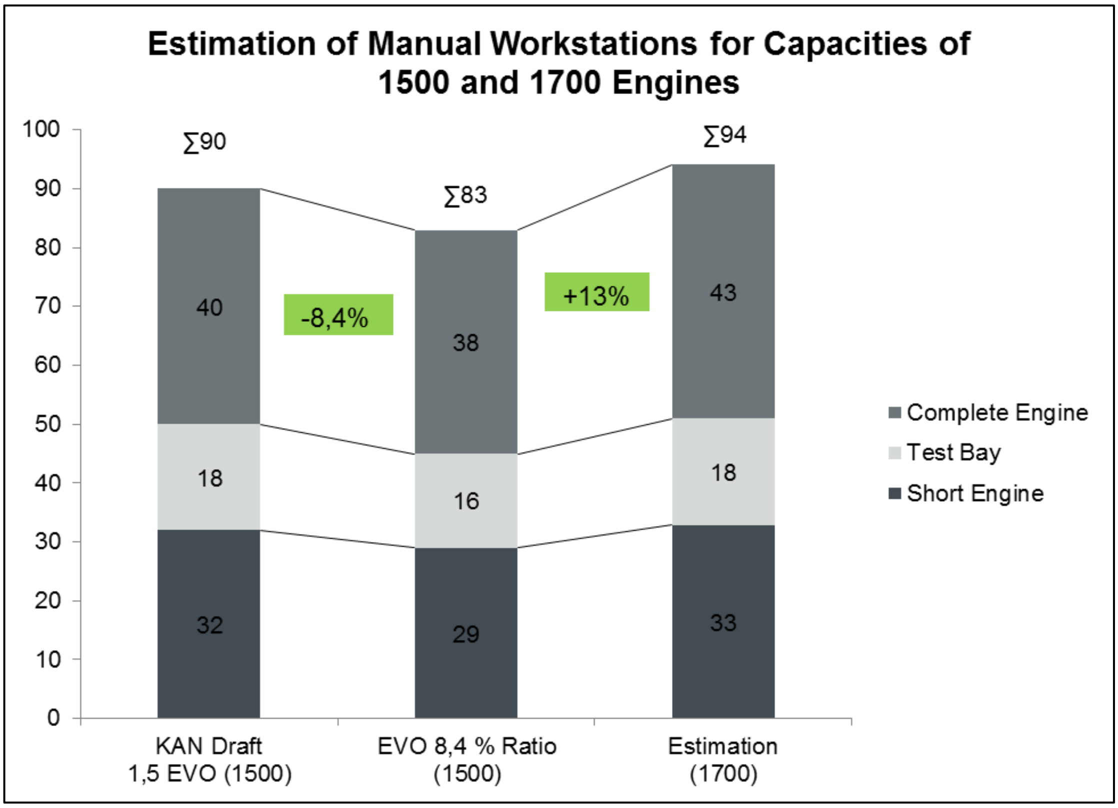

Figure 26: Anticipation for Manual Workstations for increased Capacity

However at the next "KAN" meeting on 23.10.2015 the proposal included 79 employees for a capacity of 1500 engines/day and 90 employees for a capacity of 1700 engines/day. Clearly this proposal is very ambitious, demanding further reduction of employees and putting a tight margin on the assembly line before knowing the full complexity of the production of all three engine types at the same line. A feasible solution to this problem is the introduction of more automated stations and therefore increasing the degree of automation. By doing so, the dependency on coworkers is decreased and flexibility for dealing with different construction steps is given.

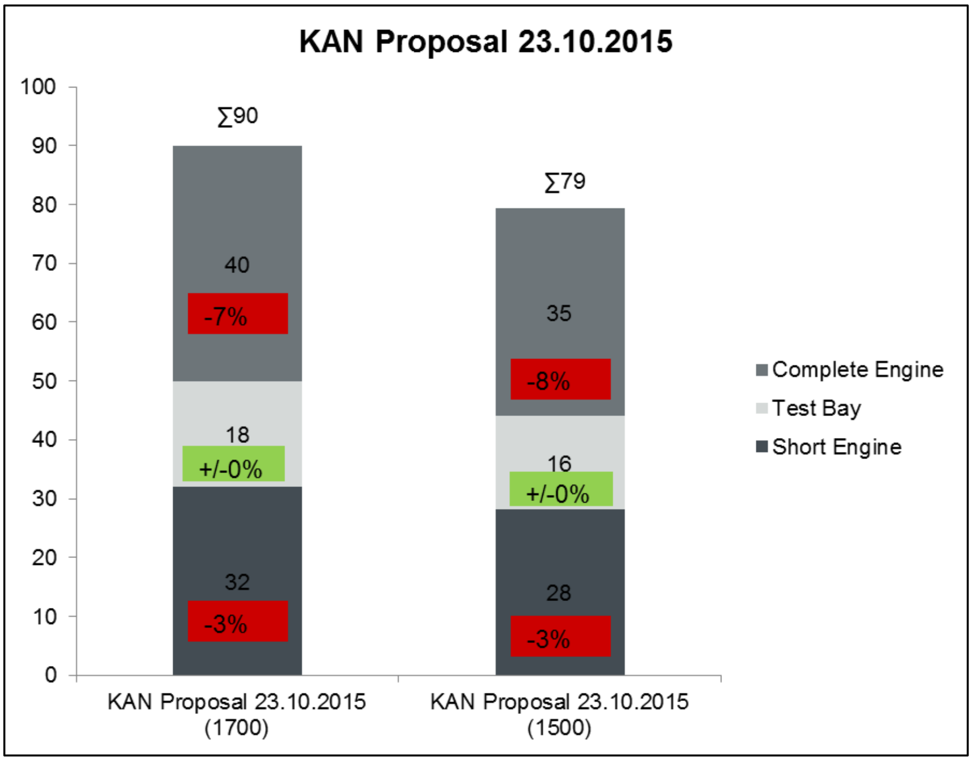

Figure 27: Actual Proposal for Manual Workstations

The numbers shown in figure 27 demand for further reduction of manual workstations, leaving automation as the only feasible solution. In the following chapters of this thesis, this is one of the reasons why as an exemplary workstation one of the affected areas is chosen to conduct a study for automation projects. Further an operational guideline for any new automation project will be established. Most importantly a clear understanding of the differences of the new engine types to the existing one is necessary to be able to make exact assumptions what kind of manual and automated workstations need to be reworked for the smooth transition in the assembling line. These differences can currently only be assumed by comparing the total part list of the existing and new engines (figure 28).

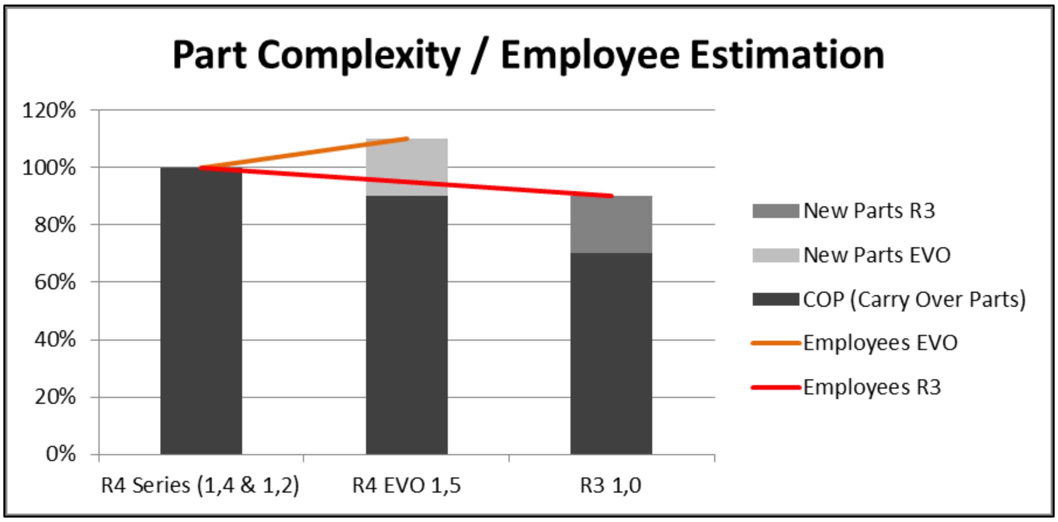

Figure 28: Illustration of Part Complexity / Estimation of Employees

Figure 28 gives an overview over a possible scenario of employee occupation for the new engine types. The assumption is made, that the part complexity directly correlates with the degree of occupation of employees, meaning, the more complex the engine, the more workstations and therefore more employees are necessary for the assembling process. In order to achieve a balanced degree of workforce utilization this again points towards the necessity of implementing automated workstations that can variably adapt to the currently manufactured engine.

3.3 Benchmarking of Current Automation Projects at AHM

In order to determine suitable areas of application for automation stations and robots at an engine assembly line, an analysis of potential automatable stations has to be conducted. For this analysis both planned and implemented projects at AHM have been selected and thoroughly examined. Reasons for the necessity of further automation in the regarded segment have been discussed in previous chapters. The outcome of this study will point out the major criterions that need to be considered before deciding on such projects and to learn from experiences that were made in other departments. The method of benchmarking has been chosen because segment P3 is not the only department aiming for a higher degree of automation at the assembly line, nor is it the only department trying to achieve more flexibility when it comes to assembling different types of engines on one line. Segment P4 can be seen as a trailblazer for others in this area, for they have a set goal of consistently implementing new ideas deriving from the Industry 4.0 philosophy as well as realizing automation projects optimizing cycle times and workforce size. Since 2015 several projects have been pushed to realize a more flexible and efficient production line, facing challenges like the production of a different type of engine and cycle time spread. P4 is a perfect candidate for benchmarking since they, like P3, are considered an absolute volume segment (figure 21) being responsible for a share of thirty percent of total engine production at AHM which accords to approximately 600.000 engines a year.

3.3.1 Description of the Projects

Projects at segment P4 have originated out of two different channels. First the technical supervisor and his team are noticing potential optimization options on a daily basis. They know their line like the back of their hands and are always looking for ways of improvement. One problem with this approach, mentioned by the supervisor in an interview, is that as an inside team there is a possibility to lose an objective view on the overall picture and one becomes "blind" to obvious solutions (Sarkany, 2016). This is the reason they activated a second channel for idea generation, namely the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA). The IPA was commissioned to analyze the entire line and identify any production steps where automation would be feasible. Results are expected in summer 2016. Current projects that are used for benchmarking in this thesis are shortly described hereafter.

3.3.1.1 Project 1 - Coworker and Robot cooperation at one manual station

A robot (type UR10) conducts the screwing of the oil-separator, a previous manual task, by itself.

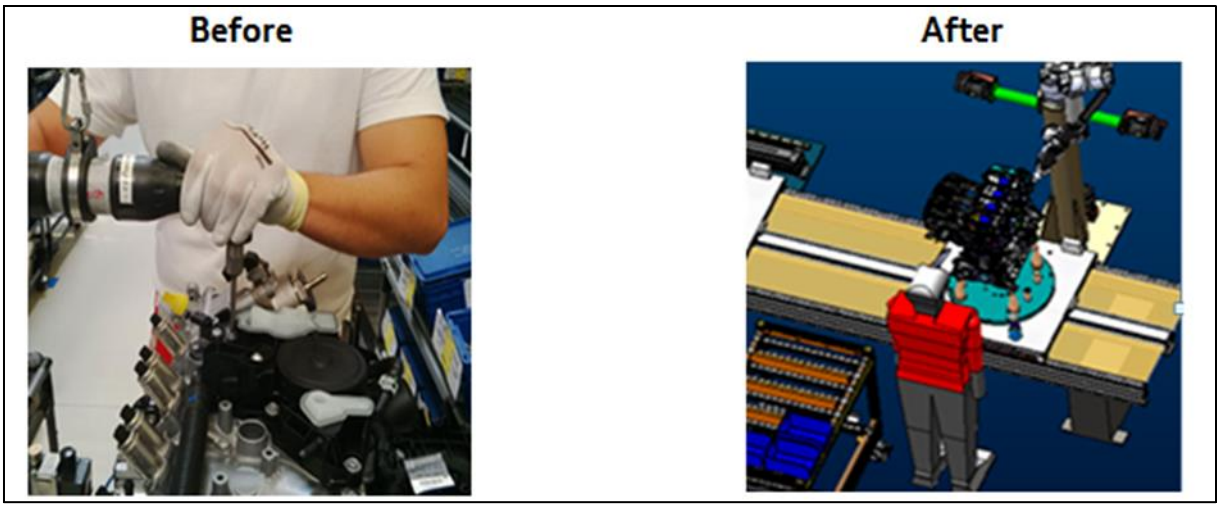

Figure 29: Screwing of Oil-Separator (adapted from: Sarkany, 2015, p. 3)

The robot successfully completely replaces a coworker for this operation, since simple screwing tasks are ideal for this type of robot. Additionally, by placing the robot on the opposite site of the assembly line, a coworker can perform a new task on the other side, both saving space and improving cycle time. The saved spaced is a significantly positive side effect on the line, since space is always a rare good for logistics and part supply. Currently the area around the robot is protected by five motion sensors creating an invisible fence in order to comply with work-safety regulations. These sensors are extremely expensive, making up for almost fifty percent of the total budget and therefore influencing the profitability of the project.

3.3.1.2 Project 2 - Sniffing Robot fuel leakage test

Previously the leakage test was conducted by a coworker with a paper-testing solution. This was problematic due to the subjective nature of such a test as well as the limited traceability and repeatability accuracy. Consequently another robot of the type UR10 was installed at this station including an automatic measurement device.

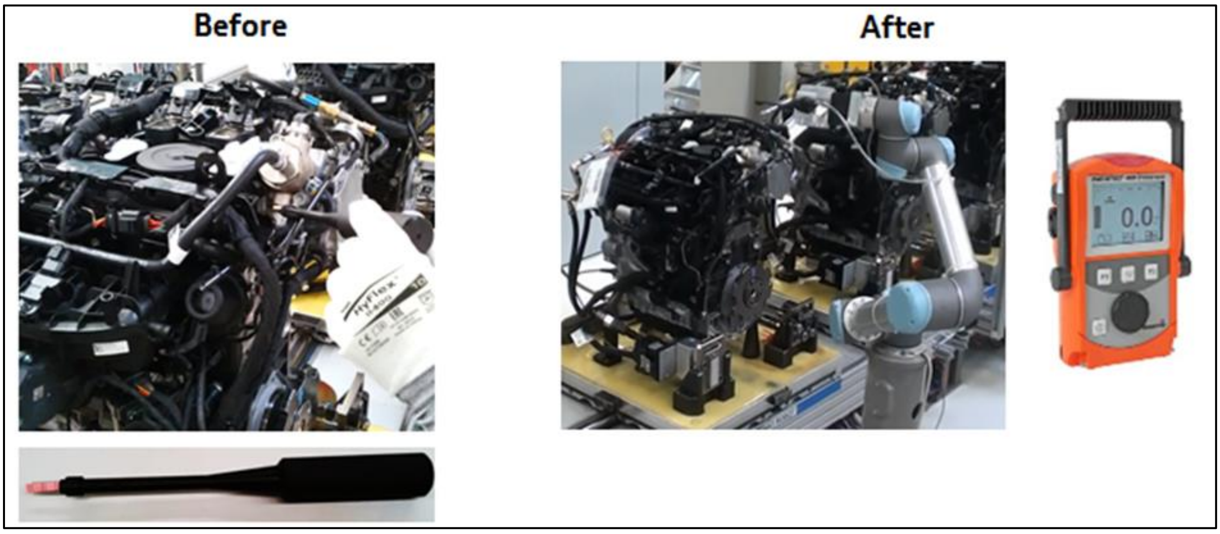

Figure 30: Sniffing Robot (adapted from: Sarkany, 2015, p. 2)

The advantages of this solution are a significant reduction of production time, a consistent traceability and an overall increase of quality. Another aspect is, that this robot could be placed between two conveyor belts in the assembly line, therefore eliminating direct contact with a coworker which means that no additional safety sensors are required.

3.3.1.3 Project 3 - Quality check during the production process

The following project is still in the implementation stage and can be viewed as an experimental Industry 4.0 project. At manual stations with many different components for assembling which are stored in separate cases, the danger of mix-up is imminent. In classical line production systems with high production volumes and various variations a coworker can easily make a mistake. At this specific workstation, four variations of lambda probes, two variations of oil-pressure switches and two variations of stud screws are being assembled. Approximately one hundred alterations of types have to be performed each day, therefore false-construction cannot be excluded. The explicit goal in production is a zero-mistake quota, which is why this project was launched. A coworker receives a wristband that checks via an ultra-sound based localization determination method the grasping movement of the coworker.

Figure 31: Ultra-Sound-Based Quality Control (adapted from: Sarkany, 2015, p. 5)

If the employee reaches for the wrong box, or the wrong parts for the current motor-type, a signal at the wristband notifies them right away. This way a mix-up is eliminated, preventing cost-intense rework at a later stage in the process.

3.3.1.4 Project 4 - Moveable Robot

This very ambitious project combines a number of challenging difficulties the line is facing and aims towards reducing cycle time spread for different engine types and distinct assembling processes at the same line. Therefore it is an ideal project for benchmarking for this thesis. As explained earlier segment P4 is assembling different types of engines on their line, one being the EA888 EVO, the other being the so-called Gen3 type. Although the engineering and planning departments work closely to keep part differences as little as possible so that existing production lines can adapt as smoothly as possible, sometimes major changes in development cannot be integrated in current machines or process steps. This can lead to an unbalanced line or cycle time spread, which has to be avoided. Especially in older assembling lines like in segment P4 and also P3, rebuilding or reprogramming of machines can only be achieved with large efforts or expensive replacement of the machinery. The on-hand example includes the screwing of the magnetic valve and the ignition coil of two engine types. These steps happen in close proximity from one another in the engine assembly sequence, additionally they don’t have further restrictions or dependencies in the process. The magnetic valve and the ignition coil of the EA888 EVO and the Gen3 engine hold unequal characteristics for assembling and consequently cannot be assembled at the same stations.

