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Intelligent Tools for the Manufacturing of Small Combustion Engines based on Principles of Industry 4.0

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AFFIDAVIT

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Abstract

Increasing volatility of global markets imposes challenges on a modern production model and requires enormous flexibility. Due to complex reconfiguration processes, this flexibility is, especially within the mechanical manufacturing, difficult to realise.
Hence, it is highly important to use an efficient and well thought out tool management to avoid errors during the reconfiguration on the one hand, and to minimise the machine downtime caused by reconfiguration on the other hand.
This thesis was conducted during an internship at the company BRP-Rotax GmbH&CoKG to gain practical insights into the manufacturing plant and to align solution possibilities to the existing system architecture. The current production is characterised by protracted set-up processes which lead to inflexibility and large lot sizes. An agile, customer orientated manufacturing, as it is required by BRP-Rotax, is impossible to achieve without new technologies. Aim of the thesis was to elaborate the actual need for actions at the present manufacturing process and the related tool handling based on theoretical and practical fundaments. So the literature research focuses on the creation of the tool as an intelligent object. The practical evaluation of internal set-up records shows effects and causes for instabilities. With the thusly achieved results, a concept for a new tool management has been created. Input during the conception phase was an involvement of all affected departments. The gained ideas have been filtered afterwards and a future state has been conducted. The concept of an intelligent tool helps to achieve this target state. It represents a cyber-physical system which enables a structured tool handling, free of errors. Furthermore, the tool has to be suitable for communication. So the concept includes two approaches: The automated identification system for the physical tool and the underlying tool database as a digital mapping of the tool data which provides relevant information for the production.
A final implementation strategy should help to realise the developed concept by a stepwise integration at the manufacturing line. The concept of an intelligent tool is part of the digitalisation of a modern production plant and base for agile manufacturing at BRP-Rotax.

Kurzfassung

Steigende Volatilität der globalen Märkte bringt große Herausforderungen an einen modernen Produktionsbetrieb. Speziell die mechanische Fertigung ist in der Wertschöpfung aufgrund aufwendiger Rekonfigurationsprozesse bis hin zur Freigabe für den Serienbetrieb äußerst schwer flexibel auszurichten. Besonders wichtig ist es hierbei, auf ein durchdachtes Werkzeugmanagement zurückgreifen zu können, um einerseits potentielle Fehler zu vermeiden und andererseits den Maschinenstillstand in der Zeit der Umrüstphase so effektiv wie möglich zu gestalten.

Die vorliegende Diplomarbeit wurde in Kooperation mit der Firma BRP-Rotax GmbH&CoKG am Produktionsstandort Gunskirchen verfasst, um die praktische Anwendung, sowie eine Implementierung erarbeiteter Lösungen in eine existierende Systemlandschaft zu gewährleisten. Aktuell ist die mechanische Fertigung von langwierigen Rüstprozessen geprägt, welche die Produktion zu großen Losgrößen zwingen und somit die Flexibilität mindern. Um eine agile, kundenausgerichtete Fertigung, wie sie von BRP-Rotax angestrebt wird, zu ermöglichen, ist die Einführung neuer Technologien unverzichtbar. Ziel der Arbeit war es somit den tatsächlichen Handlungsbedarf innerhalb der ablaufenden Fertigungsprozesse mit der dazu erforderlichen Werkzeugverwaltung zu erheben. Die Literaturrecherche beschäftigt sich hierbei mit der Definition des Werkzeuges als intelligentes Objekt. Eine Auswertung der intern dokumentierten Rüstprozesse bildet die Grundlage für den praktischen Teil der Arbeit und zeigt Ursachen und deren Auswirkung auf den Umrüstvorgang. Die dabei erlangten Ergebnisse stellen die Basis für die Konzeptionierung einer neuen Werkzeugverwaltung dar. Die Ideenfindung wurde durch Einbindung aller betreffenden Abteilungen der Fertigung vorangetrieben und ein Zielablauf des Werkzeugwechsels wurde erstellt. Mit Hilfe des intelligenten Werkzeuges soll dieser Zielablauf realisiert werden. Das Konzept stellt ein cyber-physisches System dar um in erster Linie ein strukturiertes, übersichtliches Werkzeug-Management zu gewährleisten. In weiterer Folge wird das Werkzeug kommunikationsfähig gestaltet. Dazu spaltet sich die Arbeit in zwei Blöcke: Das Werkzeug als Hardware-Bestandteil mit automatischer Identifikation neben der Werkzeugdatenbank als systemübergreifende Software für digitalen Informationsfluss und die Bereitstellung relevanter Prozessdaten.

Um das intelligente Werkzeug in die bestehende Fertigungslinie schrittweise zu integrieren wurde eine Implementierungsstrategie ausgearbeitet. Das Konzept ist ein Bestandteil der Digitalisierung einer modernen Fertigungsstraße und Grundstein für eine agile Produktion.

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List of Abbreviations

CAM	Computer aided manufacturing
CCA	Business Unit Turbo charging Systems of BRP-Rotax
CCK	Business Unit Camshaft / Crankshaft Manufacturing of BRP-Rotax
CCP	Business Unit Connection Rod Manufacturing of BRP-Rotax
CCS	Business Unit Core Components Manufacturing of BRP-Rotax
CCZ	Business Unit Cylinder Head / Crankcase of BRP-Rotax
CNC	Computer numerical control
Cf.	Confer, compare
DNC	Direct numerical control
E.g.	Exempli gratia, for the sake of example
Ed.	Editor
Etc.	Et cetera, and other things
ERP	Enterprise resource planning
FIFO	First in, first out
FT	Fertigung, internal abbreviation for manufacturing division
ID	Identification
Inf.	Information
MES	Manufacturing execution system
NC	Numerical control
NPD	New product development
OTD	Order to delivery
RVVS	Rotax Verbesserungsvorschlagssystem, internal meaning for improvement
SMED	Single minute exchange of die
TRP	Tool resource planning
VANC	Voestalpine numerical control

1 Introduction

The following master's thesis was elaborated during an internship at BRP-Rotax Gmbh & Co KG in Gunskirchen, Austria, as part of a comprehensive project in the field of digitalisation in the mechanical manufacturing.
A persistent issue in modern production processes is the reaction to the volatility of markets towards small lot sizes. Complex and manual set-up and order handling, especially affecting the mechanical manufacturing, lead to dependence on high quantities. The digitalisation offers now completely new possibilities to create more flexibility.

The order spectrum of BRP-Rotax increased drastically over the years. Therefore, the product portfolio has to be widely spread to meet the required specifications of the customers. BRP-Rotax is forced to react to this trend and currently invests in the area of digitalisation by creating a Smart Factory to face this complex project. Under the slogan of GK2020 (Gunskirchen 2020), the Smart Factory's task is the implementation of new technologies at the production plant in Gunskirchen.

1.1 BRP-Rotax GmbH & Co KG

BRP-Rotax as part of the parent company Bombardier Recreational Products (BRP) is specialised in the development and production of innovative engines and powertrains for powersport products. The broad product portfolio includes high-tech premium engines for recreational vehicles such as Ski-Doo® and Lynx® snowmobiles, Sea-Doo® watercraft, Can-Am all-terrain and side-by-side vehicles, Can-Am™ Spyder roadsters, motorcycles, go-karts and light and ultralight aircraft.
The company also focus on the development of eco-friendly technologies by ensuring high energy efficiency and lower emissions.[1]
The production is separated in three different sections: Vehicle production, engine production and the part production, which are located at different geographical positions[2]:

Part production:

- Gunskirchen, Austria
- Spruce Pine, USA

Engine production:

- Gunskirchen, Austria
- Sturtevant, USA
- Queretaro, Mexiko

[1]Cf. BRP-Rotax (2016), online source [09.01.17].

[2] BRP-Rotax (2016), internal sources.

Vehicle production:

- Valcourt, Canada
- Benton, USA
- Juarez, Mexico
- Queretaro, Mexico
- Rovaniemi, Finland

At the production plant in Gunskirchen, Austria (Figure 1), there are currently 1140 people employed and responsible for a revenue of € 546 million created by following powertrain products[3]:

- Ski-Doo® and Lynx® snowmobiles
- Sea-Doo® watercraft
- Can-Am™ ATV, SSV, Spyder
- Karts
- Motorcycles
- Light and ultralight aircraft

The core competences at Gunskirchen are design, development, industrialisation and manufacturing of complete powertrains. The site is based on an area of 46 000 m² which is about 500 000 ft².

Figure 1: BRP-Rotax Production plant in Gunskirchen, Austria, source: BRP-Rotax (2016), online source [09.01.2017]

[3] BRP-Rotax (2016), internal sources.