	EA888 Gen3	EA888 EVO
Magnetic Valve	Screwing in an automatic station	Manual screwing
Ignition Coil	Manual screwing	Screwing not necessary (Click System)

Table 7: Differences in Assembling Process for Two Engine Variations

Table 7 illustrates the set of problems for these parts for each engine type and their existing assembling methods. Since the engines possess a completely different set of magnetic valves they cannot be processed at the same automatic station that was planned for the Gen3 engine. A rebuild of this station would only be feasible with huge effort and would not be economical. The ignition coil however, due to a new click system, does not need screwing for the EVO engine, but is currently fixed manually for the Gen3 engine. Following this unfortunate constellation, a cycle time spread on the line is apparent. As a solution a flexible robot, type UR10, was installed on a movable platform, allowing it to independently move between two stations.

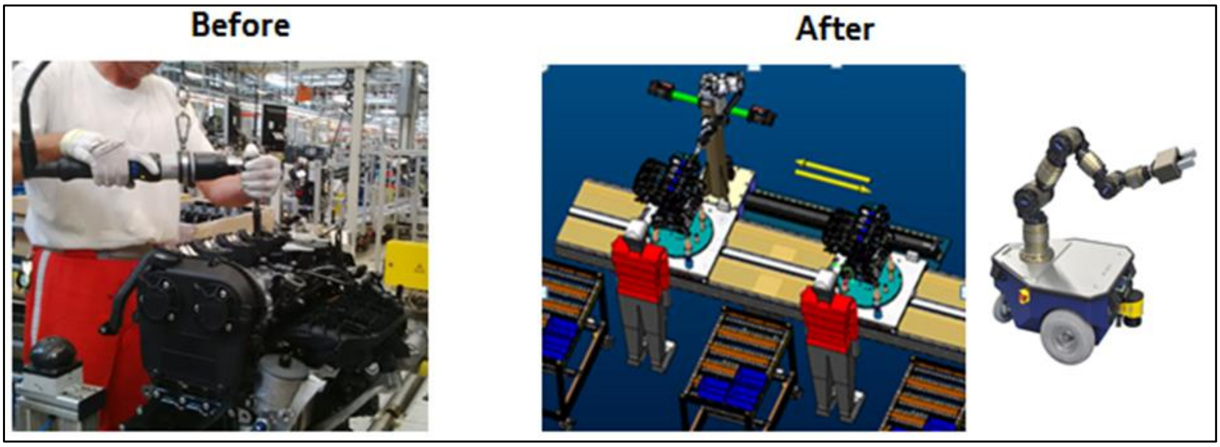

Figure 32: Moving Robot (adapted from: Sarkany, 2015, p. 4)

The before/after solution for the described dilemma is very efficient. When a Gen3 type engine is manufactured, the robot moves to the right workplace, screwing the ignition coil. However when a signal is released that an EVO engine is approaching in the line, the robot moves by itself to next workstation and conducts the screwing of the magnetic valve there, leaving space for the coworker to fixate the click-system ignition coils. This way a cycle time spread is avoided and no extra workstations need to be installed. Although it cannot be viewed as a classical human-robot-collaboration project, for the robot is still secured by numerous sensors, a human coworker can work at the same time as the robot on one work piece.

3.3.1.5 Project 5 - Roller Cam Follower assembly

This project was chosen to represent segment P3's activities for automation at the engine assembly line in this benchmarking analysis. The aim is to achieve rationalization of a workplace by replacing a human coworker by a robot. A UR10 robot was chosen to complete the task of picking eight roller cam followers per engine from a palette and placing them at the right spot in the engine block. The packaging and palletization of the parts is ideal for a robot to grab them, so that part supply can be ensured by short band conveyors, however like in the other projects an extensive safety system had to be installed.

3.3.2 Evaluation of the Projects

After having analyzed existing automation projects an evaluation is necessary to identify strengths, advantages and problems to carve out an implementation plan for further projects. Since these kinds of activities are rather new, it is vital to learn from experiences that were made and exchange knowledge between the segments. Criterions to evaluate the described projects were chosen as follows:

- Method of Automation
- Human-Robot-Cooperation
- Cycle-time Spread
- Workplace Rationalization

- Ergonomic improvement

An assessment of the project costs will deliberately not be conducted in this first stage because data from other segments is not available and numbers are based on estimates. Also some of the pilot projects do not demand direct profitability, but can be seen as pioneers for research purposes.

Project	Method of Automation	Human-Robot-Cooperation	Cycle-time Spread	Workplace Reduction	Ergonomic Improvement
1	Robot UR10	partly	no	yes	no
2	Robot UR10	no	no	yes	no
3	Ultrasound Sensor	no	no	no	no
4	Robot UR10 incl. moveable platform	partly	yes	yes	no
5	Robot UR10	no	no	yes	no

Table 8: Assessment of Benchmarking Projects

Table 8 gives an overview of the rating given for each project for the defined categories, next the conclusions drawn will be presented.

Method of Automation:
As a technique for automation, all projects involving robotics decided to choose the UR10 robot from Universal Robotics. This can be explained by the comparatively cheap price of this robot as well as the light weight. In numerous interviews with the involved stakeholders at the segment and representatives from the company responsible for the setup of the systems the conclusion can be drawn that this robot, however cheap, might not be the ideal partner for certain types of projects. Resulting from the light weight, a lack of robustness for heavy load screwing processes can for example trigger an unwanted emergency stop. This occurs when the robot, developed for human-robot-interaction falsely senses that it might be in contact with a human due to vibrations caused by the executed job. Another crucial point to take into consideration is, if high-end safety sensor systems need to be installed additionally, that are driving the costs significantly, if a HRC robot is justified or necessary.

Human-Robot-Collaboration:
Table 8 adequately shows that none of the 5 projects allows for a designation as human-robot-collaboration. Projects 2 and 3 are due to the nature of the projects not relevant for this evaluation, but the others clearly were striving for collaboration. UR10 is a classical lightweight robot that was designed for HRC including sensitive sensors to be able to react to any contact with humans. Workplace safety requirements at this point however do not allow a full HRC and

further safety sensors are necessary, limiting the potential of this type of robot and make it harder to achieve profitability. For future projects, this point has to be weighed in, before deciding for a type of robot.

Cycle time spread:

Project 4 has shown, that by detailed analysis of several process step sequences, a cycle time spread can be avoided with the help of an automated solution. In this case the lightweight construction of the robot is an advantage, making it possible to easily place it on a moveable platform therefore allowing flexible assignments for it. The positioning of the robot on the opposite side of the line also allows a coworker to fulfill additional tasks on the same work piece, further helping at reducing cycle time spread.

Workplace Reduction:

Costs and manual labor rationalization is the main driver behind all of the evaluated projects. For further projects a thorough calculation of investment costs and payback period has to be conducted. It has to be checked whether the investment in an automated solution including acquisition costs, installation costs and maintenance costs is justified. This calculation is especially important in a low-wage country like Hungary.

Ergonomic Improvement:

The investigated projects had no set goal to improve ergonomics, which is why an analysis was not performed. For future projects however an ergonomic assessment has to be conducted and the criterion of ergonomic improvement will play a larger role for decision making.

Conclusion:

The first two criterions, method of automation and human-robot-cooperation compare the system used and its implementation. The other points, cycle-time-spread, workplace rationalization and ergonomic improvement shall give an evaluation of the purpose of the activities. Based on this assessment of past and current projects, further decision factors for future projects shall be derived in order to achieve a holistic foundation for validation and decision-making. By closely evaluating and understanding the challenges and opportunities of all these projects the boundaries of an overall guideline can be set more accurately. The regarded criterions will be taken into consideration in the development of the operational guideline presented hereafter.

4 Practical Problem Solution

This chapter will present the operational guideline generated during the process of writing this master thesis. The result is a general guideline applicable to all new automation projects for the engine manufacturing process at Segment P3. The second part of the practical problem solution will be a verification of the guideline on the basis of a specific project chosen with the help of the tools provided in the guideline and afterwards thoroughly evaluated at the line. All relevant documents that were created for AUDI HUNGARIA MOTOR Kft. can be found in the appendix.

4.1 Operational Guideline for Automation Projects

The idea behind this operational guideline is to generate a consistent, uniform tool to organize, execute and assess future automation projects for the entire engine manufacturing process of segment P3. This guideline claims to be applicable for all users, whether it is on the management level or a coworker at the line detecting opportunities for improvement. Therefore it shall be available to all coworkers at the line and in the office. By establishing such a standard procedure all new projects will be directly comparable and objective decisions can be made on the basis of reproducible criterions. After execution, the documented projects will serve as representative examples and therefore facilitate and shorten the procedure for implementation of future ideas. The covered topics reach from identification of automation potentials, the entire execution process, up until evaluation of the projects and an economical assessment.

4.1.1 Describing the Initial Situation

The introduction of new engine types at the present segment, see subitem 3.1.2, the demographic development in industrial countries and the ongoing process of digitalization demand of the manufacturing and assembly lines to be more flexible including the goal of reaching a higher degree of automation. One possibility to achieve the required state is the introduction of easily transportable and reprogrammable lightweight robots at certain assembling stations. Currently no standardized procedure exists for executing these kind of automation projects at the line. The field of lightweight robotics is developing at a very fast pace and more and more products are available on the market often being cheaper solutions than classical industrial robots and more space efficient by avoiding classical safety structures. At the engine manufacturing line especially, this standard shall help raise the degree of automation.

4.1.2 Defining Goals

Overall goals of this operational guideline are:

- Clear identification of automation potentials
- Holistic assessment of automation projects

- Economical evaluation of the proposal
- Uniform comparison of different projects
- Introduction of a valid overall standard

To achieve these goals several standardized tools have been created and will be described in the following chapters. These tools need to be effective and easy to use, so any coworker with a proposal gets the chance of quickly identifying the value of their idea and have the means to work out the details and later on present them. Another positive side effect of this guideline is to raise awareness of all people involved in the production process, to detect room for improvement and get the chance to be heard by management. By the help of uniform documentation, past projects can serve as reference for similar ideas, and a culture of the will of constant improvement can evolve.

4.2 Structure of the Guideline

The specification for the skeletal structure of this operational guideline is composed as such:

- Justification of the investment
- Evaluation of the workplaces
- Technical specifications
- Economic evaluation
- Evaluation of the projects
- Basic concept

These points need to be worked through one by one as the decision of pursuing a project further often depends on a previous working step. In the following each of the points will be presented while the entire guideline and applicable tools can be found in the appendix. The structure is presented in figure 33. On the left side are the decision points that need to be passed step by step, while on the right side preparatory tasks are listed. These tasks are structured in a way, that for each heading a document respectively an excel tool is available to support the process. After having worked through the individual points of the decision tree a finished concept with collected data is on hand that describes the most important features of the automation project.

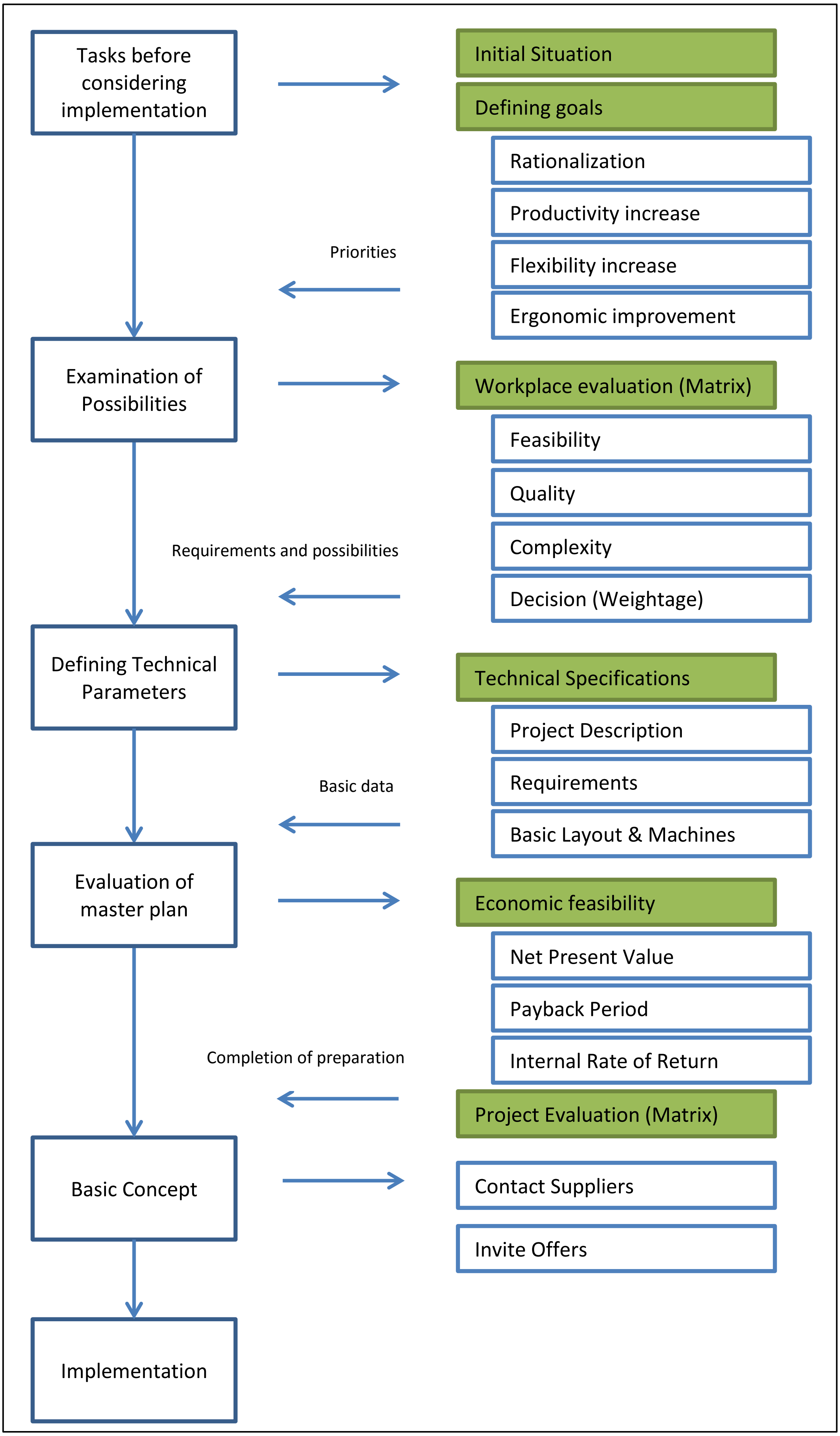

Figure 33: Skeletal Structure of the Decision Tree

4.2.1 Defining Goals - Justification for the Investment

The first step is to justify the reason behind the desire of starting a new project. There can be a vast variety of triggers for any new project in a production line, most importantly a clear reason needs to be formulated to justify an investment. Since this reason can be seen as the start of the project, it will decide the fate of success or failure at a very early stage. A justification and understandable plan needs to be formulated to underline the necessity and logic behind the idea. The core questions are, why the investment should be made at a certain station and what will be the resulting advantages for the segment.
The basic ideas for an investment in automation can be:

- Direct savings by automating a manual workstation
- Avoidance of cycle time spread
- Ergonomic improvements
- Raising the flexibility at the line
- Raising the degree of automation

It can be seen that not all reasons need to be economically justified, ergonomical improvements for example can be just as good a reason as any other. However, a clear goal needs to be established so anybody can comprehend the intention from the start. Some initiators for ideas might come directly from the line, due to the fact that coworkers often know the processes best, because they work on a day to day basis at individual stations, their suggestions are of great value. Others might come from management due to unavoidable budget targets.

4.2.2 Workstation evaluation

After clarifying the reason for an automation project, either a specific workstation is already in mind and needs to be evaluated in terms of feasibility for automation or the line in general needs to be tested and potentials for automation have to be compared. The first tool that should be used to detect a suitable workstation is the so-called workstation evaluation matrix. This matrix focuses on the most important criterions to evaluate if a workstation has the potential for automation.
The criterions are:

- Feasibility for constructional changes
- Avoidance of Cycle Time Spread
- Minor Complexity of Operation
- Ergonomic Improvement
- Employee Reduction
- Minor Risk of Technical.- & Quality losses
- No Visual Check Necessary
- Minor Variation of Components

- Simple Material Provision

These nine points for evaluation involve all important parameters to see if a workstation is a viable candidate for automation. The presented table 9 should be filled out individually by more than one person to achieve comparable results. Following this process a discussion will be held to justify the individual rating. In case more than one station is evaluated the best possible candidate is visualized and priorities can be set.

Evaluation Sheet - Workplace P3 - EA211 - Engine Assembly																
Project Nr.	AP	Operation	Details	Features	Feasibility for constructional changes	Avoidance of Cycle Time Spread	Minor Complexity of Operation	Ergonomical Improvement	Employee Reduction	Minor Risk of Technical.- & Quality losses	No Visual Check Necessary	Minor Variation of Components	Simple Material Provision	∑ Economical Evaluation	∑	Remarks
				Economical Weightage (1-3)	2	2	1	1	3	3	3	1	2			
				General Weightage (1-3)	2	3	1	2	1	3	2	2	1			
1	R1010	Engine Block Placement (ZKG Auflage)												0	0	
2	R1040	Crankshaft Placement												0	0	
3	R1060	Assembly Sealing Flange (backside)												0	0	
4	Z4020	Assembly Inlet.- Outlet Valve												0	0	
5	Z4055	Assembly Injection Valve												0	0	
6	K4070	Assembly "Unimag"												0	0	

Table 9: Workplace Evaluation Matrix

By simply evaluating one or more stations on a scale of 1 to 5 in the depicted table 9, a quick result is presented, whether or not a certain station is worth looking into in more detail. It can be seen that there are two types of weightage, one giving an overall evaluation, the other one focusing on economic factors, emphasizing the fact that the motivation or justification for an investment can be either one. This matrix should be available to everyone involved in the production process and more than one opinion can be taken into consideration.