1.1.1 History of BRP-Rotax[4]

Following, a short extract of the historical development of BRP-Rotax:

2015 Presentation of the Rotax 915 iS aircraft engine
2013 BRP Inc. completes final public offering
2011 The 7,000,000th Rotax engine leaves the line
2010 Inauguration of the RIC (Regionales Innovations Centrum)
2007 Assembly of Rotax engines for BRP offroad vehicles in Juárez, Mexico
2003 Bombardier Inc. sells its Recreational Products division
1988 Production of 2-stroke Rotax engines for Sea-Doo watercraft begins
1982 Production of Rotax 4-stroke motorcycle engines begins
1970 Rotax-Werk AG is purchased by Bombardier and becomes Bombardier-Rotax GmbH
1959 Lohnerwerke Ges.m.b.H. takes over the majority of Rotax shares
1947 Relocation to Gunskirchen near Wels, Austria
1943 Site relocation to Wels, Austria
1930 Takeover by Fichtel & Sachs AG and site relocation to Schweinfurt, Germany
1920 Founding of Rotax-Werk AG in Dresden, Germany

1.1.2 Manufacturing at BRP-Rotax, Gunskirchen[5]

The challenge BRP-Rotax has to face is the huge application spectrum of their products. The final product can be a vehicle that is used for transport on road, on snow, on water or in the air. This requires various technical specifications concerning design and functionality. Furthermore, the production covers two- as well as four-stroke engines wtih one-, two-, three- or four-cylinders and a performance range from 8 to 300 hp. Due to seasonal volatility in the demand and too little quantities of specific products, it is not possible to create an independent production line for each single engine type. In other words, the production facilities have to be used for various production steps to ensure an efficient fabrication by utilising the single machines.
The whole production plant, consisting of an assembly and a manufacturing area, is separated into following business units:

- CCA – Turbo charging Systems
- CCK – Camshaft / Crankshaft Manufacturing
- CCP – Connection Rod Manufacturing
- CCS – Core Components Manufacturing
- CCZ – Cylinder Head / Crankcase

[4] Cf. BRP-Rotax (2016), online source [09.01.2017].
[5] BRP-Rotax (2016), internal sources.

1.1.3 Industry 4.0 at BRP-Rotax[6]

Under the slogan GK2020 (Gunskirchen 2020), BRP-Rotax declares a program of future-orientated technologies and solutions in order to face upcoming challenges and to secure the company's competitiveness. BRP-Rotax is continuously implementing innovative programs and wants to become part of the fourth industrial revolution to increase the efficiency of the production plant.
This was the impetus for creating the Smart Factory, responsible for mapping a digital process flow and introducing new technologies and methods in late 2015.

Figure 2: Slogan Gunskirchen 2020, source: BRP-Rotax (2016), internal source[7]

The three pillars of GK2020 are represented by growth, agility and lean processes. The focus on growth is represented on the one hand by increasing the market share of the existing products and on the other hand by entering new markets with new products. Hence, strategies for new segments in present markets as well as for new segments in new markets have to be created.
Increasing the company's agility should help to react faster to changes in production, customer demands or technological leaps. The broad production portfolio and the offer of customised products require a high flexibility of the production. Especially the demand on customisation is increasing although there are only little possibilities of individual variants of the engine. Different sections of the value chain may be affected, depending on which part of the final product is customised.
Further, the production line should be kept lean as well. Minimising waste, preventively avoiding possible error sources or the BRP-Rotax internal continuous improvement-process (RVVS) should achieve an increase of efficiency through the whole value chain.

[6] BRP-Rotax (2016), internal sources.

[7] Translation: We are going to be the leading manufacturer of premium engines and powertrains for powersport with premium customer orientation.

1.1.4 The Smart Factory of BRP-Rotax

The Smart Factory is not a physical factory in the proper meaning of the word. It is represented by a department which is enrolled in the research and development process in the area of innovative production. New technologies are investigated and proofed in terms of feasibility and benefit at the real, physical production line.
To achieve an increase in the mentioned sections of the GK2020 pillars, the tasks of the Smart Factory are:

- Minimisation and simplification of process steps
- Creation of transparency through the production line
  - For the management: To optimise the utilisation
  - For the employees: To simplify the work tasks
- Ensure data consistency through the heterogeneous data structure
- Maximisation of the automation level

1.2 Problem Statement

The overview of the historical cornerstones in chapter 1.1.1 shows the rapid growth of the company during the last years. This led to a change in the production from a fractal manufacturing structure to a discrete structure with special requirements over the time.[8]

Grown fractal structure:

- Low consideration of value stream
- Low automation
- Manual set-up of the manufacturing machine
- Production and quality data acquisition employee depending

Discrete structure:

- Broad product portfolio
- High volatility depending on seasonal needs
- Great part variation
- Mid lot sizes in manufacturing
- Complex set-up processes

These characteristics force BRP-Rotax to create a modern manufacturing model. The production should be able to react on individual customer demand. The strategy need to go towards lot size one, away from batch work production and, further, be aligned on the assembly division in order to enable a synchronous production flow.

[8] BRP-Rotax (2016), internal sources.

Because of the broad product portfolio it is essential to use the manufacturing in a flexible way. This means that manufacturing machines are used for the production of several engine types. So, the relevant machine has to be equipped with the necessary operating material for the related product. This flexibility is a huge challenge for a production line. The current situation at BRP is characterised by complex and long set-up processes because of different specifications and the requirement of high quality. The long duration of the machine set-up leads to large lot sizes, which in turn result in high work in progress and large stock. This trend is basically the opposite of the modern manufacturing model which is wanted to achieve.

1.3 Research Aims

The aim of this project is the delivery of an innovative approach of a modern tool management system in order to face the current instabilities around the set-up process. In this way, BRP-Rotax should be able to act more agile within the manufacturing line.
Therefore, a structured analysis of the ongoing manufacturing processes is required, to detect the actual need for actions. Using the newest technologies, that are discovered by an intense literature research, a concept should be conducted. This approach is supposed to be elaborated during a close cooperation with the employees at the shop floor. Further, the concept has to be tested in terms of usability for the existing structure at the production plant in Gunskirchen.
The outcoming recommendation, based on theoretical and practical fundaments, should provide a guideline for further activities for BRP-Rotax. It should show the application of new technologies and clarify how and in which way BRP-Rotax can profit from it. To realise an implementation, a strategy related to the practical approach should finalise the elaborated concept.

1.4 Methodology

The project plan according to Six Sigma DMAIC cycle served as the overall guideline to realise a verifiable approach. This framework was aligned on the duration of the internship at BRP-Rotax with six months. Therefore the completion on-site was necessary to get a clear insight into the company and understand the ongoing processes. The single stages of the Six Sigma cycle are described in more detail in the practical chapter.
For the clarification of the problem statement a structured breakdown of the process chain through the relevant business unit was needed. Flow charts and block diagrams have been created and helped to visualise and understand the complex procedures ongoing at the shop floor. The input therefore was delivered by interviews with all affected departments and workers. To create a relation between the cause and effect regarding occurring problems, an Ishikawa model illustrated the relevant influence factors. Internal records of the set-up process have been evaluated and revealed weak points around the tool management which served as fundament for the solution finding process. Therefore,

the theoretical input was created by an intensive literature research on case studies, use reports and on adequate manufacturing literature. The manufacturing process of a partner company gave insight into a practical application of a modern tool handling.
The conception phase was again strongly orientated to the specifications of the workers at BRP. Brainstorming activities helped to figure out possible solutions. The gained input was then clustered by the use of a Morphological Box and further evaluated with utilisation analysis tools. Further, a ‘proof of concept’ examines the financial aspects of the new tool management system.
Figure 3 represents the main topics of the thesis. The content is separated in a literature and a practical research, followed by a conclusion where further steps of the concept are discussed.

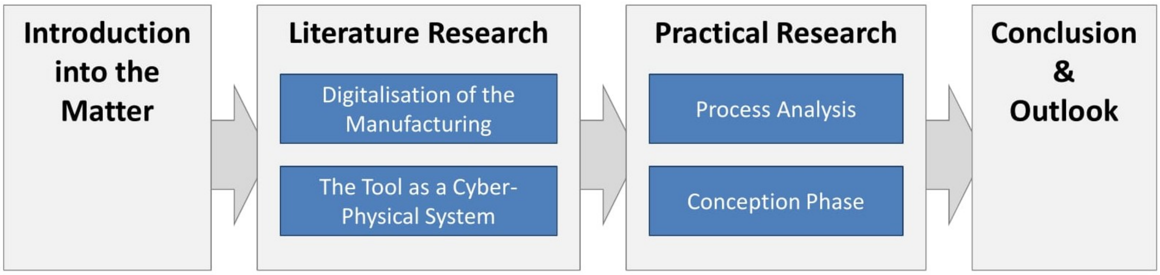

Figure 3: Illustration of the thesis‘ structure, source: own representation

2 Digitalisation of the Mechanical Manufacturing

There is no doubt that the digitalisation is affecting all areas of life, society and economy. The continuous increase of digital networking replaces consisting business models.[9] In this way, the 4th industrial revolution becomes part of conventional production processes as well.
The digitalisation of the mechanical manufacturing offers enormous potential. It assures a higher economical benefit for companies due to increasing productivity, higher quality of the produced parts or lower costs per unit.[10]

The following chapters focus on the definition of the terms ‘Industry 4.0’ and ‘Smart Factory’ as well as on the technical background of embedded and cyber-physical systems. Furthermore, the influences this topic has on current production are described and the possibilities offered are demonstrated by referring to the practical use of a cyber-physical system.
The outcomes are then discussed to create a base for the practical research at BRP-Rotax.

2.1 Industry 4.0

The 4th industrial revolution is a conceptuality which should declare an abrupt change of a system during a short period of time. The term refers to the German strategic initiative to take up a pioneering role in industrial IT. Furthermore, Industry 4.0 should start a revolution of the manufacturing engineering sector.[11] Aligned on the passed industrial revolution steps, shown in Figure 4, Industry 4.0 represents the subsequent stage by the use of cyber-physical systems.

[9] Cf. Federal Ministry of Science, Research and Economy (2016), p. 65.

[10] Cf. Denkena et al. (2014), p. 537 f.

[11] Cf. GTAI (2014), p. 3.

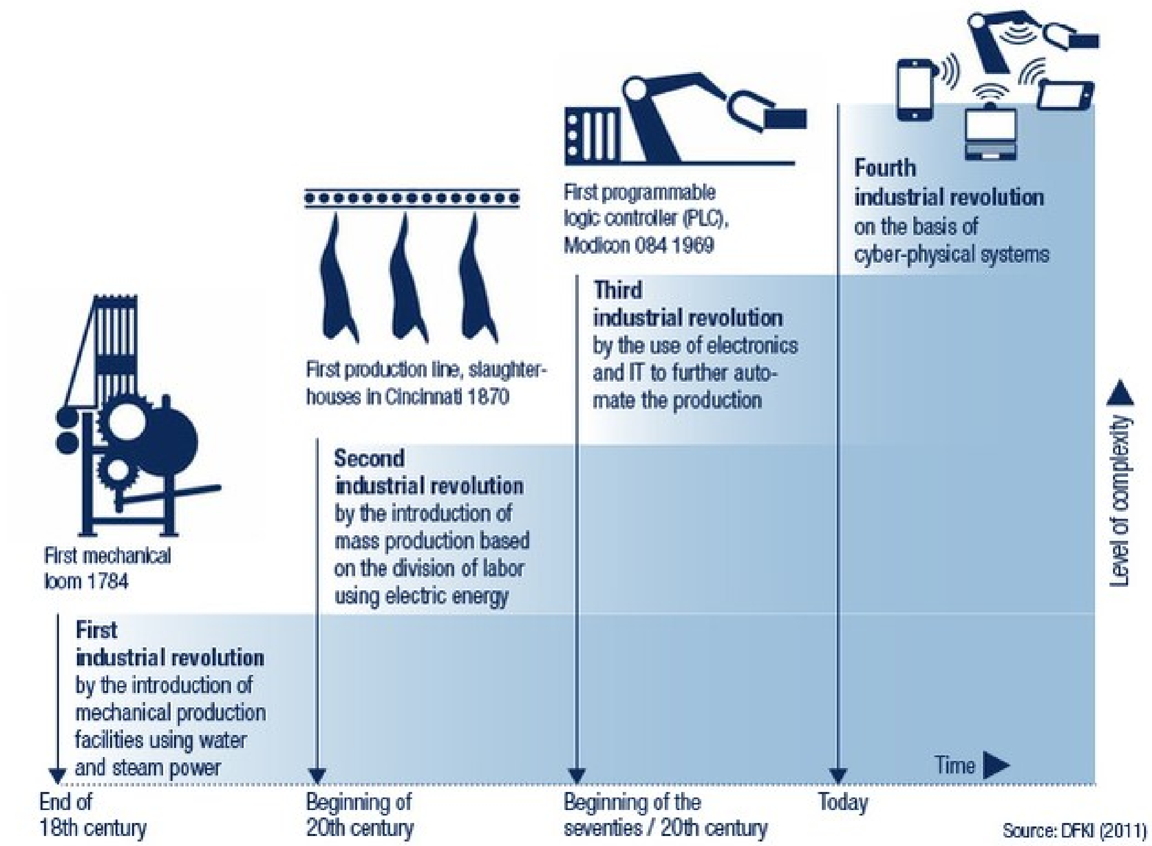

Figure 4: Industrial revolution steps, source: DFKI (2011), online source [09.01.2017]

The relevant point regarding this step is the technological evolution from embedded systems to cyber-physical systems. Information about a product or an operating material is no longer centralised. Decentralised intelligence leads to intelligent objects networking and independent process management. New aspects of the manufacturing and production process can be achieved with technological advances which constitute a reversal of conventional production process logic. The industrial production machinery is no longer only processing the product. A communication between the machinery and the used products enable specific manufacturing steps.[12]

Most companies distinguish between physical flows of material components through the supply chain and information flows about these components. This requires a consideration about where and how to coordinate and synchronise them. With a consistent communication possibility, the processed product knows information about itself and information about the work tasks required. In this way, the product is able to provide the relevant information when needed.[13]

[12] Cf. GTAI (2014), p. 6.

[13] Cf. McKinsey (2013), online source [09.01.2017].

2.1.1 Embedded Systems

An embedded system is a microprocessor-based system with a specific function. It is a combination of hardware and software and often consists of additional parts either mechanical or electronic.[14]

The characteristic of an embedded system is that the end user is not able to have an influence on the specific target function. It is not designed to be programmed for changing the functionality.[15]

2.1.2 Cyber-Physical Systems (CPS)

Cyber-physical systems represent the next evolutionary step from embedded systems. As their definition indicates, these systems enable the interaction between the virtual and the physical world.[16]

The systems consist of embedded software and are characterised by following sequential dimensions:[17]

1. Merging of physical and virtual world
2. System of systems with dynamic boundaries
3. Active control in real-time
4. Cooperative systems with distributed and changing control
5. Man-machine-cooperation

With the mentioned characteristics, cyber-physical systems create a network in which intelligent objects are able to communicate and interact with each other.[18]

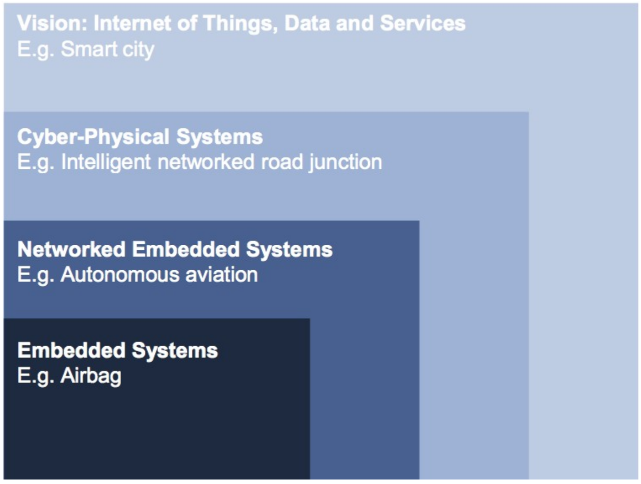

Figure 5: The evolution of embedded systems,
source: own representation, derived from acatech (2011), p. 10.

[14] Cf. Barr/Massa (2006), p. 1 f.

[15] Cf. Heath (2003), p. 2.

[16] Cf. GTAI (2014), p. 8.

[17] Cf. Acatech (2012), p. 60.

[18] Cf. GTAI (2014), p. 8.

Figure 5 illustrates the different steps of embedded systems as a practical example from the research group acatech. This evolution can be understood as follows:
The initial point is represented by a closed embedded system, e.g. an airbag. If the system is able to involve locally surrounded parties, it is called a network embedded system, e.g. autonomous aviation.[19]
The next evolution step is an open network of several communicating systems which are globally connected. An example would be an intelligent road junction using data about traffic congestion.[20]
The 4th evolution step is a vision what could be possible with cyber-physical systems in the future. E.g. an interconnection of different application areas represented by a smart city.[21]

2.2 The Smart Factory in the Context of Industry 4.0

The Smart Factory represents a core element of Industry 4.0 and is characterised by interconnectivity of autonomous, self-controlled, self-configured, intelligent production resources. With the Smart Factory, a new intensity of social-technical interaction of all parties and resources, involved in the production process, is possible.[22]

2.2.1 Definition

The definition of a Smart Factory is not consistent. In the modern manufacturing literature there are several definitions used interchangeably:[23] U-Factory (ubiquitous factory)[24], factory-of-things[25], a real-time factory[26] or an intelligent factory of the future[27].
Scholars refer to the Smart Factory as a technology[28], an approach[29], or a paradigm[30].

According to the résumé of the study of Radziwon, Bilberg, Bogers and Madsen, who investigated the mentioned definitions, a Smart Factory is a manufacturing solution that provides flexible and adaptive production processes. In this way a Smart Factory is able to solve problems arising on a production facility with dynamic and rapidly changing boundary conditions. On the one hand, this solution could be related to automation, which

[19] Cf. Acatech (2011), p. 10 f.
[20] Ibidem.
[21] Cf. Acatech (2012), p. 29.
[22] Cf. Kagermann/Wahlster/Helbig (2012), p. 12.
[23] Cf. Radziwon et al. (2014), p. 2.
[24] Cf. Yoon/Shin/Soo (2012), cited in Radziwon et al. (2014), p. 2.
[25] Cf. Lucke/Constantinescu/Westkämper (2008), cited in Radziwon et al. (2014), p. 2.
[26] Cf. Zuehlke (2010), cited in Radziwon et al. (2014), p. 2.
[27] Cf. Hameed/Durr/Rothermel (2011), cited in Radziwon et al. (2014), p. 2.
[28] Cf. Madu et al. (1994), cited in Radziwon et al. (2014), p. 2.
[29] Cf. Zuehlke (2010), cited in Radziwon et al. (2014), p. 2.
[30] Cf. Yoon/Shin/Soo (2012), cited in Radziwon et al. (2014), p. 2.

should lead to optimisation of manufacturing, resulting in reduction of labour and waste of resources. On the other hand, it could be seen in a perspective of collaboration between different partners, where the smartness comes from forming a dynamic organisation.[31]

This definition of the Smart Factory coincides with the goals of the Smart Factory of BRP-Rotax. Especially the reduction of waste is a main focus of BRP to achieve a flexible and adaptive production process (see Chapter 1.1.4).