4.2.3 Technical Specifications

Technical specifications can be formulated after a project has passed the feasibility assessment of the workstation evaluation matrix. According to the DIN Norm 69901-5:2009-01 (Project management - Project management systems - Part 5: Concepts) technical specifications should include the "entirety of requirements for supplies and performances for contractors within a (project-) order". Generally the technical specifications will be drafted by the client as a basis for obtaining offers. The advantage of handing over the technical requirements to a contractor is that they have expert competences in the regarded field (Angermeier, 2009). The aim behind the prior investigation with the help of the workstation evaluation matrix is, so that no resources are wasted on formulating time-intense documents before a project provides a promising outcome. The principle layout of the technical specifications includes a project description and a list of requirements. These can vary from company to company. For this operational guideline main points were established in cooperation with the technical supervisor.

1. Project description:
    a. Introduction and objective target
    b. Product overview and Application
    c. Current state
    d. Description of the Target State

2. Requirements:
    a. Functional requirements
    b. Non-Functional Requirements
    c. Technical basics
    d. Quality Requirements
    e. Requirements for Space (Floorplan Layout)
    f. Material Provision
    g. Operational Requirements
    h. Safety Requirements
    i. Time Requirements and Deadlines (Project handling)
    j. Site of Installation

After having worked through these points, the project is ready to be evaluated economically, a basic idea of required machines and surrounding structures has been established and so costs can be estimated. At a later stage these technical specifications can be transferred to the project specific part[5] of the official AHM document provided by the planning department.

4.2.4 Economic Evaluation

An economic evaluation is a challenge at an early stage of any project, especially when offers have not yet been made to suppliers. The usual routine would involve the controlling department, which decides about the clearance after offers have been returned from suppliers and implementers. The idea behind making a very basic calculation tool accessible to all workers is, that before the process of establishing a detailed concept and performing work intense preparation, it can be illustrated if a project even has the chance of getting cleared. This saves time and enables any worker to get an idea whether to carry on with their efforts. Also it can be used as a backup to support the case when introducing it to supervisors or management. In close cooperation with the controlling department the criterions for an investment calculation have been analyzed and an excel tool has been created. Within the boundaries of its limitations, investment costs can be directly compared to possible savings,

[5] The entire document is made up of standard requirements for suppliers of AHM. The project specific part is formulated individually for each project.

while at the same time payback period, net present value and internal rate of return are calculated. The precondition was to make a well arranged, easy to use tool, with conventional company internal calculation methods. The result can be seen in table 10. There are simple input boxes where investment costs and savings can be filled in, while the tool calculates and illustrates the most important data on a separate sheet.

Input							
Investment [€]				**Salary Savings [€]**			
		Kosten	Typ	Workplace	No. of coworkers		1
Type	Device	50000			3-Shifts		
	Attachments	50000			Assembly		
	Safety System	10000					25000
	Installation	3000			Own value		0
	∑	**113000**				∑	**75000**

Table 10: Input Parameters - Investment Calculation

For Investments (left side) four different boxes can be filled in, initially with estimations and at further stages with exact data. For savings of a workplace (right side) some parameters have to be chosen.

- Investments include: Costs for the automation device (e.g. robot, automation machine), attachments (e.g. gripper), safety systems (e.g. sensors) and installation costs. This data provides a sum of the total investment.
- Savings are summed up as follows: The user can chose the amount of saved workplaces, the type of shift system and the wage category, giving a total sum of savings. The wage category can either be mechanical processing or engine assembly, since the basic salary differs, or the user can fill in an own value.

As soon as this data is determined, all necessary values for an investment decision are being calculated and provided to the user in the manner depicted in table 11.

Net Present Value (9% tax)		176.514 €	NPV
Payback Period		2,494	Years
Internal Rate of Return		44%	IRR

Table 11: Output - Investment Calculation

These are:

- Net Present Value
- Payback Period
- Internal Rate of Return

Following internal guidelines, an automation project must not have a payback period of more than two years. Net present value and internal rate of return both need to have a positive value and according to company guidelines need to satisfy the requirement of 9% internal interest rate at a minimum. Finally the user is provided with a structured report that can be printed and attached to the previously generated data. The report sheet is held in a simple manner so that the user only needs to fill in personal data like, name, date and project title. The other numbers are provided automatically in a systematical way, so that only the most important data is provided and a well-structured report can be handed in. Until now this was only possible after offers from suppliers have returned and controlling calculated the exact numbers. Now the department can internally perform an approximation and right away see the results in a report sheet, exemplary depicted in table 12.

Economic Calculation P3 - EA211			
Editor		Date	
Project Title			
Initial Values	Sum of Investment	113.000 €	
	Workplaces Saved	1	
Calculated Values	Net Present Value	176.514 €	
	Payback Period [years]	2,49	
	Internal Rate of Return	44%	
Comments:			
Recommendet course of action:			

Table 12: Report Sheet - Investment Calculation

Furthermore this sheet provides the possibility for entering comments and suggestions for a course of action. One of the aims is to empower every user to see behind- and understand the reasons behind monetary decisions.

4.2.5 Project Evaluation

Finally the regarded project can be evaluated as a whole. A project evaluation matrix helps guiding through the entire process to build the final basis for decision making. Major points need to be evaluated before being ready to introduce the project to a broader group of people. Besides the economic.- and payback period calculation, aspects established in the technical specifications and a basic concept of the method of automation are regarded individually. As can be seen in table 13, the project evaluation matrix on the one hand gives a revision of the so-far processed documents and gives an opportunity to rate the individual points accordingly, on the other hand it gives a final evaluation of the project. For reasons of simplicity and manageability the rating is kept in a classical traffic light format to clearly show the excellent, sufficient and insufficient parameters.

3	= excellent
2	= sufficient
1	= insufficient

On the right side (table 13), once again the provided tools of this general operational guideline as a basis for profound judgment are listed. (Workplace Evaluation Matrix, Technical Specifications, Economic Evaluation Tool).

Evaluation Sheet - Projects **P3 - EA211 - Automation Projects**						
			Project 1	Project 2	Project 3	
Criteria		Process (Feasability)	1	2	3	Work Place Evaluation Matrix
		Ergonomics	2	3	1	
	Method of Automation	Human-Robot-Collaboration	3	1	2	Technical Specifications
		Full Automation	1	2	3	
		Modular Application	2	3	1	
		Occupational Safety	3	1	2	
		Payback Period	1	2	3	Economic Evaluation Tool
		Economic Evaluation	2	3	1	

Table 13: Project Evaluation Matrix

Each individual point needs to be addressed and evaluated on a scale from 1 to 3. This needs to be done in a team consisting of coworkers and technical supervisors. The matrix can be used for evaluation of one or more projects. A basic idea of the means of realization needs to be available at this point to make an estimation of the costs and the type of automation machines that will be used. A reevaluation can be made at a later stage, after offers have been formulated. With the help of this method either a comparison of different projects can be visualized, or individual insufficient preconditions can be carved out. Only after having a worked through the entire matrix and no insufficient points have been detected, moving onwards to defining a basic concept is reasonable. Again this avoids wasting time and realizing if a project is feasible at an early stage.

4.2.6 Basic Concept

The final point in this operational guideline includes the assembly of all data in a structured map, including all excel sheets, technical specifications and evaluation sheets. These serve as a basis for the concept which then will be presented to either the technical supervisor or the management. With the help of this guideline the process of introducing new ideas receives a new structured way, providing all employees, no matter the position, with the necessary tools to pitch ideas or realize an entire project, while saving time and effort and opening room for new innovative thinking in the workforce.

4.3 Concept verification – Sealing Flange Module

In order to verify the effectiveness and practicability of the described operational guideline, hereafter a workplace evaluation is conducted and the guideline is implemented on the identified workstation. The justification for investment is detailed described in the previous chapters.

4.3.1 Choosing a workstation

Identifying a suitable workstation to test the formulated operational guideline was done on the basis of the results of a workshop (3P workshop). Since the segment currently is facing the above described restructuring process, the issues are tackled involving all departments in a guided workshop, designed to help integrate the new engine types smoothly. During this workshop, several stations turned out to show the necessity for remodeling in order to suit the future production challenges. Main issues were the rise of capacity to 1700 engines per day and therefore a reduced cycle time of 46,32 seconds per station. Also significant differences in the assembling process for the new engine types showed for some stations. By evaluating the identified workstations with the help of the workstation evaluation matrix, two workplaces turned out to be most suitable for automation. One is the crankshaft placement, the other the assembly of the sealing flange module. The premise was given by the technical supervisor that at this stage the focus should lie on looking into an economically feasible solution. Planning department took over the investigation of workstation R1040, crankshaft placement, while workstation R1060, sealing flange, was chosen to test this operational guideline and will be presented in subitem 4.3.2. The exact procedure will be described in the following subitems.

4.3.1.1 3P Workshop

The so-called 3P workshop for the engine assembly line was conducted in three stages, since the necessity to get to know the new engines thoroughly was evident. 3P stands for Production-Preparation-Process, giving different involved departments the opportunity to discuss and tryout problems and solutions the introduction of the new engine types might bring with it. The stages were divided upon calendar weeks 10, 16 and 24. In the first stage each individual workstation was analyzed and all three engines were compared whether or not the workstations show similarities or differences. The other two workshop weeks were used to

define problems concerning cycle-time spread. The participants include engineering, planning and technical supervisors.
Goals of the workshops are clearly defined by Mr. Károlyi and Mr. Buga (2016, p. 3) as:

- Identifications of differences
- Identification of synergies
- Identification of critical steps in the process
- Addressing strategic topics like Industry 4.0

While premises include:

- Increase of capacity from 1500 to 1700 engines/day
- EA211 R4 serial engine, EA211 R4 EVO and R3 EU6ZD need to run on one line
- Introduction of turn able palettes

A classic worksheet produced for a workstation is illustrated in figure 34.

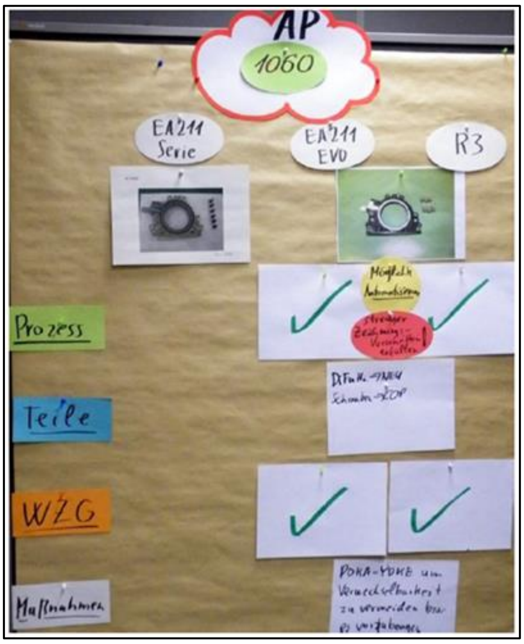

Figure 34: 3P Process for AP1060 (Buga & Karolyi, 2016, p. 44)

During the workshop, every single workstation was regarded individually in the order concerning the process, work pieces and tools involved. This is was done for all new engine types compared to the currently produced serial engine and at the end ideas for measures were discussed. As a result, 26 stations in the area of short engine, 5 stations in the area of cylinder head, and 40 stations in the area of complete engine assembly were analyzed. Additionally a restructuring of the test bay was discussed. Finally 107 measures were defined, including an evaluation whether automation is possible at certain workstations. For this thesis focuses on automation potentials, those automatable stations are most relevant:

- R1010 Engine Block Placement
- R1040 Crankshaft Placement
- R1060 Assembly Sealing Flange (backside)
- Z4020 Assembly Inlet.- Outlet Valve
- Z4055 Assembly Injection Valve
- K4070 Assembly "Unimag"

R… Short Engine
Z… Cylinder Head
K… Complete Engine

After having participated in the workshop, the input was picked up for testing of the operational guideline. The input was processed with the help of all the tools that were introduced earlier in chapter 4.

4.3.1.2 Workplace Evaluation Matrix

For defining the feasibility of automation of the identified stations, the workplace evaluation matrix is used. All six stations were visited at the line and the processes were studied precisely. Later the matrix was filled out and weighed generally as well as economically.

Evaluation Sheet - Workplace P3 - EA211 - Engine Assembly																
Project Nr.	AP	Operation	Details	Features	Feasibility for constructional changes	Avoidance of Cycle Time Spread	Minor Complexity of Operation	Ergonomical Improvement	Employee Reduction	Minor Risk of Technical.- & Quality losses	No Visual Check Necessary	Minor Variation of Components	Simple Material Provision	∑ **Economical Evaluation**	∑	Remarks
				Economical Weightage (1-3)	2	2	1	1	3	3	3	1	2			
				General Weightage (1-3)	2	3	1	2	1	3	2	2	1			
1	R1010	Engine Block Placement (ZKG Auflage)			5	1	3	4	3	5	1	4	3	56	55	
2	R1040	Crankshaft Placement			5	3	4	4	5	5	4	4	3	76	70	
3	R1060	Assembly Sealing Flange (backside)			5	1	4	2	5	5	5	5	4	76	65	
4	Z4020	Assembly Inlet.- Outlet Valve			4	1	4	1	5	2	4	4	3	58	47	
5	Z4055	Assembly Injection Valve			4	4	3	1	5	5	4	4	3	72	64	
6	K4070	Assembly "Unimag"			4	1	4	4	4	5	5	4	3	70	63	

Table 14: Workplace Evaluation - Projects 3P

As seen in table 14, two stations can be identified as most promising to automate. The first one being Crankshaft Placement with a general score of 70 points and an economically weighed score of 76. The second station is the sealing flange (backside) assembly station with a general score of 65 and an economically weighed score of 76 also. The decision was made to further look into automation possibilities for both stations. This thesis will deal with the sealing flange assembly station, while the planning department will work on the crankshaft placement station. The presented workstation, “AP R1060”, R stands for short engine, 10 for team 1 and 60 for station 6, includes the assembling steps of pressing the sealing flange module on the backside of the crankshaft, as well as positioning six screws for a posterior screwing process in the right holes. The entire evaluation sheet and the technical specifications can be found in the appendix. A short introduction will be made in the next subitem.

4.3.2 Sealing Flange Module

The sealing flange module has the function of providing a static and dynamic sealing between the crankshaft and the crankcase, plus measuring the rotational speed of the crankshaft and measuring a reference mark with a transmitter wheel and an engine speed sensor (Hoepke & Breuer (eds.), 2013, pp. 497-498). The tasks can be summarized as such:

- sealing
- engine speed measurement
- determination of exact position of the crankshaft
- constitution of the injection.- and ignition point

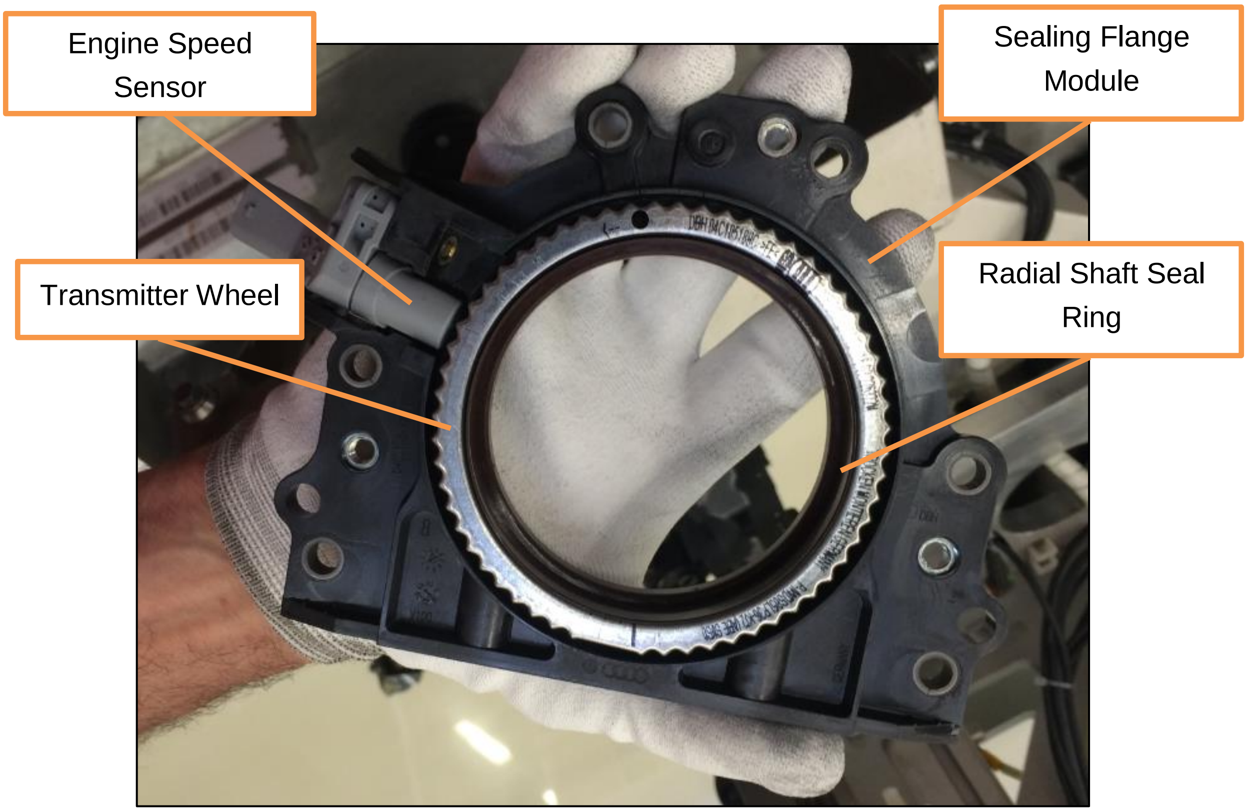

Figure 35: Sealing Flange Module

The engine speed sensor is integrated into the sealing flange (figure 35), which in turn is screwed onto the cylinder block. It has the task of scanning a 60-2 transmitter wheel on the crankshaft and on the basis of these signals the engine control unit determines the engine speed. A 60-2 wheel has the characteristics that there are 58 defined cogs on the rotor with a tooth-gap of two. The gap serves as such, that a predefined crankshaft-angle before the top dead center can be recognized. With the help of this data the point of injection time, the duration of injection and the point of ignition time can be arithmetically specified (Meinig, von Geisau, & Kammerer, 2002, pp. 280-287).