2.2.2 Characteristics of the Smart Factory

A completely new production logic shapes the processes of the Smart Factory. The products and resources are uniquely identifiable, locatable at any time and hold information about themself. The product is now an information transporter as well.[32]

	Past Industry 1.0 & 2.0	**Present** Industry 3.0	**Future** Industry 4.0
Super-system	Analogue Communication • Local markets • Mainframe computer	Internet and Intranet • Export markets • PCs	Internet of Things • Localised markets • Mobile and cloud computing
System	Neo-Taylorism • Make to stock • Performance orientated • Supervisor organisation	Lean Production • JiT-Production • Process orientated • Team organisation	Smart Factory • Individual production • Resilient production • Augmented operators
Sub-system	Mechanisation • Conventional machines • Work plans • Drawing boards	Automation • CNC machines • ERP/ MES • 3D CAD-CAM	Virtualisation • Social machines • Virtual production • Smart products

Figure 6: Comparison of revolution steps aligned on different stages, source: own representation, derived from Kagermann/Wahlster/Helbig (2012), p. 12.

Figure 6 compares the industrial revolution steps aligned on different stages of the production system. The illustration shows the development at the upper- middle and lower hierarchy of the production.

[31] Cf. Radziwon et al. (2014), p. 4.

[32] Cf. Kagermann/Wahlster/Helbig (2012), p. 12.

2.2.3 Resources of the Smart Factory

A Smart Factory needs the appropriate facilities and infrastructure to meet all the mentioned specifications.
In chapter 2.1.2, the cyber-physical system, a core element of the Smart Factory in its present form, is explained. The use of these cyber-physical systems in production systems gave birth to the Smart Factory.[33] These components store information about themself and know exactly their area of application and their configuration possibilities. With the application of cyber-physical systems, manufacturing lines can be created which are reacting in real-time on changes in the supply chain. So, whole production processes can be optimised.[34]

Capabilities which are necessary for the manufacturing of a product can be clustered in stationary and mobile resources. A stationary resource is a workstation, a manufacturing or an assembling machine. Mobile resources are understood as operating materials that are used, e.g. tools or measuring equipment.[35] Figure 7 represents these resources and the creation of a factory object.

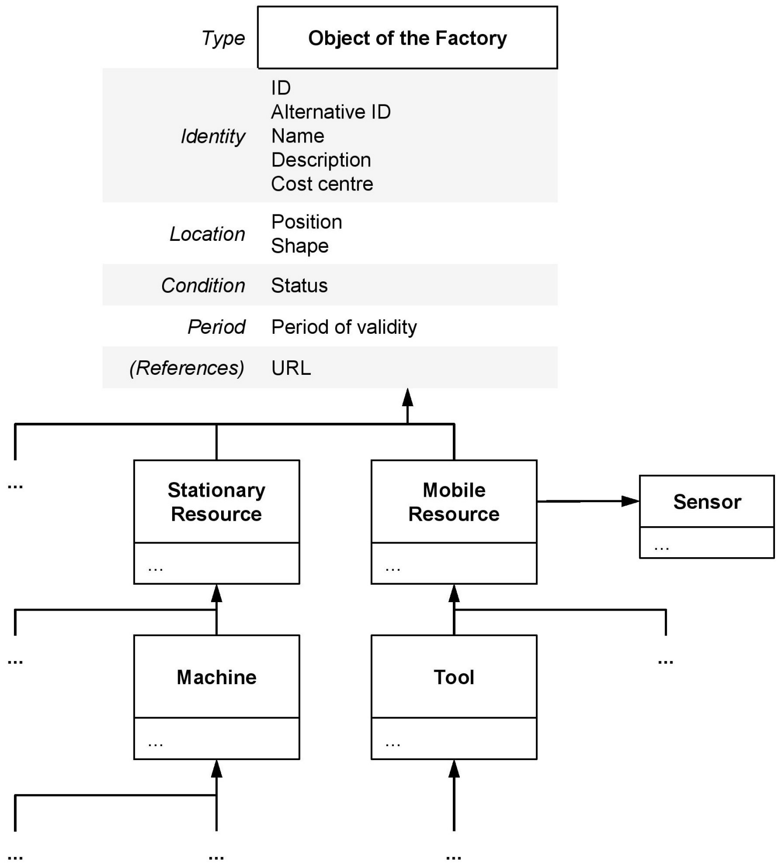

Figure 7: General object of the Smart Factory, source: own representation, derived from Westkämper et al. (2013), p.259.

[33] Cf. GTAI (2014), p. 6

[34] Cf. Acatech (2011), p. 23.

[35] Cf. Westkämper et al. (2013), p.251.

2.3 Intelligence of Products

The production system of the Smart Factory is characterised by the individualisation of single units. This requires smart products and smart materials to enable a CPS-production system.[36]

Because of this specification, an investigation about the relation between intelligence and objects is necessary. Existing definitions of object intelligence from the literature are listed and compared in the following chapters. The design parameters of an object always refer to the specific application areas. This leads to different interpretations.

2.3.1 Definition by McFarlane et al.

McFarlane et al. define an intelligent product as a physical and information-based representation of a product. Figure 8 shows an appropriate example. In this figure, the spaghetti sauce can is the physical product. The information-based representation of the product is stored in the database and the intelligence is provided by the decision making agent. A tag and a reader are used for the connection between the physical product and the information-based representation.[37]

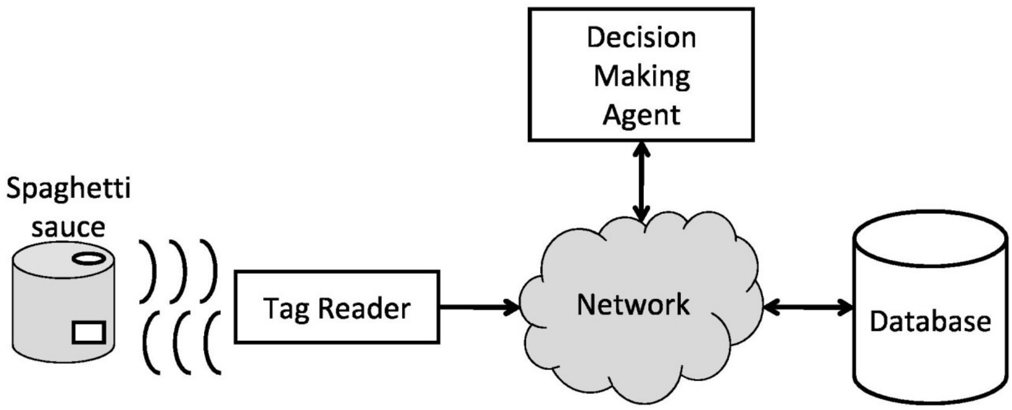

Figure 8: Intelligent spaghetti sauce can, source: Wong et al. (2002), p.2.

[36] Cf. Kagermann/Wahlster/Helbig (2012), p. 14.

[37] Cf. McFarlane et al. (2003), cited in Meyer et al. (2009), p. 3.

According to McFarlane et al., an intelligent product has the following properties:[38]

1. It possesses a unique identification
2. It is capable of communicating effectively with its environment
3. It can retain or store data about itself
4. It deploys a language to display its features, production requirements, etc.
5. It is capable of participating in or making decisions relevant to its own destiny

With this definition, Wong et al. have defined a two-level classification of intelligence. When the intelligent product only covers points 1 to 3, it is information oriented. A product which covers all points, and is called decision oriented.[39]
This representation is based on the on a separation between the physical product and its information-based counterpart. Therefore, it is mainly intended to describe the use of Radio-Frequency Identification (RFID) technology in for example manufacturing and supply chain purposes, without covering for instance products with embedded processing and communication capabilities.[40]

2.3.2 Definition by Kärkkäinen et al.[41]

According to Kärkkäinen et al., an intelligent product is able to identify its own position in the supply chain and knows how to be handled. In this way the products should possess the following properties:

1. Globally unique identification
2. Links to information sources about the product across organizational borders, either included in the identification code itself or accessible by some look-up mechanism
3. Ability to communicate what needs to be done with them to information systems and users when needed (even pro-actively)

In a similar way to the definition by McFarlane et al., the classification reaches from no intelligence (unique identification only) towards decision oriented products. Despite a slightly bigger consideration for embedded processing capabilities and the whole product lifecycle, also this classification is still mainly focused on the use of RFID technology.

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[38] Cf. McFarlane et al. (2003), cited in Meyer et al. (2009), p. 3 f.

[39] Cf. Wong et al. (2002), p. 2.

[40] Ibidem.

[41] Cf. Kärkkäinen et al. (2003), cited in Meyer et al. (2009), p. 4.

2.3.3 Definition by Meyer et al.[42]

The definition of Meyer et al. is the most comprehensive representation. In contrast to the previous mentioned interpretations, which are focusing on a section, Meyer et al. define the intelligence by splitting the relevant characteristics into three independent dimensions. As illustrated in Figure 9, the three dimensions are: The level of intelligence, the location of intelligence and the aggregation level of intelligence.

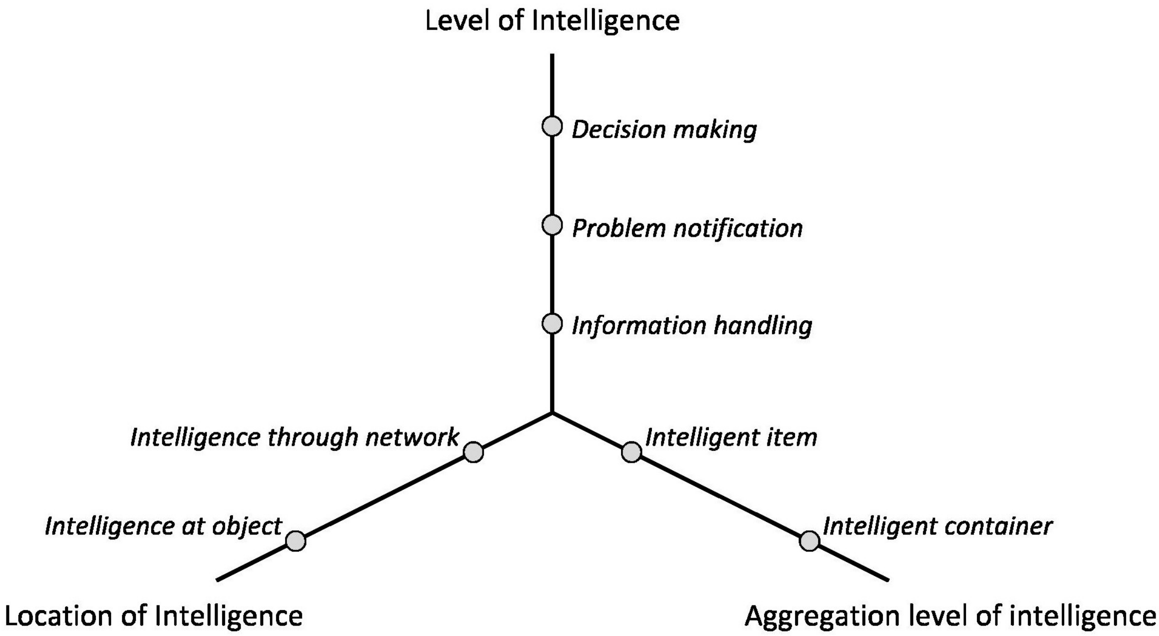


Figure 9: Intelligence of objects represented at three independent axes, source: Meyer et al. (2009), p. 7.

Level of intelligence:

Similar to the definition of McFarlane et al. and Kärkkäinen et al., the degree of intelligence varies from 'dumb' products to pro-active products. According to this, the level is separated into three categories:

- Information handling: An intelligent product should be able to provide information about itself in a suitable form. Sensors, RFID-readers or other techniques should be able to process this information.
- Problem notification: A more intelligent product can notify the operator if a problem occurs, e.g. the temperature is too high.
- Decision making: The most intelligent product in this scale is able to manage its own life completely and makes decisions without any external intervention. E.g. the temperature is too high, so the object initiates the cooling.

[42] Cf. Meyer et al. (2009), p. 7 f.

Location of intelligence:

Object intelligence does not necessarily mean that the intelligence is located at the object. Two possibilities can be distinguished:

- Intelligence through network: The intelligence of the product is at a different location completely outside the physical product, e.g. at a server or database.
- Intelligence at object: All the intelligence, whether this is only information handling, or advanced decision making, is stored at the physical product itself. In this case, the object needs computational power, storing capacities and network connectivity.

Aggregation level of intelligence

The aggregation is also an important dimension, as many products are composed from parts, which can also be products in it. E.g. a car is an assembly of components that are manufactured by different organisations. These parts may be composed of other parts as well. All these single components may have different levels of intelligence of itself. To analyse this, the dimension is separated into two sections:

- Intelligent item: The object only manages information, notifications or decisions about itself. If it contains any components, they cannot be distinguished as individual objects.
- Intelligent container: The intelligent container is also aware of the components that it is made of.

3 The Tool as a Cyber-Physical System

The economic view at the value chain is the key to identify potential for optimisation and further to follow a cost-efficient production strategy.[43] Especially the already mentioned growing product variety, as answer on the demand in individualised products at mass ware prices, leads to an increase in complexity of the production system.[44]
To face these requirements, a flexible position of the manufacturing line is essential. Therefore shorter set-up times are needed to realise smaller lot sizes and enable this flexibility towards the customers demand.[45] Lower set-up times lead to:[46]

- An increase of the available time for production per period
- Lower work in progress
- More possible set-up processes by constant machine capacity

In a mechanical manufacturing the change of the required tools has a big influence on the set-up time, as it is declared later at the practical example of BRP-Rotax (see chapter 4.2.6). A central obstacle for the realisation of existing optimisation potentials is the lack of information transparency within the tool life cycle. The tool passes an enormous amount of different systems during its physical and digital life. The key technology to increase the information transparency is the cyber-physical system.[47] With its physical life cycle within the shop floor and digital entry in different software systems, the tool is predestined as a cyber-physical system.

3.1 The Intelligent Tool in the Mechanical Manufacturing

The fundamentals of object intelligence have been discussed in chapter 2.3. To demonstrate the characteristics of an intelligent tool the definition by Meyer et al. is used with a slight modification concerning the level of intelligence. The definition by Meyer et al. represents no subdivision at the information handling level, which is vitally important regarding the tool handling within the mechanical manufacturing. According to the three dimensions an intelligent tool has to be assignable at each of the three axes.

[43] Cf. Abele/Reinhart (2011), cited in Sauer/Grosch/Abele (2014), p. 542.

[44] Cf. Kagermann/Wahlster/Helbig (2012), p. 14.

[45] Cf. Syska (2006), p. 128 f.

[46] Ibidem.

[47] Cf. Kagermann/Wahlster/Helbig (2012), cited in Sauer/Grosch/Abele (2014), p. 542.

3.1.1 Level of Intelligence Regarding a Manufacturing Tool

Meyer et al. distinguish between information handling, problem notification, or even own decision making. According to McFarlane et al., the information handling is now separated into:

- Unique identification
- Communicating capability
- Storing data about itself

For better understanding this modified dimension is illustrated in Figure 10. The left axis represents the initial dimension according to Meyer et al. The right axis serves as an additional sub-element in accordance with the information orientated intelligence of McFarlane et al. (see chapter 2.3.1).

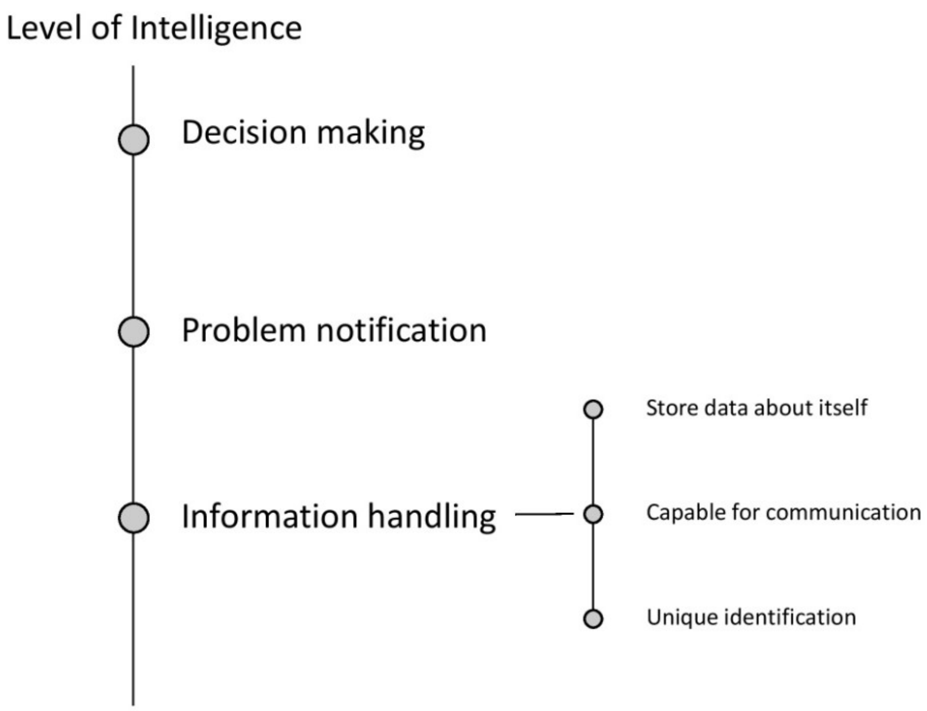


Figure 10: Modified Dimension 'Level of Intelligence', source: own representation, derived from Meyer et al. (2009), p. 7.

A simple information provision would represent the lowest form of intelligence in this dimension. This information handling can be performed by very different methods. Also the volume of the information which is handled ranges from a simple identification to data about the part, the sub-parts etc.