4.3.3 Justification for Investment

The overall goal is to automate a manual workstation completely and in effect save labor costs of one coworker. This project additionally has the character of a trailblazer-project at the engine assembly line for further automation in consideration of the fact that in the near future four different types of engine will be assembled at this line. Flexibility of the automation solution, as well as automatically distinguishing between types, without forfeiting any quality characteristics is the primary objective. Summarized the following justifications for an investment were deducted:

- automating a manual workstation
- reducing labor costs
- establishing a trailblazer project

4.3.4 Workplace Evaluation

Following the results of the general workplace evaluation done after the 3P workshop, see subitem 4.3.1 above, the outcome can be seen as persuasive especially under the light of an economic weightage. Table 15 describes all the criterions that were evaluated in the workplace evaluation matrix and further led to the decision to pursue automation at this station.

Criterions	Assessment	Description
Feasibility for constructional changes	5	The floorplan of this assembly station provides enough room for reconstruction and introduction of new automated machines.

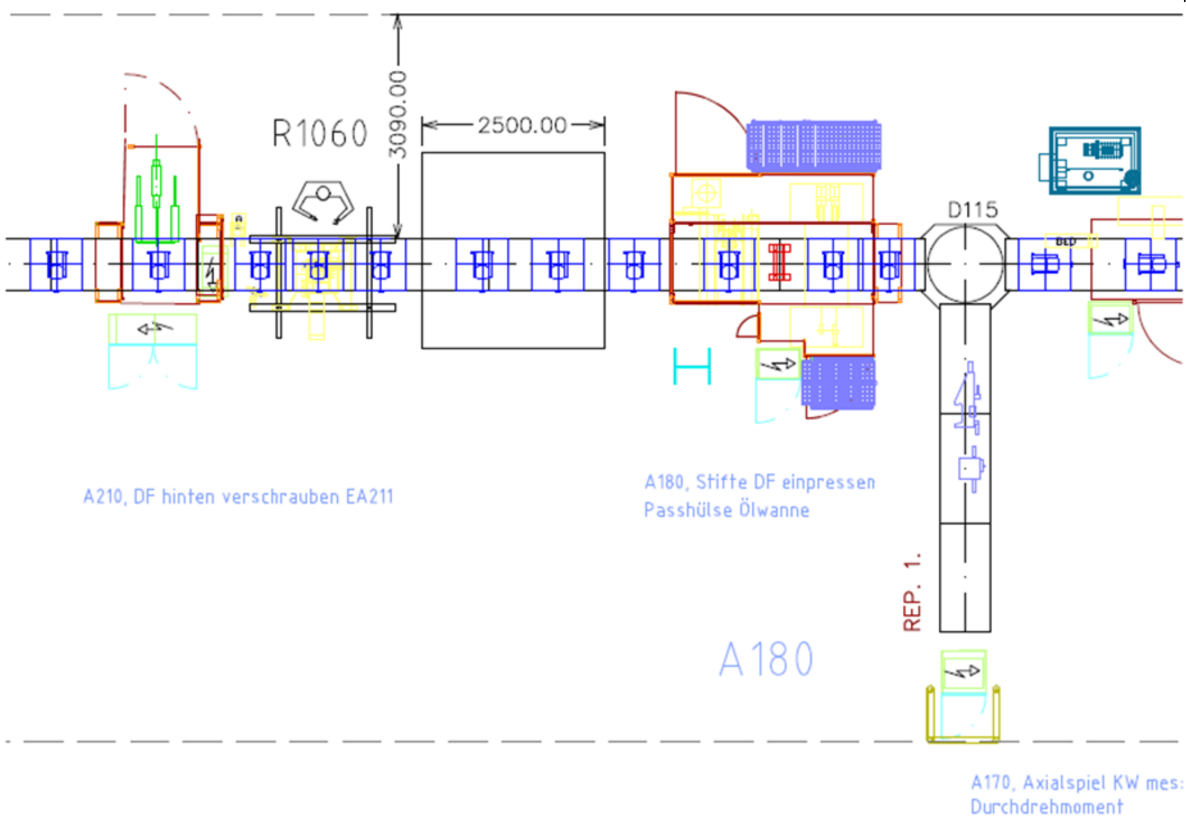

Figure 36: Floorplan - Station R1060 Sealing Flange (Szabo, 2016)

Criterions	Assessment	Description
Avoidance of Cycle Time Spread	1	There is no cycle time spread to be expected at this station, all engine variations require the same assembling steps
Minor Complexity of Operation	4	The process for picking, placing and pressing the sealing flange module as well as positioning the screws is well automatable. However due to the amount of process steps there is a slight deduction in the evaluation
Ergonomic Improvement	2	There is no big ergonomic improvement to be expected since this station already satisfies ergonomic requirements. The

Criterions	Assessment	Description
		module itself is low-weight, the pressing activity is guided by a fixed press
Employee Reduction	5	After the automation of this assembly station one coworker will be able to be let go. In a three-shift system that amounts to a total of three employees for the cost-calculation
Minor Risk of Technical.- & Quality losses	5	There is no influence on quality or technical issues to be expected. Sensors will be able to precisely distinguish modules from one another
No Visual Check Necessary	5	The modules are provided in special containers so that they already have a high degree of quality assurance. Sensors of the automated system will be able to detect any problems with a batch
Minor Variation of Components	5	There are small variations between the modules for the different types of engines, however a visual camera sensor can simply distinguish between them

Criterions	Assessment	Description
 Figure 37: Protective Cap		
Simple Material Provision	4	The existing containers can be used. The parts are perfectly sorted and simple to be extracted, however a transport system will need to be installed to lead them to the reaching radius of the robot
 Figure 38: Material Provision Box		
Sum	**65**	Multiplied with the general weightage key
Sum (Economical Weightage)	**76**	Multiplied with the economic weightage key

Table 15: Evaluation of Station R1060

Weightages are distributed between 1 – 3 and give an emphasis on the field that is prioritized. The economic weightage prioritizes the points employee reduction, minor risk of technical.-

and quality losses, no visual check necessary and simple material provision over the general weightage. It is especially important that no quality loss or technical risk is being taken. The later an issue of this type occurs, the more cost intense the adjustment will be. A total sum of 65 after the general rating, and an explicit sum of 76 following the economic rating make the station R1060 a perfect candidate for automation. Following the established guideline, next the technical specifications have to be formulated. However, owed to the size of the document of technical specifications, it can be found in the appendix. A process description will be made hereafter to define the desired type of automation and in turn a rough economic calculation can be conducted.

4.3.5 Process

The current-state process has to be described in detail and be fully understood before describing a desired target state after the automation project is completed. The sealing flange (incl. crankshaft-seal ring) and transmitter wheel are always mounted conjointly. For the assembling process both have to be correctly positioned on a mounting device. To avoid inversion of the sealing lip of the radial shaft seal ring, a special bell-shaped positioning tool is placed on the shaft. Without this tool it is not possible to position the transmitter wheel exactly (Meinig, von Geisau, & Kammerer, 2002, pp. 285-287). To ensure the right accuracy of the mounting device, its tolerances have to be measured two times per shift.

Figure 39: Mounting Device - Sealing Flange (Pichler Werkzeug, n.d., p. 30)

The in figure 39 illustrated mounting device is exemplary for the tool used to correctly position the sealing flange module. It is integrated on an a press system and guided by a co-worker.

4.3.5.1 Current State – Operational Steps

The current state of the entire process can be described in twelve operational steps:

1. Arrival of the engine block:
   The engine block pulls into the station, and stops at the right position.
2. Extraction of the sealing flange module:
   A coworker picks the module out of the delivered box.
3. Positioning on the press equipment:

The transmitter wheel is positioned on the mounting device. A thorn helps finding the exact position.

4. Approaching to the crankshaft:
   The coworker places the sealing flange module in front of the crankshaft.
5. Pressing:
   By pushing 2 buttons the module is pressed onto the crankshaft.
6. Force/Displacement measurement:
   Force and displacement are measured automatically and have to be within the range of tolerances.
7. Removal of protective cap:
   The coworker removes the plastic protective cover that remains on the positioning tool.
8. Transport of protective cap:
   The coworker throws the protective cap into a bin.
9. Re-Positioning of the engine block:
   Engine block moves aside of the pressing tool in order to have room for placing the screws.
10. Extraction of screws:
    The coworker picks 6 screws out of an unsorted box.
11. Fixing the screws:
    The coworker positions the 6 screws in the holes.
12. Pulling out of the station:
    The coworker presses a button, initiating the engine block, incl. pressed sealing flange module and positioned screws to leave the station.

4.3.5.2 Target State

The manual workstation shall be replaced with a combination of a light weight robot and an automatic screwing/fixing system that operates fully automatically. The desired future state should be organized in the following sixteen steps:

1. Arrival of the engine block:
   Engine block pulls into the station, and stops at the right position
2. Extraction of the sealing flange module:
   A robot picks the module out of the delivered box
3. Identification of the module:
   A recognition sensor checks the type of module that has been extracted (e.g. a camera system distinguishes the colors of the protective cap)
4. Positioning on the press equipment:
   Provided with sensors, the robot determines the exact position of the transmitter wheel and positions the sealing flange module exactly on the pressing device (e.g. by latching of a positioning stud)
5. Checking crankshaft position:
   It has to be once more ensured that the crankshaft position is correct (positioning happens in the previous station)

6. Approaching to the crankshaft:
   The press places the module automatically at the predefined position in front of the crankshaft.
7. Fixation of the engine block:
   Engine Block has to be fixed to endure pressing forces.
8. Pressing:
   Pressing is done automatically.
9. Force/Displacement measurement:
   Force and Displacement are measured automatically and have to be within the range of tolerances.
10. Removal of protective cap:
    By a short retraction movement the plastic protective cover, that remains on the positioning tool, is pushed off by a thorn.
11. Transport of protective cap:
    The protective cap falls onto a small transport band that moves it to a bin.
12. Re-Positioning of the engine block:
    Engine block moves aside of the pressing tool in order to have room for placing the screws.
13. Extraction of screws:
    A vibrating machine pre-sorts the screws and transports them pneumatically to a screwing head.
14. Fixing the screws:
    The screwing head is fixed on a robot that places them into the 6 positions.
15. Pulling out of the station:
    The engine block, including the pressed sealing flange module and positioned screws leaves the station.
16. Trouble Shooting:
    In case of any dysfunction in the process (e.g. wrong crankshaft position, incorrect force/displacement measurement, faulty fixation of the screws…) the engine block has to automatically move to the reworking station

After defining the current situation in detail and comparing it to the desired target state the main differences can be seen in the process steps involving extractioning, identification, positioning, checking, removal and screw-picking (points 2, 3, 4, 5, 10 and 13). These steps have in common that they need the precise dexterity comparable to a human hand and the cognitive abilities of a human. The other steps are programming tasks perfectly handle able by a machine. Therefore the choice of the right type of automation will be crucial in order to fully replace a human.

4.3.6 Technical Specifications

The official document for technical specifications at AHM is split into four parts and 302 pages. It includes a general part where basic parameters and terms of the contract are described, a technology specific part regulating framework of technological requirements, a project specific part, dealing with the regarded assignment and the fourth part consisting of further applicable documents. The content of the project specific part of the technical specifications are defined in subitem 4.2.3. and are individually defined for each project. The other parts are general rules defined by Audi Hungaria. In the appendix the project specific part of the technical specifications developed for this thesis sent to suppliers can be found. Due to its length it will not be displayed in the main part of this thesis.

4.3.7 Type of Automation

The objective of automating this workstation and replacing a coworker, as well as introducing new robot technologies at the assembly line defines the type of automation that shall be used in this project. In order to fully replace a coworker, two robots will need to be installed, one of whom is a classical pick-and-place robot with a gripper, the other one a screwing robot with an additional screwing head and screw supply lines. Exemplified a sketch of the future working station will look as depicted in figure 40.

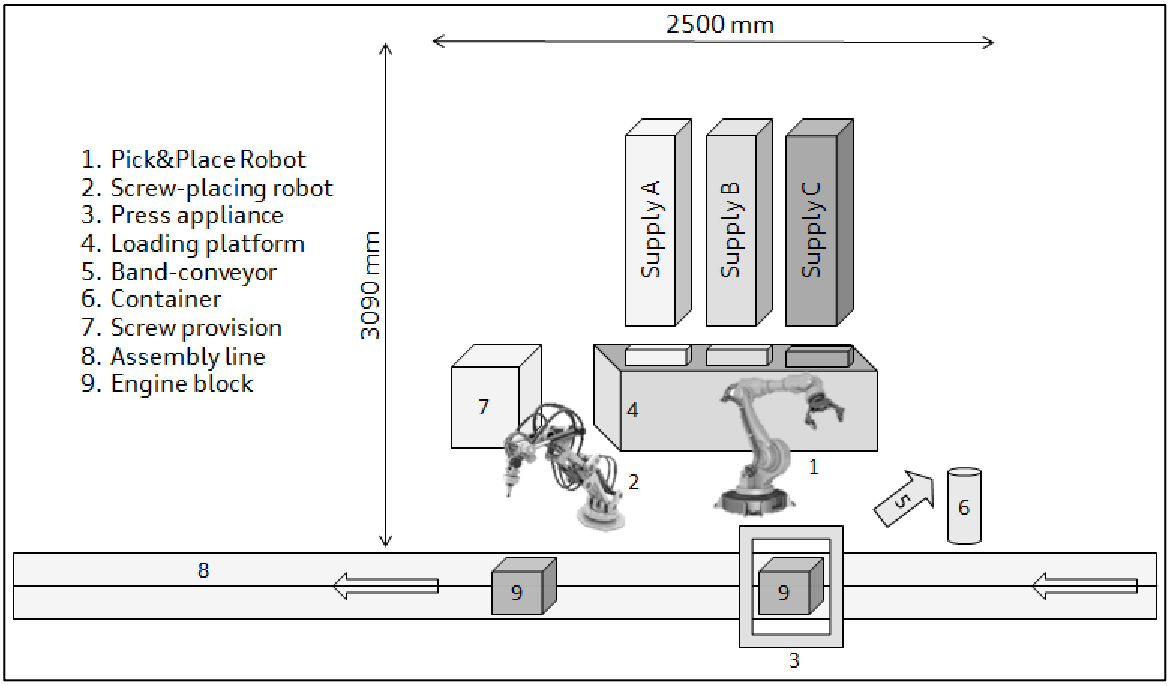

Figure 40: Concept of the Automated Workstation (own illustration)

Upon arrival of the engine block a pick&place lightweight robot will position the sealing flange module onto the press system. At the point of extraction from the loading platform, the right module for the right engine needs to be picked by the robot requiring an additional camera-based sensor system on the robot arm. The press appliance will be provided by the supplier and needs to satisfy the same purpose as the current system plus an additional removal mechanism for the plastic protective cover. A small conveyor band will fulfill the purpose of transporting the used covers into a bin. After pressing, the engine block moves to its next position where a second lightweight robot will place the screws into the holes. This system consists of a screw separator device to pre-sort the screws which then drop into a pneumatic tube. The screws are further transported through the tube to the screwing head and one by one fed to the screwdriver fixed on the robot arm. The robot arm is programmed to fix the screws on 6 positions, seen in the overlapped hole pattern for all relevant engine types in figure 41.

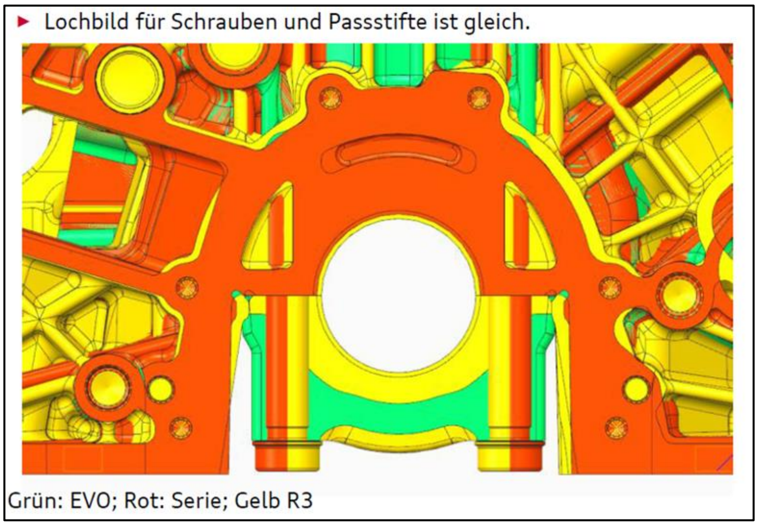

Figure 41: Hole Pattern - Serial and New Engine Types (Szalai, 2015, p. 4)

Facilitating the programming task for this robot is the fact that the screw hole positions of all engine types are located at the same coordinates. After the screws have been placed the cylinder block can move to the next station. The necessary automation devices can now be formulated accurately under the prerequisite of a more flexible and ideally reusable type of automation. This can be achieved by establishing two lightweight robots with individually interchangeable tools or grippers. Accessories are the screw separator, the screw transport tube and the transport band as well as necessary sensors for part distinguishing and precise placement. The necessary devices to realize this project are collected in table 16. These are conceptional, depending on the supplier different brands might be in the final realization.

Device	Price [€]
Robot 1	25.000
Robot 2	25.000
Gripper	1.000
Screwdriver unit	5.000
Screw feeding system	9.000
Transport band	5.000
Press (incl. Pressing Thorn)	40.000
Safety-Sensors (3x)	15.000

Installation & Central control unit	8.000
Sum	**133.000**

Table 16: Basic Components of the Automated Assembling Station

Prices of the components are based on publically available data and estimations deducted from several interviews conducted at the fair *“Smart Automation Austria”* in May 2016. Exact numbers will be provided by the implementing company after offers have been compared. For the purpose of a rough calculation these numbers are accurate enough to get an idea about the feasibility of restructuring this workstation. The overall estimated sum for this investment is 133.000 € and will in the next steps be put into the cost calculation tool to identify economic potentials.