A very popular method is, for example, to put a sticker onto the tool which is used to transfer the correct actual data about the tool to the machine. With this data the machine is going to be equipped. This method causes loss of production time due to time-consuming typing of the data. Further it is a big risk in terms of data transfer errors.[48] A lot of companies try to avoid this risky and protracted method of data transfer and unite the physical and the digital information flow of the tool. Due to the harsh ambient conditions within a mechanical manufacturing, the identification system has to be well thought. The ID has to withstand the high pressure when the cooling lubricant hits the tool holder as well as the liquid itself. During the manufacturing, but especially during the shrinking process, high temperatures occur and may influence the ID.[49]

According to the sub-dimension, illustrated in Figure 10, the unique identification would represent a conventional serialisation of the tools, no matter in which form the ID takes place at the tool. An identification system which is capable for communication has to be intelligent at least through a network (see chapter 2.3.3). Furthermore, the tool has to be implemented digitally in a database. Another option would be to ensure the communication through the tool itself by using an ID system which is providing the data about itself. In this way, the data is located at the tool and lead to the third level of the sub-dimension.

A further step of the intelligence level is the automated problem notification. Regarding intelligence of a manufacturing tool, an example would be a machine stop because of a problem with the tool. Typical issues are a sudden tool breakage, abnormal wear or the limit of the tool life is reached. These are typical tasks of a manufacturing execution system (MES) or a central linked tool database. The indicators are detected by the machine and transferred to the system.[50,51]

The third level according to Meyer et al. is the ability to solve the problem after recognition. In this way, the tool initiates the procedure to, for instance, change the tool or avoid using a broken tool, on its own. This is only possible if the correct replacement tool is already located at the machine store. Similar to the problem notification, these are basically tasks of the machine control unit which is linked to the MES, or to a central tool database.

[48] Cf. Abele/Hueske/Albrecht (2010), p. 46.

[49] Ibidem.

[50] Cf. Fastems (2016), online source [09.01.2017].

[51] Cf. Zoller (2016), p. 24.

3.1.2 Location of Intelligence Regarding a Manufacturing Tool

Regarding the location of the tool intelligence the strategies vary between centralised and decentralised information placement. The goal of the first option is to maximise the transparency by controlling the system via a central database. On the contrary, the goal of the second option is to act as flexible as possible by being not dependant of a system, because all required information is delivered with the object.[52]

Aligned on an automated identification system (see chapter 3.2) these two strategies are comparable in following way:[53]

- Read-only-system (see Figure 11)
- Read-write-system (see Figure 12)

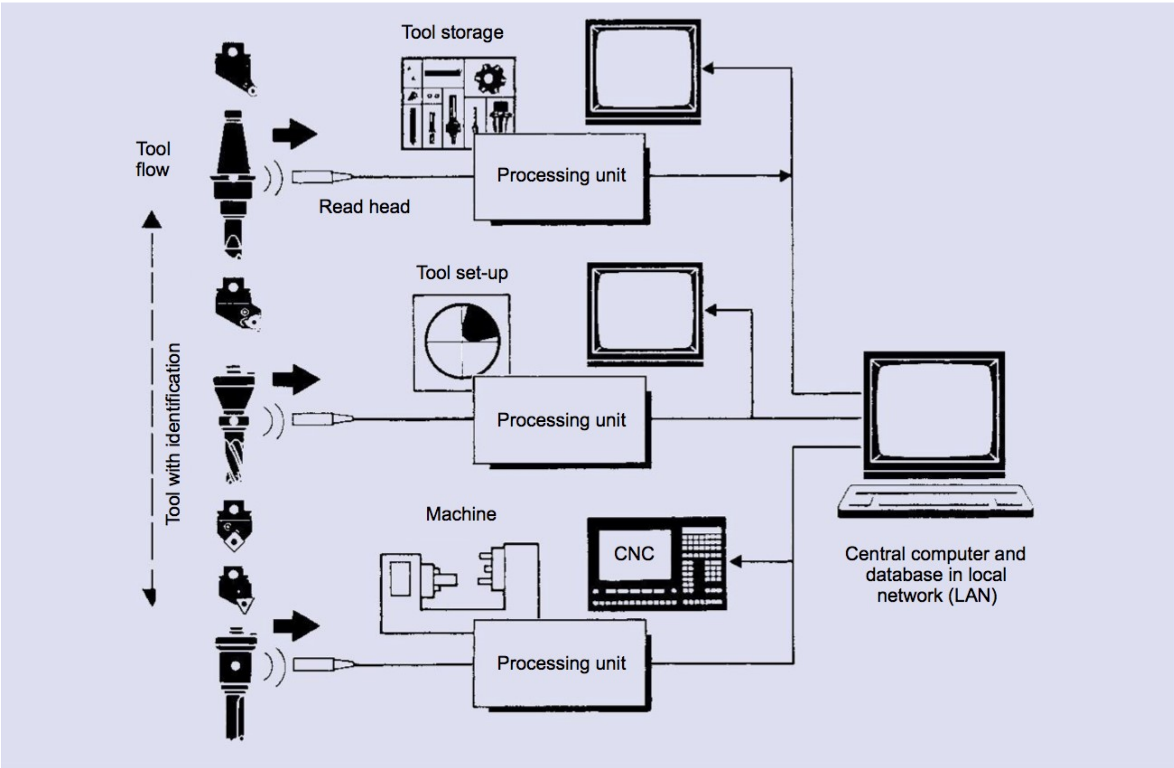


Figure 11: General structure of a read-only-system, source: Kief/Roschiwal/Schwarz (2013), p. 420, modified

[52] Cf. Röschinger et al. (2015), p. 61.

[53] Cf. Kief/Roschiwal/Schwarz (2013), p. 419 f.

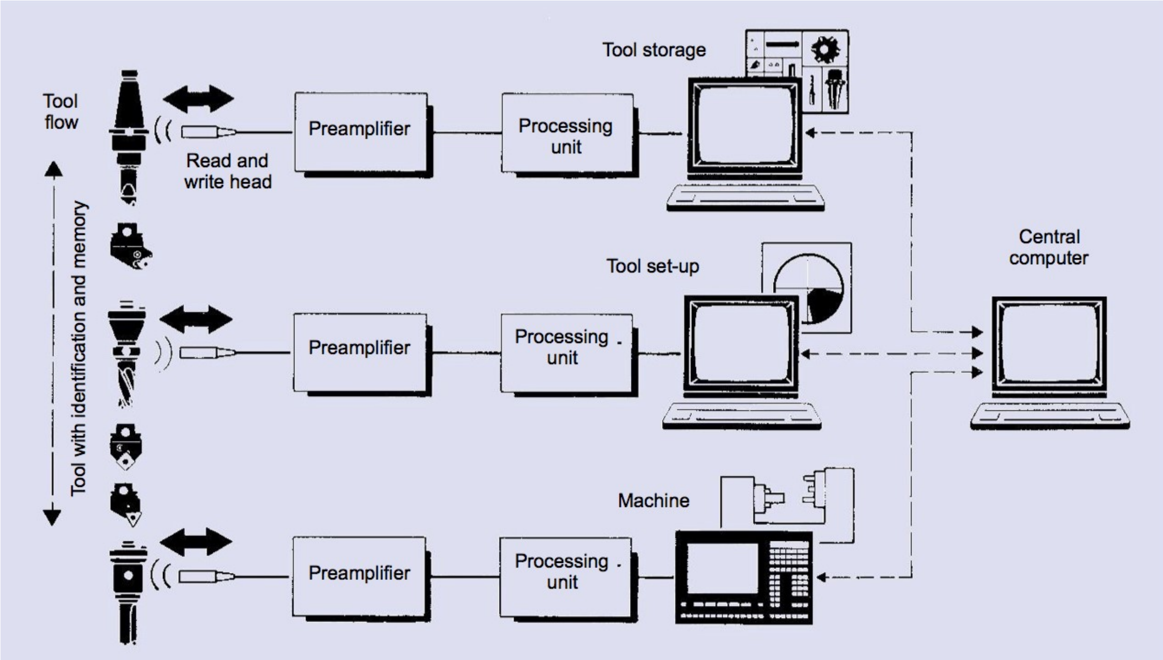


Figure 12: General structure of a read-write-system, source: Kief/Roschiwal/Schwarz (2013), p. 420, modified

The big difference between these two systems is the configuration of the tag which is located at the tool. The read-only system identifies the tool and receives the appropriate information via a central database. On the contrary, the read-and-write-system uses the information provided by the tool itself. Therefore the tool is equipped with a memory tag for identification and information. In this way the tool delivers the necessary information directly to the device and can be programmed and read directly.[54] All information which is provided by the database can be stored decentralised. For example, the tool life is located at the RFID-tag. When the machine finished production the newly calculated remaining tool life is then stored at the tag again and the elder entry is going to be overwritten. The big advantage of such systems is the independency of a central computer. When the tool is put into the machine no direct connection to a central database is necessary, because the tool delivers its information.[55]

[54] Cf. Kief/Roschiwal/Schwarz (2013), p. 420.

[55] Cf. Kief/Roschiwal/Schwarz (2013), p. 419 f.

3.1.3 Aggregation Level of Intelligence Regarding a Manufacturing Tool

The list of tool data necessary for the manufacturing is enormous and dependent on the application arbitrary expandable. The following extract of the CNC handbook 2013/2014 gives an overview about which type of data is detected:[56]

- Tool type
- Tool number
- Replacement tool
- Position in machine store
- Standard / serial / special tool
- Drill / facing head
- Tool weight
- Max. feed and torque
- Tool life / remaining tool life
- Warning limit for remaining tool life
- Tool broken / failure
- Fixed / variable place
- Tool radius
- Cutting edge radius
- Collision radius
- Tool length
- Collision length
- Special tool code
- Wear correction
- Tool locked
- Error code
- Machine allocation

The information about the tool consists of direct information about the tool, as well as of indirect information about the sub-components. Hence, the aggregation level of intelligence represents a mixture of the two levels. It is not possible to detect all characteristics of the sub-components, since it the type of information varies strongly with the application of the tool.

Modern tool management focuses on implementing surrounded areas and evaluating this data together with the tool data (see chapter 3.3). A practical example would be an assembly instruction for the pre-setter, which is stored at the tool and provides information about the sub-components, e.g. the screws.

[56] Cf. Kief/Roschiwal/Schwarz (2013), p. 418.

3.2 Technologies for an Automated Identification System

An automated identification system is essential to achieve a level at any of the discussed dimensions of intelligence. The term *AutoID* is understood to collect the identification of an object or part automated.[57]

In general, three categories can be distinguished: mechanical, optical, or electrical (see Figure 13). Although this figure is already outdated, it represents the main technical categories for the identification of an operating material. Regarding the tool, the optical and the electrical ID system, in form of a chip, prevailed.[58,59]

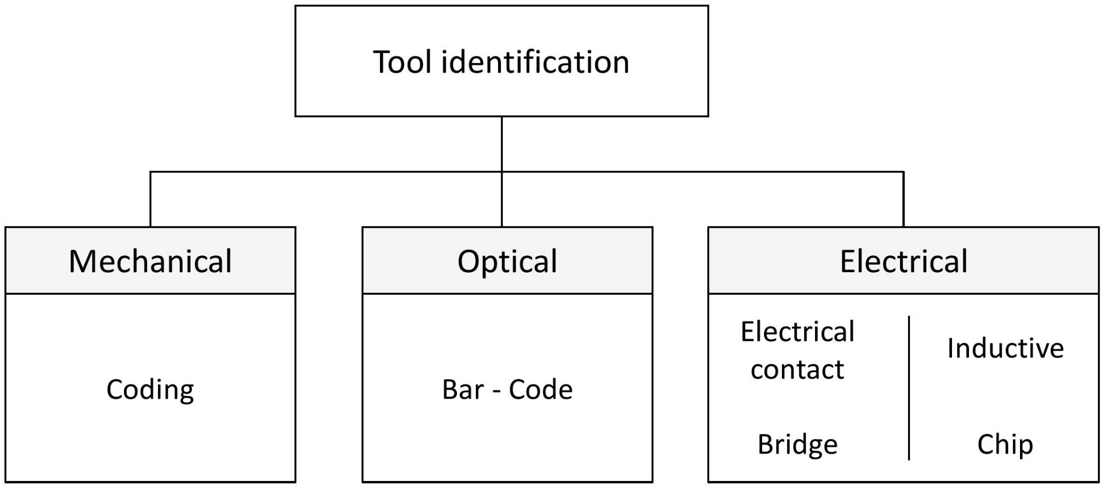


Figure 13: Possibilities to identify operating material, source: own representation, derived from Zipper (1994), p. 24

[57] Cf. Röschinger et al. (2015), p. 59.

[58] Cf. Röschinger et al. (2015), p. 61.

[59] Cf. Kief/Roschiwal/Schwarz (2013), p. 422 f.

3.2.1 Mechanical Identification

In the manufacturing literature this method is, due to various aspects, not recommended and will be more and more eliminated by modern identification systems.[60,61,62,63]
The main aspects are the, like already mentioned, risky and protracted data transmission, as well as the huge amount of information which has to be handled.[64]

3.2.2 Optical Identification

Significantly more information is transferable by an optical identification, compared to the discussed, mechanical identification. These systems are widespread, especially in logistics, because of a very cost-economic production possibility and an international standardisation.[65]
In general, the optical coding can be separated into following main groups:[66]

- 1D-Codes: Barcodes
- 2D-Codes: Stacked Codes, Composite Codes, Dot Codes, Matrix Codes
- Typefaces
- Other codes

The coding has to be as small as possible to fit at the tool holder, for the application as a tool identification system. Nonetheless, the capacity must not be limited to ensure biunique identification. In this way, the Matrix Code represents the only possibility for the specifications of tool identification. The character set is compared to the other coding types much higher and the code ensures omnidirectional readability (independent for tilting angle) for the reading devices. Furthermore, the codes are print- and readable at nearly any materials with the appropriate illumination. The only disadvantages are the higher costs of the reading devices compared to other optical coding.[67]
Figure 14 represents the general structure of a Matrix Code.

[60] Cf. Zipper (1994), p. 24f .

[61] Cf. Röschinger et al. (2015), p. 61.

[62] Cf. Abele/Hueske/Albrecht (2010), p. 46.

[63] Cf. Kief/Roschiwal/Schwarz (2013), p. 418 f.

[64] Ibidem.

[65] Cf. Arnold et al. (2008), p. 817.

[66] Cf. Arnold et al. (2008), p. 818.

[67] Cf. Arnold et al. (2008), p. 820 f.

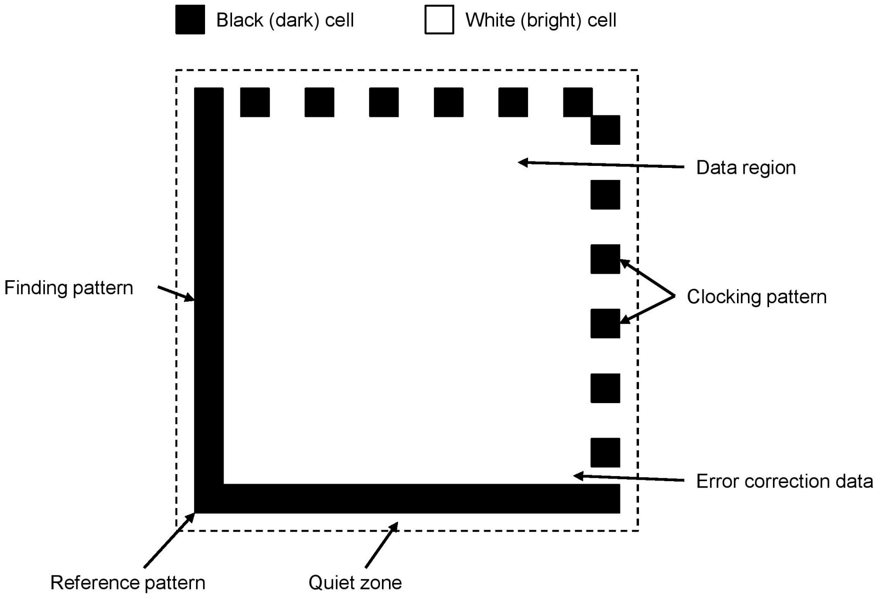


Figure 14: Structure of a Matrix Code,
source: own representation, derived from Arnold et al. (2008), p. 820

There are a lot of different standards for the shaping of the Matrix Code. A common coding is the type *Data Matrix ECC 200* which is the pedant to the *QR-Code*, used in the area of Eastern Asia.

The optical identification represents only an identification of the part (static data). Since it is not possible to store data at the tag, a link to a central database is prerequisite to enable a data transmission. Each device, which is interacting with the tool, has to be linked to this database. Further, a big challenge for optical identification is the manufacturing environment. Residents of, for example, lubricants or chips can impede the readability.[68]

[68] Cf. Abele/Hueske/Albrecht (2010), p. 46 f.

3.2.3 Electrical Identification

In earlier systems the data transmission between data chips and the related control system took place via electrical contacts. Thereby, wear and dirt occurring within the manufacturing lead to reading errors from time to time. Nowadays, inductive devices provide a significantly higher reading reliability.[69] The system that prevailed working with inductive devices, is known under Radio Frequency Identification (RFID). These system and the components withstand the harsh manufacturing environment because no optical contact has to be ensured.[70] Also the metallic and ferrous environment of the tool holder represents no problem for the connection. Although the problems occur at higher frequencies, the tags which are suitable for tool identification are special products.[71] The design is ‘ferroident’, which represent a consistent defect prevention on metal.[72]

RFID systems are separated by frequency. The main frequencies are: MW (Medium Wave), UHF (Ultra High Frequency), HF (High Frequency) and LF (Low Frequency). An increasing of the frequency leads to higher ranges and transmission rates. LF is typically in use for the identification of tools, with a frequency range from 125-135 kHz.[73]

A conventional RFID-system consists of following components (see Figure 15):[74]

- Data carrier
- Send- and receiving unit
- Processing unit
- Connection to the superior information system

[69] Cf. Kief/Roschiwal/Schwarz (2013), p. 419.

[70] Cf. Kief/Roschiwal/Schwarz (2013), p. 422.

[71] Cf. Mähnz (2007), p. 8 ff.

[72] Cf. Balluf (2016), p.7.

[73] Cf. Arnold et al. (2008), p. 826.

[74] Cf. Arnold et al. (2008), p. 825.