4.3.8 Economic Calculation

After defining all relevant criteria for the regarded project, a rough price estimation led to the sum of 133.000 Euros for the entire system. Under the prerequisite of saving costs for one full employee in a three shift working plan and the given number of costs per worker at the engine assembly line being 25.000 Euros per year this gives a total of 75.000 €/a savings.
Applied to the Economic calculation tool in excel this provides the following data.

Type	Value
Net present Value	170.550 [€]
Internal Rate of Return	39%
Payback Period	2,75 years

Table 17: Values of the Economic Calculation

It can be seen in table 17 that, although a clear positive net present value and a high internal rate of return is given, the payback period is still over three years of time. Figure 42 compares the accumulated net present values and illustrates the payback period of this investment.

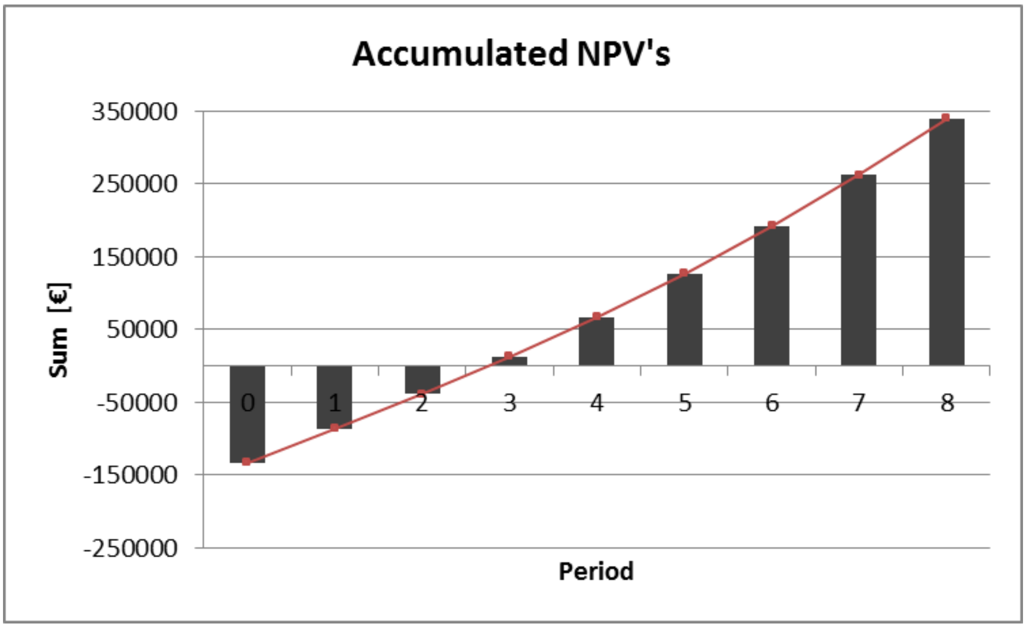

Figure 42: Payback Period

According to internal regulations, a project of this size however must not have a higher payback period than two years. Definite offers of suppliers must be waited for to be able to make a final decision about an investment decision but regarding the current numbers a release from the controlling department is unrealistic.

4.3.9 Project Evaluation

Following the structure of the introduced operational guideline at this point the project evaluation matrix can be filled in. Data about the feasibility, technical requirements and the rough economic estimation are available and provide the most important information for a decision. Table 18 illustrates the evaluation for the on-hand workstation according to the previously collected data.

Evaluation Sheet - Projects P3 - EA211 - Automation Projects			
			AP R1060
Criteria		Process (Feasability)	3
		Ergonomics	2
	Method of Automation	Human-Robot-Collaboration	2
		Full Automation	3
		Modular Application	3
		Occupational Safety	3
		Payback Period	1
		Economic Evaluation	2

Table 18: Project Evaluation AP R1060

The first two criterions that were evaluated with the help of the workstation evaluation matrix get an excellent and sufficient rating. During the thorough evaluation of the whole process, the workstation turned out to be a perfect candidate for automation, an ergonomic improvement is not the focus of this project and therefore it is rated neutrally. The next group of criterions is summarized as method of automation, it can be evaluated after defining the technical specifications. The goal for automation for this workstation is full automation, however the choice of automation appliances is a modular system, reusable in any way. By choosing lightweight robots, a human-robot-collaboration could even be realized in the future. When choosing the right type of lightweight robots both criterions, full automation and modular application can be implemented perfectly and get an excellent rating. Also the possibility for future human-robot-collaboration at this workstation is given and therefore a neutral rating is given allowing for further investigation into this option. Criterion occupational safety is rated excellently because the robot chosen for automating this workstation are categorized as lightweight robots fulfilling all common safety standards. When turning this station into a HRC workplace this criterion has to be reevaluated in accordance with suppliers and internal safety inspectors. The last two criterions can be answered after conducting the economic calculation. As can be seen the payback period does not fulfill the strict standard of two years and therefore it has to be rated as insufficient. The overall economic calculation is still sufficient because internal rate of return and net present value clearly show the economic potential. However an insufficient rating in the project evaluation matrix is a knock-out cause and the project cannot be realized in the described way. After consultation with the technical supervisor a decision was made to find alternative ways to conduct automation for the assembly of the sealing flange module. A possibility for the further handling of this project will be discussed in subitem 4.3.10.

4.3.10 Alternative Handling

This station shows great potential for automation and also a necessity for restructuring the assembly line is given, therefore a solution will be further aspired. A major criterion for looking further into realizing the regarded project is the fact that currently no emergency strategy is in place. Meaning, if the existing press fails, production would have to stop. In order to be able to handle the new engine types and shortened cycle times, a new press will have to be purchased to have an alternative plan. During the detailed examination of this workstation the opportunity for automation clearly showed, making it interesting to investigate in alternative ways to achieve the desired implementation. Hereafter an alternative strategy for this workstation will be contemplated. First of all the distribution of the project costs need to be individually examined to get an idea about the major cost drivers (figure 43).

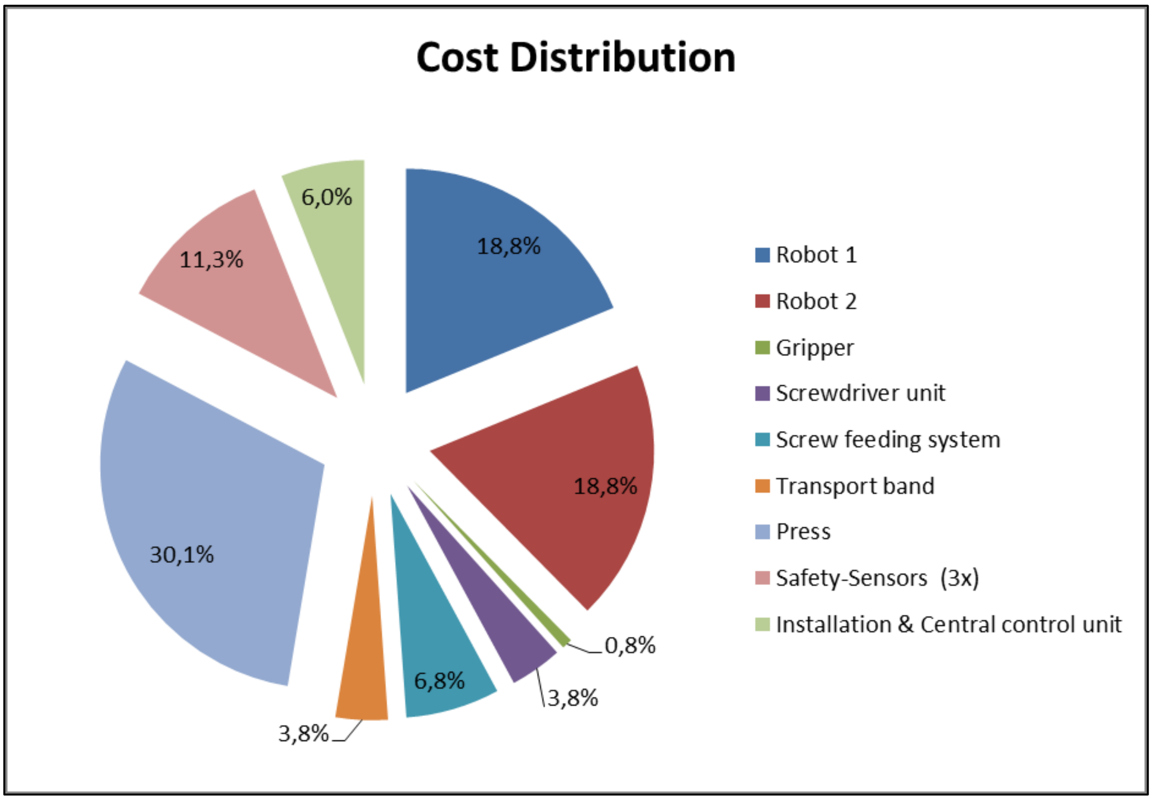

Figure 43: Cost Distribution of the Automation Project

Taking a closer look at the cost distribution of the project in figure 43 some numbers evidently come to attention. The highest cost drivers are the press, the two robots and the safety sensors. The press sticking out especially generating over thirty percent of total project costs. Keeping in mind the inevitable purchase of a new press, the suggestion for splitting up the project into two parts comes to mind. One part is the renewal the press and at the same time realizing an emergency strategy, the other one is the rise of degree of automation and saving of costs for one workplace by implementing two lightweight robots. This means that this project will have to be handled in two stages, the first one being the renewal of the press already considering the compatibility with a robot. And at a second stage implementing the proposed robotic system to save costs of an employee.

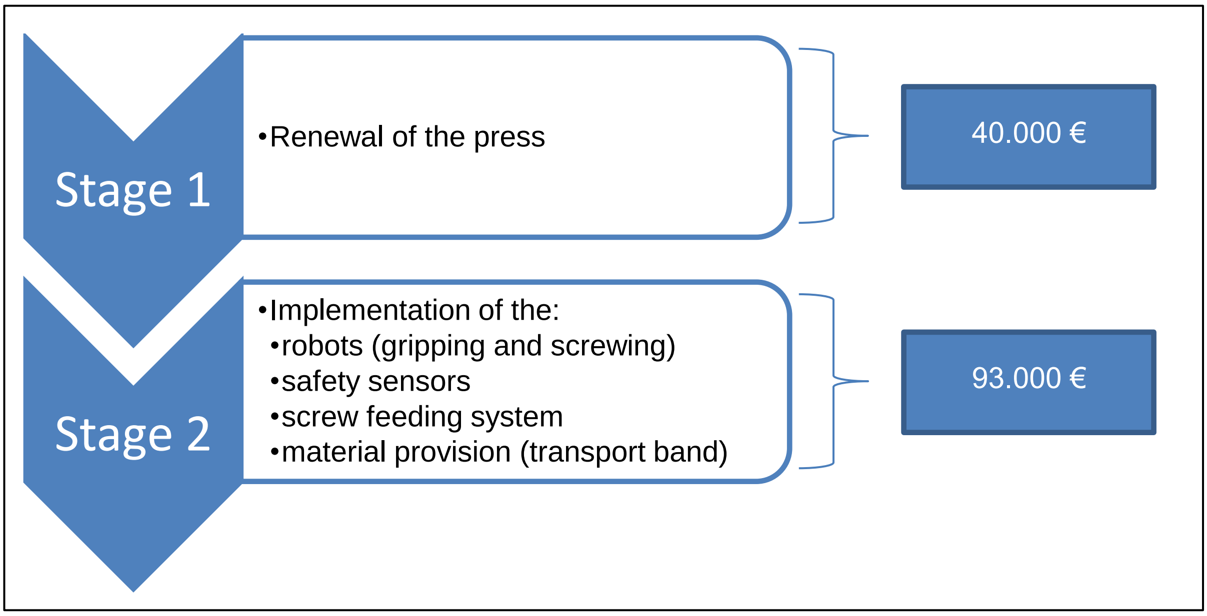

Figure 44: Alternative Handling

In this scenario the costs will be split among the two stages, making each feasible on its own. Stage one would fall under a completely different budget of general machine renewal that would not have to be handled at the same time as the actual automation project. This investment is estimated to sum up to 40.000 EUR. Stage two, the actual implementation of the suggested robotic system will therefore add up to an investment of 93.000 EUR shortening the payback period below the required two years of time. In this manner the secure renewal of the workstation R1060 is achieved and the proposed operational guideline for implementing automation stations and assembly robots is tested. As of now no decision about further proceedings can be made, the two stage plan shall be understood as a suggestion for further discussion.

5 Conclusion

Assembly lines traditionally have the lowest degree of automation in the manufacturing process of automobiles. This is owed to the precise tasks often requiring fine dexterity only provided by a human hand. Past technological advancements have shown however, that technological developments have accompanied and redefined our way of producing and seeing the production process as a whole time after time. This is why new technologies like lightweight robots are on the rise in the industry. Their fine construction accompanied by new work-safety systems and norms allow for broader application in close proximity to humans. Further-on the challenge of an increasingly older workforce and the expected lack of qualified technical staff in the near future demand of labor intense segments, like engine assembly lines, to reconsider their way of production. Therefore, even in so-called low-cost countries, like Hungary, a rise in degree of automation in all fields has to be examined. The engine assembly line of segment P3 at AUDI HUNGARIA MOTOR Kft. is currently facing a big restructuring process introducing new engine types in the upcoming years. This challenge is accompanied by the opportunity to examine all assembling stations and identify possible optimization potentials in the process.

This thesis set a goal for describing challenges an engine production line faces in a time of fast technological advances and a rising demand for flexibility in all production sectors. The outcome is to give an overview over recent developments in the field of industrial robots and a technology screening of the trend in the area of lightweight robots. An expanded field of application for this technology is the set goal of manufacturers, implementers and end customers. Robots will be equipped to work hand in hand with humans and, if implemented in the right way, the two will be able complement each other by synchronizing strengths of both.

Ultimately an operational guideline, applicable to all engine manufacturing lines of the regarded segment, for new automation projects, is introduced. The guideline is build up in such a way that it can accompany the entire process, from the initial idea, to the evaluation of workplaces, technical specifications, an economic evaluation and a final assessment. Several tools and forms are provided to help establish a uniform documentation for any new project. Especially for the economic consideration a careful investment calculation has to be performed since initial investments can be high and therefore the profitability has to be analyzed.

After building the framework in form of the operational guideline it was decided to test its effectiveness on an actual station at the assembly line. A precise analysis of several stations with the help of involved engineers and technical supervisors resulted in the decision to examine the automation potential of the press station of the sealing flange module. This station was set to be equipped with a new press, in order to handle all new types of engines and to establish an emergency strategy in case the existing press fails, beforehand. Going through the described process of the operational guideline, the station proofed to be a viable candidate for full automation. The result can be regarded positive, a concept was created and sent out to suppliers to invite offers. A cost calculation however pointed out that the payback period would not fulfill the internal specification of a payback period under two years. This parameter, however, is a must-criterion for such projects and a release for investment is not possible without fulfilling it. A second strategy for a successful implementation of the project is contemplated at the end of this thesis. As of now no decision has been made as offers have to be awaited.

In conclusion it can be said that a uniform and holistic approach for regarding any new technologies is important to identify possibilities and get to know the potentials of them. The guideline proofed to be a helpful tool to support the decision making and implementation process of an automation project. However, in low-cost countries like Hungary a big challenge is the achievement of the short payback period required by internal guidelines and an exact economical study is crucial in the process. The matter of human robot collaboration in automation is a field that should be regarded especially when thinking about stations at an assembly line because spatial circumstances often determine a close proximity to a human coworker. Another big precondition, as of now, is to set a clear legal framework for safety reasons to achieve acceptance of the robot as a partner at work. In the future light-weight robots will be able to support humans in the production process, however, internal acceptance a clear framework and economical feasibility will determine the faith of its success.

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Terms and Abbreviations

AG	Aktiengesellschaft
etc.	et cetera
EUR	Euro
AHM	AUDI HUNGARIA MOTOR Kft.
OEM	Original Equipment Manufacturer
ISO	International Organization for Standardization
TFSI	Turbo Fuel Stratified Injection
MPI	Multi Point Injection
DIN	Deutsches Institut für Normung
IPA	Fraunhofer-Institut für Produktionstechnik und Automatisierung
KAN	Konzernausschuss Neuprojekte
EA211	Entwicklungsauftrag 211
NPV	Net Present Value
IRR	Internal Rate of Return
COP	Carry Over Parts
HRC	Human Robot Collaboration
CE	Conformité Européenne
EC	European Union

Appendix

Appendix 1: Handlungsleitfaden Automatisierung

AUDI
HUNGARIA MOTOR Kft.
H-9027 Győr, Kardán út 1.
Magyarország

Audi
Hungaria

Handlungsleitfaden Automatisierung
Segment P3 EA211

Handlungsleitfaden für die Inbetriebnahme von modularen Automatisierungsinseln und Montagerobotern in der Motorenfertigung unter Betrachtung wirtschaftlicher Potentiale

Győr, im Juni 2016

Einführende Erklärung

Der vorliegende Handlungsleitfaden soll als Richtlinie zur internen Behandlung von Automatisierungsthemen im Segment P3 der AUDI HUNGARIA MOTOR Kft. dienen.

Dieser Leitfaden ist direkt als Ableitung aus der Masterarbeit mit dem Titel *„Operational Guideline for Implementing Modular Automation Stations and Assembly Robots in an Engine Manufacturing Line including an Examination of Economical Potential"* entstanden. Theoretische Grundlagen und Behandlung von speziellen Themen können in dieser nachgelesen werden.

In erster Linie dient dieses Dokument als Richtlinie zur Vorgehensweise und Hilfestellung für zukünftige Automatisierungsprojekte in der Motorenfertigung des betrachteten Segments. Die behandelten Themen beginnen bei der Identifikation von automatisierbaren Arbeitsplätzen und reichen bis zur Projektbewertung inklusive wirtschaftlicher Betrachtung der jeweiligen Projekte.

Dieser Handlungsleitfaden ist in enger Zusammenarbeit mit Herrn Tibor Czingráber, Herrn Szabolcs Kudomrak und Herrn Zsolt Heszler entstanden und ist Eigentum von Herrn Tibor Czingráber und dem Segment P3.

Da Teile des vorliegenden Handlungsleitfadens nur durch interne Informationen und Dokumente entstehen konnten werden diese folgend als solche gekennzeichnet:

- Dokumente zur Arbeitsplatzidentifikation wurden in Abstimmung mit Herrn Kudomrak von einer existierenden Bewertungsmethode abgeändert.
- Dokumente zur Investitionsrechnung wurden in Zusammenarbeit mit Herrn Heszler erstellt.

Inhaltsverzeichnis

1 Einleitung

In diesem Abschnitt wird kurz auf die Hintergründe zur Entstehung dieses Dokuments eingegangen, des Weiteren sollen Ziele und Umfang des Projekts abgesteckt werden. An dieser Stelle soll noch einmal darauf hingewiesen werden, dass dieser Handlungsleitfaden eine kompakte Ableitung aus der Masterarbeit *„Operational Guideline for Implementing Modular Automation Stations and Assembly Robots in an Engine Manufacturing Line including an Examination of Economical Potential"* darstellt.

1.1 Ausgangssituation

Durch Fertigung verschiedener Varianten und Einführung neuer Motortypen auf der Linie muss diese flexibler und modularer gestaltet werden. Eine Möglichkeit hierfür ist der Einsatz von Leichtbaurobotern für diverse Montageschritte. Da es zur Zeit keinen einheitlichen Standard zur Durchführung von Automatisierungsprojekten gibt und durch die Entwicklung am Roboter-Markt immer mehr flexible Leichtbauroboter zur Verfügung stehen deren Kosten bedeutend geringer als die klassischen Industrieroboter sind, soll dieser Standard einen Überblick bzw. Bewertungsmethoden für potenzielle Neuprojekte liefern. Vor allem an der Motormontagelinie könnte so der Automatisierungsgrad gesteigert werden, der an dieser Linie traditionell relativ gering ist.

1.2 Ziele

Die Ziele dieses Handlungsleitfadens sind:

- Übersichtliche Identifikation von potentiell automatisierbaren Stationen
- Ganzheitliche Bewertung des Automatisierungsprojektes
- Wirtschaftliche Betrachtung des Projekts
- Einheitlicher Vergleich von unterschiedlichen Projekten
- Erstellung eines allgemeinen gültigen Standards

Um diese Ziele zu erreichen wurden diverse Excel-Sheets erstellt um eine schnelle Bewertung zu ermöglichen und um eine erste Kostenberechnung durchzuführen. Auch soll hiermit jeder Mitarbeiter der Automatisierungspotentiale an der Linie entdeckt, die Möglichkeit bekommen diese selbstständig auszuarbeiten und vorzustellen. Am Ende der Auswertung eines jeden Projekts, oder mehrerer Projekte, kann dieses einheitlich präsentiert und realisiert werden. Der Standard dient auch dazu von bereits durchgeführten Projekten für die Zukunft zu lernen und durch die übersichtliche und einheitliche Darstellung schnell und einfach Referenzen zu entdecken.

2 Aufbau

Das Grundgerüst des Handlungsleitfadens setzt sich aus folgenden Punkten zusammen:

- Begründung des Investments
- Arbeitsplatzbewertungsmatrix
- Lastenheft
- Wirtschaftlichkeitsrechnung
- Projektbewertungsmatrix
- Grobkonzept

Die Punkte müssen einzeln in der korrekten Reihenfolge behandelt werden da die Weiterverfolgung eines Projekts stark von den Resultaten des vorangegangen Punktes abhängt. Diese werden in den folgenden Kapiteln erklärt und die jeweiligen Tools zur Vorgehensweise werden dem Anhang beigefügt. Die ganzheitliche Struktur ist in Form eines Entscheidungsbaumes in Abbildung 1 dargestellt. Links sind die jeweiligen Entscheidungspunkte zu sehen, rechts die vorzubereitenden Themen. Die in grün hinterlegten Themenfelder beinhalten jeweils ein vorbereitetes Dokument bzw. ein Excel Tool um den Prozess zu unterstützen. Nach dem Durchlaufen des gesamten Entscheidungsbaums und der Behandlung aller Punkte steht am Ende ein fertiges Konzept welches durch strukturierte Daten und berechneten Kenngrößen ein aussagekräftiges Ergebnis liefert. Nach Einholung mehrerer Angebote von Zulieferern und Implementeuren können einzelne Punkte (e.g. Wirtschaftlichkeitsrechnung) neu berechnet werden, oder die Daten an die Controlling Abteilung weiter gegeben werden.

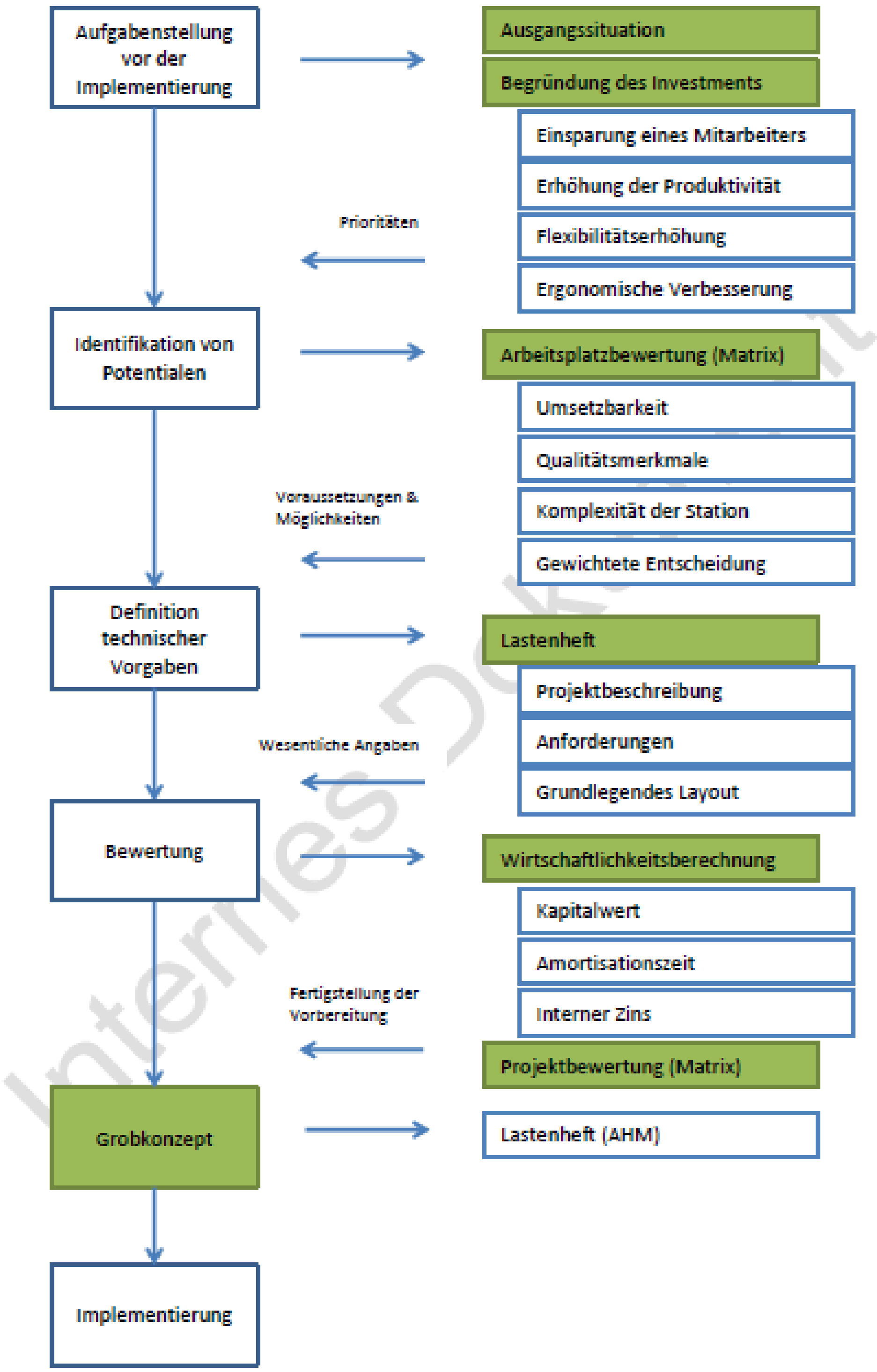


Abbildung 1: Entscheidungsbaum Automatisierungsprojekte

2.1 Ausgangssituation - Begründung des Investments

Der Anstoß für ein Automatisierungsprojekt kann vielseitig sein, es gilt auf jeden Fall zu begründen warum an einer spezifischen Stelle investiert werden soll und welche Vorteile ein Investment für das Segment bringen kann.
Beispiele hierfür sind:

- Direkte Einsparung von Mitarbeitern (Ratio)
- Vermeidung von Taktzeitspreizung
- Ergonomie Verbesserung
- Flexibilitätserhöhung an der Linie

Ein Vorschlag kann von jedem Mitarbeiter kommen, ob dieser nun durch Vorgaben von Einsparungsprogrammen ausgelöst wird, oder durch eigenständige Mitarbeit zur Verbesserung an der Linie. Diese eigenständigen Vorschläge müssen in jedem Fall gefördert werden da durch die tägliche Arbeit an.- und die Auseinandersetzung mit der Linie oft hier die idealsten Lösungen gefunden werden können.

2.2 Arbeitsplatzbewertungsmatrix

Die Arbeitsplatzbewertungsmatrix dient als Grundgerüst zur Bewertung aller möglicher Arbeitsplätze und Stationen. Ein ähnliches Projekt existierte schon in Vergangenheit auf Ungarisch und wurde vom Rumpfmotormontageleiter Szabolcs, Kudomrak bereitgestellt. Für diesen Handlungsleitfaden wurde sie jedoch auf Deutsch ausgearbeitet und die Kriterien neu erstellt. Unter anderem wurde eine zweite Gewichtung mit Fokus auf Wirtschaftlichkeitspotenzialen eingeführt um neben der generellen Bewertung für Automatisierbarkeit, eine fokussierte wirtschaftliche Handlungsempfehlung zu bekommen.

Die Kriterien sind:

- Einfache Umbaumöglichkeit
- Vermeidung von Taktzeitspreizung
- Geringe Komplexität der Operation
- Ergonomie Verbesserung
- Einsparung eines Mitarbeiters
- Geringes Technisches.- und Qualitätsverlustrisiko
- Keine Sichtkontrolle notwendig
- Geringe Anzahl der Bauteilvarianten
- Einfache Materialbereitstellung

Beispielhaft wird sie nachfolgend in Abbildung 2 illustriert.

Arbeitsplatzbewertungsblatt
P3 - EA211 - Motormontage

Projekt Nr.	AP	Operation	Details	Besonderheit	Einfache Umbaumöglichkeit	Vermeidung von Taktzeitspreizung	Geringe Komplexität der Operation	Ergonomieverbesserung	Einsparung eines Mitarbeiters	Geringes Technisches- & Qualitätsverlust Risiko	Keine Sichtkontrolle notwendig	Geringe Anzahl der Bauteilvarianten	Einfache Materialbereitstellung	Σ Wirtschaftliche Bewertung	Σ	Anmerkungen
				Gewichtung Wirtschaftlich (1-3)	2	2	1	1	3	3	3	1	2			
				Gewichtung Prinzipiell (1-3)	2	3	1	2	1	3	2	2	1			
1	R1010	ZKG Auflage	Auflage, Sichtkontrolle	Dichtflächenkontrolle	5	1	3	4	3	5	1	4	3	56	55	
2	R1040	Kurbelwelle Auflage			5	3	4	4	5	5	4	4	3	76	70	
3	R1060	Montage Dichtflansch hinten			5	1	4	2	5	5	5	5	4	76	65	
4	Z4020	Montage Einlass.- und Auslassventil			4	1	4	1	5	2	4	4	3	58	47	
5	Z4055	Montage Einspritzventil	Sicherheitsring auflegen		4	4	3	1	5	5	4	4	3	72	64	
6	K4070	Montage Unimag			4	1	4	4	4	5	5	4	3	70	63	

Abbildung 2: Arbeitsplatzbewertungsmatrix

Diese Matrix sollte sowohl von den verantwortlichen Leitern als auch den direkten Mitarbeitern an der Linie ausgefüllt werden. Die Stationen mit den in Summe höchsten Punkten werden dann in weiteren Schritten mit der folgenden Matrix genau bearbeitet und beurteilt. Die zwei unterschiedlichen Gewichtungen (Wirtschaftlich & Prinzipiell) sind je nach Relevanz mit einem Faktor 1 – 3 versehen. Die wirtschaftliche Gewichtung legt einen zusätzlichen Fokus auf wirtschaftliche Potentiale nach einer Investition.

2.3 Lastenheft

Die Arbeit an einem Lastenheft kann begonnen werden sobald ein Projekt positiv in der Arbeitsplatzbewertungsmatrix erachtet wird. Die Prinzipiellen Gliederungspunkte sind folgende:

1. Projektbeschreibung
   a. Einführung und Zielbestimmung
   b. Produktübersicht und Einsatz
   c. Aktuelle Situation (Istzustand)
   d. Beschreibung des Soll-Konzepts (Sollzustand)

2. Anforderungen
   a. Funktionale Anforderungen

b. Nichtfunktionale Anforderungen (Leistungen, Daten)
c. Technische Grundlagen
d. Qualitätsanforderungen
e. Anforderungen an den Platz (Floorplan Layout)
f. Materialbereitstellung
g. Anforderungen an den Betrieb und den Einsatz
h. Sicherheitsanforderungen
i. Zeitliche Vorgaben und Deadlines (Projektabwicklung)
j. Aufstellungsort

Vor Versenden an potentielle externe Ausrüster muss dieses Lastenheft in den „Projektspezifischen Teil" des offiziellen Lastenhefts von AHM nur mehr übertragen werden.

2.4 Wirtschaftlichkeitsrechnung

Für die Wirtschaftlichkeitsrechnung steht ein Excel-Tool bereit in dem die Investitionskosten dem Einsparungspotential gegenübergestellt werden. Zugleich wird die Amortisationszeit und der interne Zins berechnet um eine Ausgangsbasis für einen Vorschlag an die jeweilige Kostenstelle zu machen. Hier sieht man sehr schnell ob und wann sich eine Investition rentiert. Das Excel-Sheet ist in Zusammenarbeit mit Herrn Heszler, Zsolt aus der Controlling Abteilung entstanden und orientiert sich an den Konzern-üblichen Berechnungsmethoden.
Zunächst gibt es Eingabefelder wo alle relevanten Daten erfasst werden können. Diese teilen sich in Investitionen und Lohn-Einsparungen.

- Bei den Investitionen, oder den Kosten des Projekts wird zwischen vier Kostenarten unterschieden. Der Roboter, das Zubehör (Greifer, Sensoren…), falls nötig, ein zusätzliches Sicherheitssystem (Sick-Sensoren, Kameras) und die Installationskosten. Die Summe daraus ergibt die anfängliche Gesamtinvestition die zu tätigen ist.
- Beim Punkt der Lohn-Einsparungen gibt es zunächst die Möglichkeit die voraussichtliche Anzahl der Arbeitsplätze die eingespart werden können einzustellen, des Weiteren kann zwischen 2. und 3.- Schicht-Betrieb unterschieden werden. Danach werden die Lohnkosten eingestellt, Standardwerte für Jahresgehälter für Mechanische Bearbeitung und Montagemitarbeiter sind vorgegeben auswählbar, jedoch gibt es auch die Möglichkeit in der Drop-Down Liste die Einstellung „Eigener Wert" zu wählen, und somit im Feld „Eigener Wert" in der nächsten Zeile die exakten Einsparungen zu definieren.

Aufbau 7

Eingabefelder							
Investitionen [€]				Lohn-Einsparungen [€]			
		Kosten	Typ	Arbeitsplatz-beschreibung	Anzahl der Arbeitsplätze		1
Art	Roboter	25000			3-Schicht		
	Zubehör	10000			Mechanische Bearbeitung		
	Sicherheitssystem	7500					25000
	Installation	10000			Eigener Wert		0
	∑	52500				∑	75000

Abbildung 3: Eingabefelder der Investitionsrechnung

Sobald diese Daten erfasst sind berechnet das Excel-Sheet die relevanten Werte für eine Investitionsentscheidung aufgrund der von der Controlling vorgegebenen Parameter:

- Kapitalwert
- Interner Zins
- Amortisationszeit

Beispielhaft in der folgenden Darstellung illustriert:

Wirtschaftlichkeitsrechnung AHM [in Tsd. €]											
Jahre		0	1	2	3	4	5	6	7	8	Summe
Investition		52500									52500
Kostenauswirkungen		0	-26425	-44540	-43952	-43482	-43482	-43482	-43482	-43482	-332325
	Material										
	Fertigungslohn		-75000	-75000	-75000	-75000	-75000	-75000	-75000	-75000	
	Löhne/Gehälter indirekt										
	Instandhaltung										
	Fremdleistungen		20000	11000	11000	11000	11000	11000	11000	11000	
	sonst. Gemeinkosten		20000								
	Sonstige Einsparungen										
	Steuerauswirkung Kosten		12250	22400	22400	22400	22400	22400	22400	22400	
	Steuerauswirkung AfA		-3675	-2940	-2352	-1882	-1882	-1882	-1882	-1882	
Zahlungsreihe statisch		-52500	26425	44540	43952	43482	43482	43482	43482	43482	279825
Kapitalkosten	9%		-4725	-2772	987	5032	9398	14157	19344	24909	
Addition		-52500	21700	41768	44939	48513	52879	57639	62826	68480	
Zahlungsreihe kumuliert		-52500	-30800	10968	55907	104420	157300	214838	277784	346245	

Abbildung 4: Rechnung der Investitionsrechnung

In dieser Tabelle muss der Mitarbeiter nichts einstellen oder abändern sondern bekommt lediglich die folgende Ausgabe präsentiert.

Kapitalwert (bei 9% nach Steuern)		173.769 €	NBW
Amortisationszeit		1,737	Jahre
interner Zins		69%	IKV

Abbildung 5: Ausgabefelder der Investitionsrechnung

Konzernvorgaben folgend soll ein Automatisierungsprojekt auf jeden Fall weniger als 2 Jahre Amortisationszeit vorweisen um erfolgreich vorgestellt werden zu können. In so einem Fall erkennt man sofort anhand der Färbung der Zelle ob ein weiteres Vorgehen realistisch ist. Abschließend kann ein einheitlicher Bericht gedruckt werden und dem Projektvorschlag beigelegt werden. Dieser ist in der nächsten Abbildung dargestellt.

Wirtschaftlichkeitsberechnung P3 - EA211 - Motormontage			
Bearbeiter		Datum	
Projektbezeichnung			
Ausgangs-werte	Investitionssumme	52.500 €	
	Mitarbeitereinsparung	1	
Errechnete Werte	Kapitalwert	173.769 €	
	Amortisationszeit [Jahre]	1,74	
	Interner Zins	69%	
Kommentare:			
Handlungsempfehlung:			

Abbildung 6: Druckvorlage der Investitionsrechnung

Die relevanten Werte sind automatisch ausgefüllt und müssen vom Projektbeantragenden nun durch seine Kommentare ergänzt werden.

2.5 Projektbewertungsmatrix

Die Projektbewertungsmatrix ist anschließend durchzuarbeiten. Diese dient der ganzheitlichen Analyse des Projekts und kann als Entscheidungsgrundlage für eine Umsetzung dienen. Im Verlauf werden alle wichtigen Kriterien für das ausgewählte Projekt oder mehrere Projekte ausgearbeitet und verglichen. Enthalten sind neben den relevantesten Punkte aus der Arbeitsplatzbewertungsmatrix, die spezifische Anforderungen aus dem Lastenheft und die Wirtschaftlichkeits.- und Amortisationsrechnung.

Projektbewertungsblatt
P3 - EA211 - Automatisierungsprojekte

Kriterien			Projekt 1	Projekt 2	Projekt 3	
Kriterien		Prozess (Umsetzbarkeit)	3	3	2	Arbeitsplatzbewertung
		Ergonomie	1	2	3	
	Automatisierungsmethode	Mensch-Roboter-Kollaboration	3	3	2	Lastenheft
		Voll Automatisch	3	3	3	
		Modularer Einsatz	2	1	2	
		Arbeitssicherheit	1	1	1	
		Amortisationszeit	3	3	3	Wirtschaftlichkeits-berechnung
		Wirtschaftliche Bewertung	3	3	3	

Abbildung 7: Projektbewertungsmatrix

Jeder der aufgelisteten Punkte wird anschließend in einem Komitee von 1 – 3 bewertet. Sollten mehrere Projekte zur Auswahl stehen erhält man somit einen direkten Vergleich. Sollte nur ein Projekt bewertet werden kann man die Bewertung als Richtlinie für eine weitere Umsetzung sehen.

2.6 Grobkonzept

Wenn alle Excel Sheets und Daten aus dem Lastenheft gesammelt und durchgearbeitet sind, kann mit der Erstellung ein Grobkonzepts vorgelegt werden. Dieses wird in Form einer einheitlichen Mappe erstellt. Die grundlegenden Dateien die durch diesen Handlungsleitfaden erarbeitet wurden werden nun Strukturiert beigelegt und dienen als Grundlage des Konzepts.

Abbildungsverzeichnis

Anhang

Anhang 1: Begründung des Investments

Für die Begründung des Investments steht nachfolgendes MS Word Dokument bereit. Dieses ist auszufüllen und kann in einem späteren Schritt dem Grobkonzept beigefügt werden.

1_Begründung des Investments.docx

Anhang 2: Arbeitsplatzbewertungsmatrix

Die nachfolgende Arbeitsplatzbewertungsmatrix steht als MS Excel Tool zu Verfügung. Dieses ist auszufüllen und kann in einem späteren Schritt dem Grobkonzept beigefügt werden.

2_Arbeitsplatzbewertung.xlsx

Anhang 3: Lastenheft

Das Grundgerüst des Lastenhefts ist als MS Word Dokument für das jeweilige Projekt auszufüllen. Falls das Projekt als durchführbar eingestuft wird ist dieses in einem späteren Schritt mit Hilfe der Planungsabteilung im offiziellen AHM Lastenheft im Projektspezifischen Teil einzufügen. Das hier erstellte Lastenheft wird dem Grobkonzept beigefügt.

3_Lastenheft.docx

Anhang 4: Wirtschaftlichkeitsberechnung

Nach den Erkenntnissen der technischen Grundlagen aus dem Lastenheft können nun Kosten für das Projekt abgeschätzt werden und eine grundlegende Wirtschaftlichkeitsrechnung durchgeführt werden. Dazu steht ein MS Excel Tool bereit welches auszufüllen ist. In diesem soll das Tabellenblatt „Ausdruck" dem Grobkonzept beigefügt werden.

4_Wirtschaftlichkeits
rechnung.xlsx

Anhang 5: Projektbewertungsmatrix

Nun soll eine abschließende Bewertung des Vorhabens getätigt werden. Um diese zu illustrieren steht eine MS Excel Matrix bereit. Dieses Dokument soll dem Grobkonzept abschließend beigefügt werden.

5_Projektbewertung.xlsx

Anhang 6: Grobkonzept

Die Vorlage für das Grobkonzept soll der Vereinheitlichung der Darstellungsweise bei der Behandlung von Automatisierungsprojekten dienen. Die vorher behandelten Dateien sollen hier eingefügt werden um eine Abschließende Projektmappe einreichen zu können.

06_Grobkonzept.docx

Appendix 2: Anforderungskatalog Montage – Dichtflansch hinten

AUDI
HUNGARIA MOTOR Kft.

H-9027 Győr, Kardán út 1.
Magyarország

Audi
Hungaria

Anforderungskatalog
Montage – Dichtflansch hinten

Prinzipieller Anforderungskatalog für Automatisierbarkeit des Arbeitsplatzes
AP R1060

Győr, im Mai 2016

Inhaltsverzeichnis

1 Projektbeschreibung

Es handelt sich hierbei um den Arbeitsplatz, AP R1060, wobei R für Rumpfmotor, 10 für Team 1 und 60 für Station 6 steht. Die Arbeitsinhalt dieses Arbeitsplatzes ist die Montage und Verpressung des Dichtflansches hinten, sowie das heften von 6 Schrauben. Das ausgewählte Projekt hat sich nach einer gründlichen Arbeitsplatzevaluierung mit den Montageleitern und Inputs aus einem Workshop unter Einbeziehung der Planung als geeignet erwiesen um eine Automatisierung unter Voraussetzung der Einsparung eines Mitarbeiters zu realisieren.

1.1 Einführung und Zielbestimmung

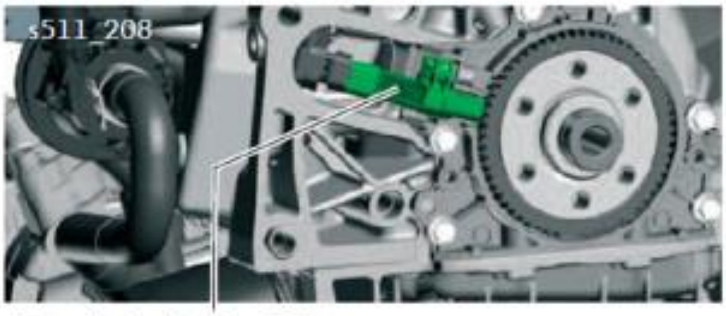
Das prinzipielle Ziel ist es einen derzeitigen Handarbeitsplatz zu automatisieren und dadurch einen Mitarbeiter einsparen zu können. Des Weiteren soll das Projekt den Charakter einer Vorreiterrolle im Bereich der weiteren Automatisierung an der Montagelinie erhalten unter der Betrachtung, dass zukünftig 4 verschiedene Motorentypen auf der Linie gefertigt werden. Die Unterscheidung der Typen und Flexibilität der Automatisierungslösung ohne Einbußen der Qualitätsaspekte steht im Vordergrund. Die genaue Arbeitsfolge des Ist.- und Sollzustands wird in den nächsten Punkten definiert.

1.2 Produktübersicht und Einsatz

Das Dichtflanschmodul hat die Aufgabe eine dynamische und statische Abdichtung, zwischen Kurbelwelle und Kurbelgehäuse zu realisieren, sowie Kurbelwellendrehzahl- und Bezugsmarkenmessung durch ein Geberrad und den Motordrehzahlgeber zu erfassen.

Aufgaben:

- Abdichtfunktion
- Motordrehzahl erfassen
- Exakte Stellung der Kurbelwelle ermitteln
- Festlegen von Einspritz- und Zündzeitpunkt durch das Motorsteuergerät



Motordrehzahlgeber G28

Der Motordrehzahlgeber ist getriebeseitig in den Dichtflansch integriert, welcher wiederum am Zylinderblock angeschraubt ist. Er tastet ein 60-2-Geberrad auf der Kurbelwelle ab. Anhand dieser Signale erkennt das Motorsteuergerät die Motordrehzahl.
60-2 bedeutet, dass sich auf dem Rotor 58 Zähne befinden und eine Zahnlücke von 2 Zähnen (quasi von 60 Zähnen fehlen 2). Die Zahnlücke ist dazu da, um einen definierten Kurbelwellenwinkel vor OT (Oberer Totpunkt) zu erkennen.
Mit den Signalen werden der berechnete Einspritzzeitpunkt, die Einspritzdauer und der Zündzeitpunkt bestimmt.

1.3 Aktuelle Situation (Istzustand)

Dichtflansch (inkl. Kurbelwellen-Dichtring) und Geberrad werden immer gemeinsam montiert. Zur Montage wird beides auf der Montagevorrichtung ausgerichtet. Um ein Umstülpen der Dichtlippe des Radialwellendichtrings zu verhindern, wird vor der Montage eine Anführhilfe in Form einer Glocke auf die neue Welle gesteckt. Ohne das Werkzeug ist das Geberrad nicht exakt zu positionieren. Dieses wird 2 Mal pro Schicht nachgemessen.

Istzustand		
	Arbeitsschritt	Beschreibung
1	Ankunft des ZKG	ZKG fährt ein und hält an der vorgegebenen Position
2	Entnahme des Dichtflanschmoduls	Der Mitarbeiter entnimmt das Modul aus der angelieferten Box
3	Positionierung auf der Pressvorrichtung	Das Geberrad wird auf der Vorrichtung exakt positioniert, eine vorgegebene Bohrung hilft bei der richtigen Positionierung Auf der Hinterseite der Presse wird die KW zusätzlich abgestützt um die richtige Position aus der vorigen Station zu festigen
4	Ansetzen	Der Arbeiter setzt das Dichtflanschmodul an der KW an
5	Verpressung	Durch Betätigung von 2 Knöpfen wird das Modul auf die KW Gepresst
6	Kraft/Weg Messung	Die Kraft/Weg Messung erfolgt automatisch und muss sich im Toleranzbereich befinden
7	Entfernung der Schutzabdeckung	Die auf der Anführhilfe verbliebene Kunststoff Schutzabdeckung wird vom Arbeiter entfernt
8	Transport der Schutzabdeckung	Der Mitarbeiter wirft die Schutzabdeckung in einen geeigneten Behälter

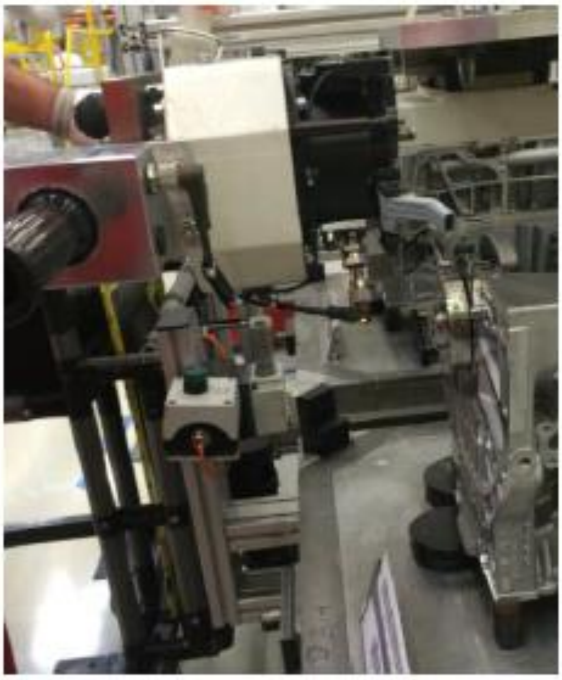
9	Neu-Positionierung des ZKG	Das ZKG fährt ein Stück weiter, um Platz für den Heftvorgang zu machen
10	Schrauben Entnahme	Der Mitarbeiter entnimmt aus einer ungeordneten Box 6 Schrauben
11	Schrauben heften	Der Mitarbeiter positioniert die Schrauben in den Schraublöchern
12	Ausfahrt	Durch Betätigung eines Knopfs fährt das ZKG inkl. Dichtflanschmodul und gehefteten Schrauben in die nächste Station wo die Schrauben automatisch festgezogen werden

Bilder der bisherigen Verpressanlage:

Gesamte Verpressanlage

Presse von vorne

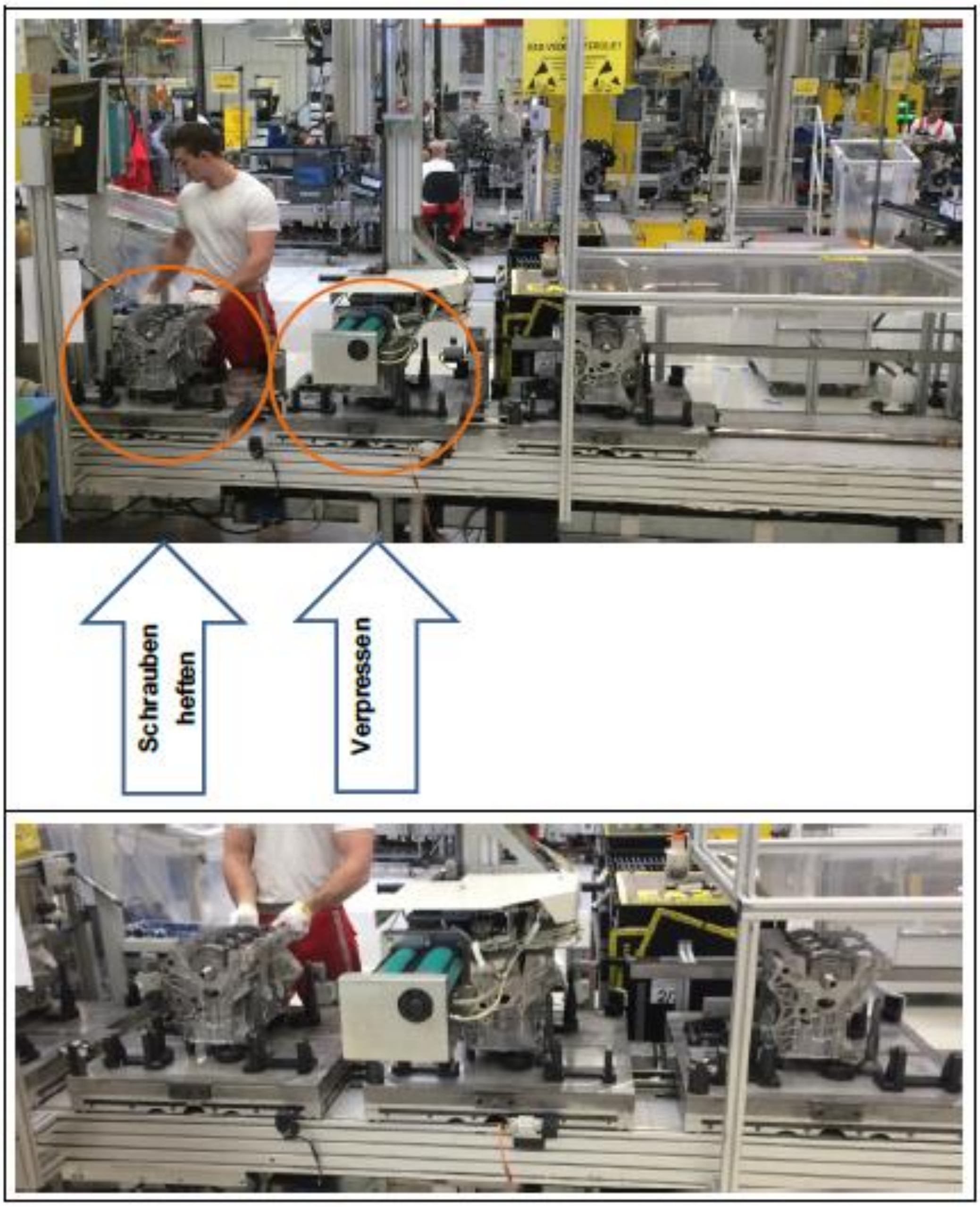
Presse von der Seite

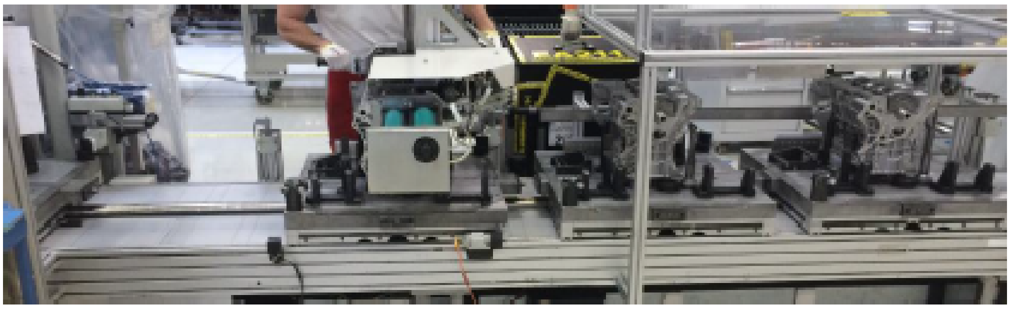


Ansetzen an Kurbelwelle

Verpressen

Bilder der Stoppstellen:





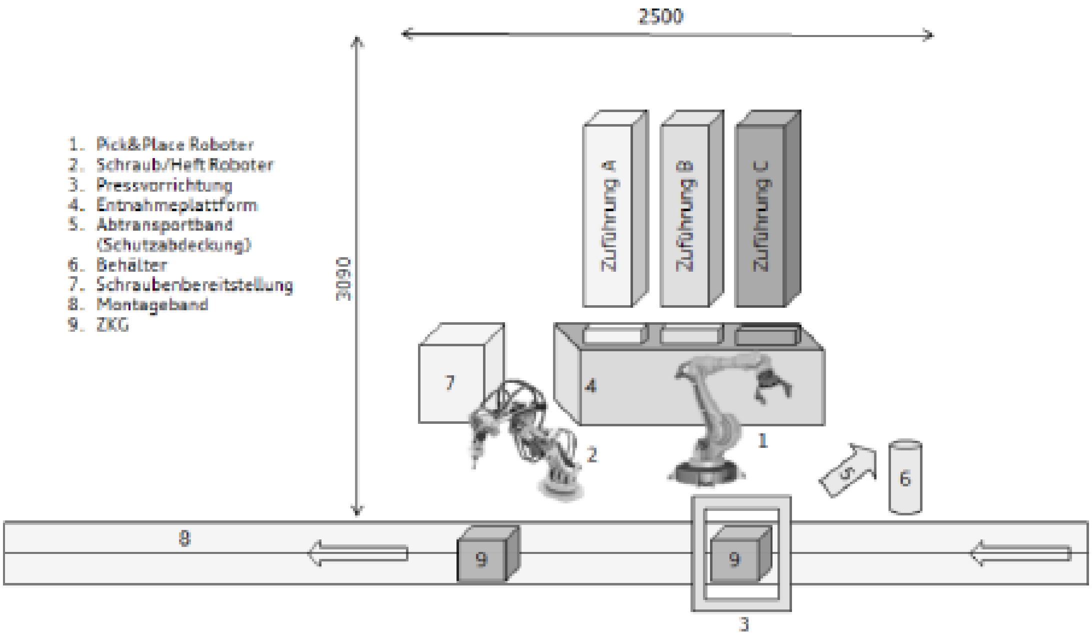
1.4 Beschreibung des Soll-Konzepts (Sollzustand)

Die Handarbeitstätigkeiten sollen durch Einsatz von Leichtbaurobotern (Pick&Place) bzw. automatischen Schrauben-Heft-Systemen komplett automatisiert werden.

Sollzustand		
	Arbeitsschritt	**Beschreibung**
1	Ankunft des ZKG	ZKG fährt ein und hält an der vorgegebenen Position
2	Entnahme des Dichtflanschmoduls	Der Roboter entnimmt das Modul aus der Box
3	Identifizierung des Dichtflanschmoduls	Der Roboter überprüft mittels Erkennungssensoren (e.g. Kamerasystem welches die Farben Schutzabdeckung der Dichtlippe) um welchen Modul Typ es sich handelt
4	Positionierung auf der Pressvorrichtung	Mittels Sensoren erkennt der Roboter die richtige Position des Geberrads und positioniert das Dichtflanschmodul auf der Pressvorrichtung z.B. durch Einrasten eines Positionierstifts *Vergleich mit R3 nötig, da dieser kürzer ist, Hinterseite der Presse muss variabel sein und nach vorne fahren*
5	Prüfung der Position der Kurbelwelle	Es muss sichergestellt sein, dass sich die KW in der richtigen Position (Positionierung bei Vorgängerstation) befindet
6	Ansetzen	Die Presse setzt das Dichtflanschmodul automatisch an die KW
7	Fixieren des Zylinderkurbelgehäußes	Das ZKG muss gegen die Presskraft fixiert werden
8	Verpressung	Die Verpressung erfolgt automatisch
9	Kraft/Weg Messung	Die Kraft/Weg Messung erfolgt automatisch und muss sich im Toleranzbereich befinden
10	Entfernung der Schutzabdeckung	Die auf der Anführhilfe verbliebene Kunststoff Schutzabdeckung fällt durch kurzes rückziehen hinunter und wird automatisch abgeführt Variante: Die auf der Anführhilfe verbliebene Kunststoff Schutzabdeckung fliegt durch Stoßen eines Doms hinunter und wird automatisch abgeführt

11	Transport der Schutzabdeckung	Die Schutzabdeckung fällt auf ein kleines Transportband welches wiederum zu einem Behälter führt
12	Neu-Positionierung des ZKG	Das ZKG fährt ein Stück weiter, um Platz für den Heftvorgang der Schrauben zu machen
13	Schrauben Entnahme	Die Schrauben müssen durch eine Vereinzeler.- oder "Rüttel-Maschine" sortiert und einzeln nach vorne transportiert werden Variante: Schrauben müssen vereinzelt werden und der Schraubvorrichtung am Roboter zugeführt werden, dieser fährt nur mehr die Positionen ab.
14	Schrauben heften	Ein Roboter entnimmt die Schrauben einzeln und heftet sie an die vorgegebene Position
15	Ausfahrt	Das ZKG inkl. Dichtflanschmodul und gehefteten Schrauben fährt in die nächste Station wo die Schrauben automatisch festgezogen werden
16	Bei Störung	Bei jeglicher Störung: • Falsche Position der KW • Fehlerhafte Kraft/Weg Messung • Fehlerhaftes heften der Schrauben • .... muss das ZKG zum Notstrategie.-/Nachbearbeitungsplatz fahren und dort auf einen Mitarbeiter warten

Beispielhaft sieht das neue Konzept wie folgt aus:



2 Anforderungen

Der hohe Automatisierungsgrad in der Automobilindustrie bedingt, dass gegebenenfalls in speziellen Transportbehältern ans Montageband angelieferte Module problemlos, mit der richtigen Positionierung des Geberrads zur Kurbelwelle, von Montagerobotern verbaut werden können. Ein ausreichender Kraftschluss zwischen Kurbelwelle und Geberrad muss gewährleistet sein.

Der automatisierte Verbau in der Motorenmontage mittels Industrieroboter soll folgendermaßen funktionieren. Die Sensor-Dichtflansch-Module werden mittels einer Greifvorrichtung aus einer speziellen Transportbox entnommen, das Geberrad mittels eines Positionierstifts in Umfangsrichtung ausgerichtet und mittels eines pneumatischen Zylinders aufgepresst.

2.1 Funktionale Anforderungen

- Greifen des Dichtflanschmoduls
- Typerkennung
  - Erkennung der Unterschiedlichen Dichtflanschmodule für verschiedene Motortypen
  - e.g. Kamerasystem erkennt Farbe der Schutzabdeckung der Dichtlippe
  - Automatische Kraftregulierung der Presse
  - Bei Pressung auf KW muss OT von KW mit Passloch übereinstimmen (Unterschiedliche Typen)
- Positionierung des Dichtflanschmoduls auf der Pressvorrichtung
- Prüfung der Position der KW
- Ansetzen an KW
- Fixieren des ZKG
- Verpressvorgang
- Kraft/Weg Messung
- Ausstoß der Kunststoff Schutzabdeckung
- Abtransport der Schutzabdeckung
- Neu Positionierung des ZKG
- Schrauben vereinzeln und zuführen
- Heften von 6 Schrauben (Unterschiedliche Typen)
- Ausfahrt
- Bei Störung Signal geben und zum Handarbeitsplatz fahren

2.2 Nichtfunktionale Anforderungen (Leistungen, Daten)

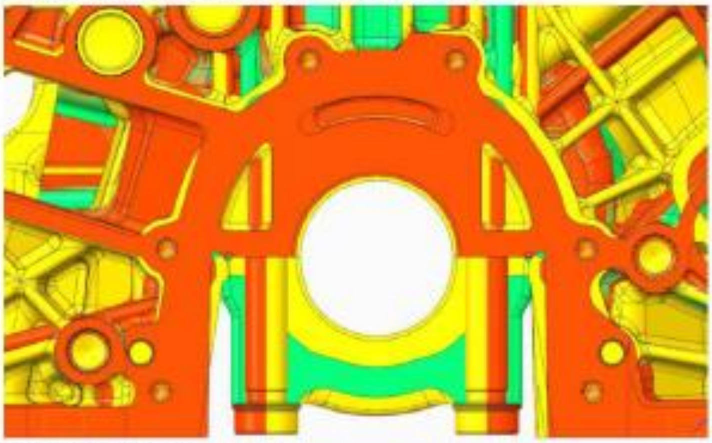
- Abtransport der Schutzabdeckung

2.3 Technische Grundlagen

	EA211 1,2L	EA211 1,4L	EVO	R3
Einpressposition	$0{,}5 \pm 0{,}1mm$	$0{,}5 \pm 0{,}1mm$	$0{,}5 \pm 0{,}1mm$	$0{,}5 \pm 0{,}1mm$
Bohrungsposition	$0^{\circ} \pm 0^{\circ}30'$	$0^{\circ} \pm 0^{\circ}30'$	$0^{\circ} \pm 0^{\circ}30'$	$0^{\circ} \pm 0^{\circ}30'$
Einpresskraft	Erfahrungswert	Erfahrungswert	Erfahrungswert	Erfahrungswert
Einpressweg	Erfahrungswert	Erfahrungswert	Erfahrungswert	Erfahrungswert
Schraubentypen	6Kt-Schraube N10653301	6Kt-Schraube N10653301	6Kt-Schraube N10653301	
Anziehkraft Schrauben	10 Nm ± 15% (8,5-11,5 Nm)	10 Nm ± 15% (8,5-11,5 Nm)	10 Nm ± 15% (8,5-11,5 Nm)	10 Nm ± 15% (8,5-11,5 Nm)
Dichtflansch Teilenummer	04E103170D	04E10317OA	04E10317OH	
Vorschrift	WSK014166G	WSK014166G		

Das Lochbild ist für alle Motortypen gleich, des Weiteren kann das gleiche Werkzeug für alle Module für den Pressvorgang verwendet werden.

- Lochbild für Schrauben und Passstifte ist gleich.



Grün: EVO; Rot: Serie; Gelb R3

2.4 Qualitätsanforderungen

- Kraft/Weg Messung der Verpressung laut Tabelle 2.3

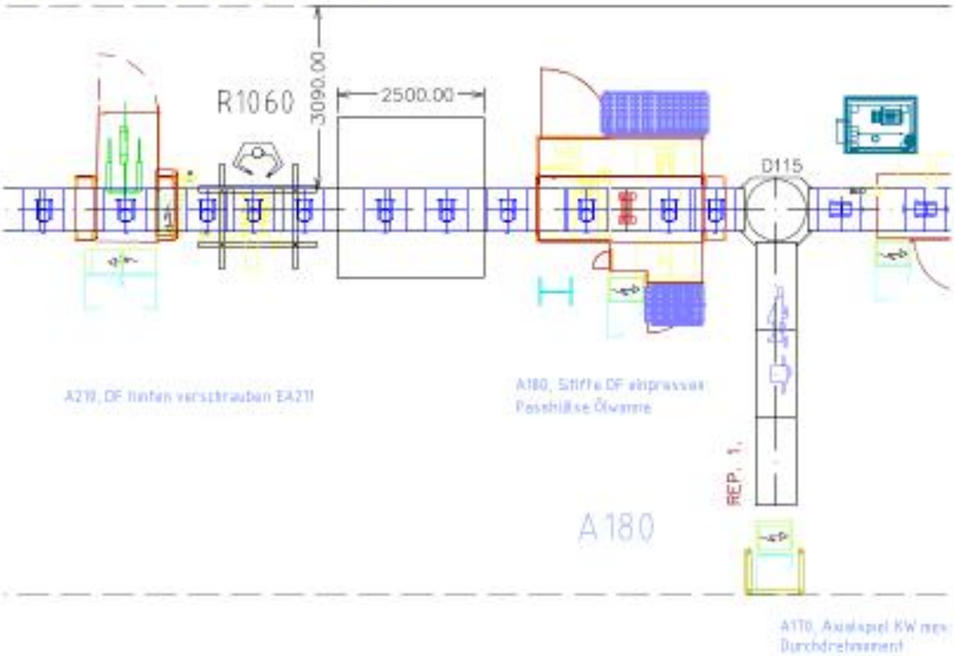
- Toleranzen laut Tabelle 2.3
- Anforderungen R3 & EVO sind ident
- Einstellung der Toleranzen geschieht über 2 Überprüfungsmerkmale:

1. Einpressposition
   Wird 2 Mal pro Schicht überprüft. Die Messung erfolgt durch ein Gerät welches die Planarität der Oberfläche auf ±0,1mm Toleranz abtastet
2. Bohrungsposition
   Wird 2 Mal pro Schicht überprüft. Die Bohrungsposition wird mit einem Gerät überprüft welches den Oberen Totpunkt der Kurbelwelle mit einem Passloch überprüft. Die Abweichung darf hierbei ±30' nicht überschreiten

- ESD geschützter Bereich (Elektrostatisch gefährdete Bauteile)
- Bei Pressung auf KW muss OT von KW mit Passloch übereinstimmen
- Rückverfolgbarkeit und Datenspeicherung in Open CAQ

2.5 Anforderungen an den Platz (Floorplan Layout)

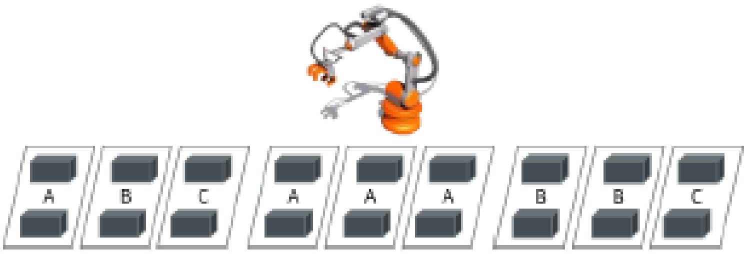
Es steht ein maximaler Platz von 2500mm entlang der Linie (siehe Skizze unten) und 3900mm nach hinten zu Verfügung.



2.6 Materialbereitstellung

Eine Transportbox beinhaltet 54 Dichtflanschmodule auf drei Reihen zu jeweils 18 Stück aufgeteilt. Pro Transportwagen werden zwei Boxen angeliefert.

Für die drei unterschiedlichen Module die in Zukunft benötigt werden soll eine flexible Materialbereitstellung realisiert werden. Je nach Produktionsplan sollen Module der verschiedenen Typen in unterschiedlicher Form bereitgestellt werden können die der Roboter erkennt und zu jeder Zeit weiß wo sich welches Modul befindet.
Beispiel:



A… Modul Typ A
B… Modul Typ B
C… Modul Typ C

Vorgaben:

- Flexible Materialbereitstellung
- Der Roboter muss wissen auf welcher Position welcher Dichtflanschtyp befindet
- Über Poka-Yoke Karten wird dem Roboter die derzeitige Bestückung der bereitgestellten Boxen mitgeteilt.

2.7 Anforderungen an den Betrieb und den Einsatz

- Derzeitige Anlage bleibt als Notstrategie
- Sofortige Umstellung bei Typenwechsel
- Maschinentaktzeit für alle Typen von 41 sek.
-

Die Anlage arbeitet je nach Auslastung im 1, 2 oder 3-Schichtbetrieb. Sie ist in Ausbaustufen auf eine Endkapazität von 1.700 Motoren / Tag auszulegen.

Motoren/Tag	Linientaktzeit	Verfügbarkeit
1.700	46 s	95%

2.8 Sicherheitsanforderungen

- Lichtschranken bei Werkstück Ein.-/Ausfahrt
- Variante kollaborierender Roboter benötigt Sicherheitssensoren
  - 4 Schutzprinzipien von Mensch-Roboter-Kollaboration laut EN ISO 10218
  - CE-Kennzeichnung
  - Grenzwerte laut ISO/TS 15066

2.9 Zeitliche Vorgaben und Deadlines (Projektabwicklung)

Das Projekt kann im laufenden Betrieb neben der zukünftigen Notstrategiestation aufgebaut werden.

2.10 Aufstellungsort

AHM Győr
Land: Ungarn
Halle: G1
Linie: Motormontage EA211

Maximale Maße der Anlage für Aufstellung (Dimension Fahrwege und Öffnungsmaß der Hallen-Tür): Breite 3 m, Höhe 3 m.

Appendix 3: Arbeitsplatzbewertungsblatt

Arbeitsplatzbewertungsblatt
P3 - EA211 - Motormontage

Projekt Nr.	AP	Operation	Details	Besonderheit	Einfache Umbaumöglichkeit	Vermeidung von Taktzeitspreizung	Geringe Komplexität der Operation	Ergonomieverbesserung	Einsparung eines Mitarbeiters	Geringes Technisches.- & Qualitätsverlust Risiko	Keine Sichtkontrolle notwendig	Geringe Anzahl der Bauteilvarianten	Einfache Materialbereitstellung	**∑ Wirtschaftliche Bewertung**	∑	Anmerkungen
				Gewichtung Wirtschaftlich (1-3)	2	2	1	1	3	3	3	1	2			
				Gewichtung Prinzipiell (1-3)	2	3	1	2	1	3	2	2	1			
														0	0	
														0	0	
														0	0	
														0	0	
														0	0	
														0	0	