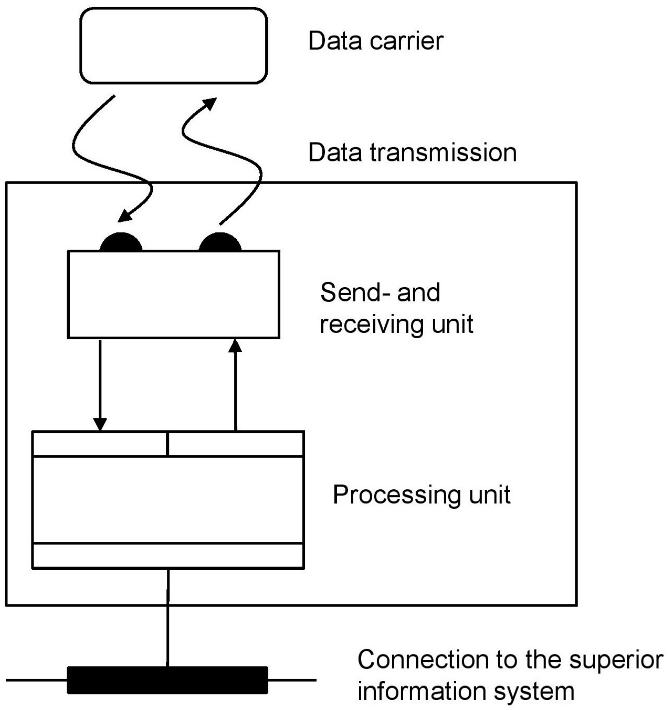


Figure 15: Structure of an RFID-identification system,
source: own representation, derived from Arnold et al. (2008), p. 820

The data carrier is attached at the object and serves as the identification it. Depending on the memory of the transponder, different amounts of data can be stored at it. In this way the carrier can store related information about the object as well, aside from its identification.[75] The send- and receiving unit represents the stationary counterpart of the data carrier and is called the 'antenna'. It is responsible for the conversion of the wireless into the line-bound data transmission.[76] The line-based control of the send- and receiving unit and the evaluation of the data carrier signal is performed by the processing unit. This is the core-element of the RFID-system and serves as interface between identification and information system.[77]

Beside the advantage of the better readability, the RFID-system is in this way able to transfer static (identification of the object) as well as dynamic data (information about the object).[78] But behind these benefits, substantial investment costs occur. For an implementation of an RFID-system additional indirect costs, beside the mentioned components, have to be considered as well. For example the weight of the sensors: Due to the additional mass that is attached, the tools have to be balanced again. Also new tool holders are required if the existing do not innately have the appropriate hole for the sensor.[79]

[75] Cf. Arnold et al. (2008), p. 825.
[76] Ibidem.
[77] Ibidem.
[78] Cf. Abele/Hueske/Albrecht (2010), p. 47.
[79] Cf. Abele/Hueske/Albrecht (2010), p. 47.

3.3 Advanced Tool Management

In addition to the physical components of an automated identification system, appropriate software is required to store and handle the data. This software controls all activities that are related to the tool.[80]

3.3.1 Definition of Tool Management

Tool management describes the whole organisation behind the tools required for CNC machining operations. The tool management represents a core element of the manufacturing system, because of the high priority of tool provision in time, at the right place and with the correct data. The use of computer systems makes it possible to control the whole tool flow within complex production facilities. In this way, large amount of data can be managed effectively at the same time.[81]
Task of the tool management is to enable error-free and efficient work orders regarding the appropriate tool flow. Hence, all information about each single tool in use has to be created, kept up-to-date and stored in a database.[82] Thus, a well-organised, with the latest tool data and mostly automated tool management is one of the most important characteristic of modern CNC-manufacturing.[83]

3.3.2 Suppliers of Tool Management Software

The issue of tool management is clearly of very great importance. This is recognisable by taking a look at the volume of new and further development in the section of tool management.
The list of suppliers is enormous with focus on any possible conceptions. In the following, a short extract of possible suppliers of tool databases is provided:

- Zoller (tool and measuring equipment manufacturer), *TMS Tool Management Solution*
- Walter (tool manufacturer), *TDM systems*
- Kelch (measuring equipment manufacturer), *Smart Factory Services*
- Coscom (machining software developer), *Tool director*
- Magna (supplying industry), *TRP Tool Resource Planning*
- WinTool (machining software developer), *WinTool*

[80] Cf. Kief/Roschiwal/Schwarz (2013), p. 421 ff.
[81] Cf. Eversheim (1989), p. 101.
[82] Cf. Kief/Roschiwal/Schwarz (2015), p. 491.
[83] Ibidem.

3.3.3 New Developments in the Area of Tool Management

The key words of new developments and the focus of new software are transparency, integration of the whole tool life cycle and cloud-based data. Thus, suppliers attract with set-up reduction, increase in tool utilisation, savings at storage costs and more.[84]
These benefits should be achieved by using a central tool database which enables a neat interaction with the existing system. For the realisation, the developers follow the strategy to implement more and more of the surrounded software from one provider. So an expansion to adjoining areas is tried to achieve.
TDM systems, for example, attract with a central database that enables access for global spread production lines. This offers the possibility of a central CAM division at one single plant which provide the digital data for all other factories.[85]
A representation for creation transparency would be the TMS Tool Management Software of Zoller that uses a special user interface for the illustration and graphical visualisation of tool use, tool wear as well as remaining stock and required material. [86]
Coscom, for its part, tries to minimise the losses caused by unnecessary interfaces. Therefore, the company offers a broad product portfolio which enables a connection of the Tool director (tool database) to the Factory director (MES). Such integrated systems offer an efficient way to implement the cycle of resources (operating material) into the cycle of production planning, because all machines in use are recognised by the MES.[87]

Another practical example would be the Maschinenfabrik Reinhausen located in Regensburg, Germany. The company was awarded the prize for successful realisation of Industry 4.0 in 2013 with the software ValueFacturing.[88]
ValueFacturing is a web-based solution in addition to the existing CAM software and tool database. The software uses the huge amount of data created by the digitalisation. After an evaluation, this data is distributed by a data hub. A new innovation of the system is the cloud-based application that enables a processing of the data on an outsourced server. Hence, the software is paid by service (for example per tool pre-set).[89]

[84] Cf. Zoller (2016), p. 6.

[85] Cf. TDM systems (2016), online source [09.01.2017].

[86] Cf. Zoller (2016), p. 12.

[87] Cf. Coscom (2016), p. 14.

[88] Cf. Produktion (2013), online source [09.01.2017].

[89] Cf. Microsoft Newsroom (2016), online source [09.01.2017].

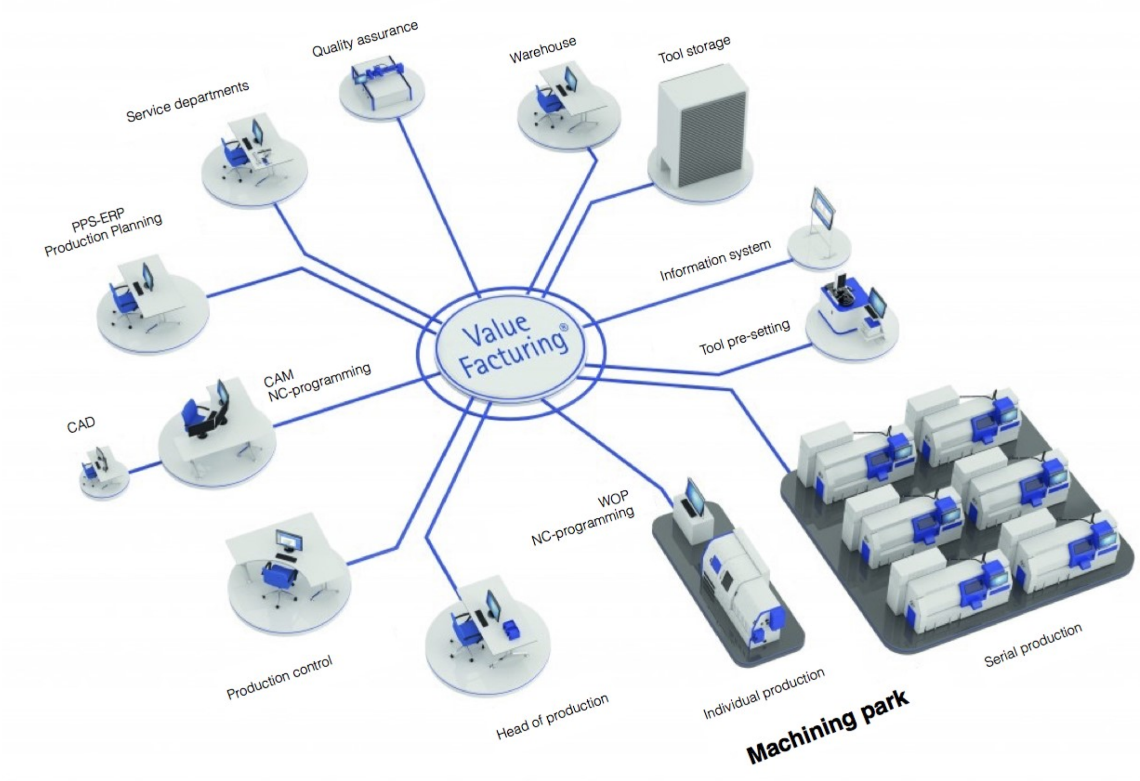


Figure 16: Illustration of the ValueFacturing strategy, source: Microsoft Newsroom (2016), online source [09.01.2017], modified

The illustration of Figure 16 should demonstrate the system landscape when using the ValueFacturing. The software represents the web-based data hub that provides the required data for each single involved party. Maschinenfabrik Reinhausen attracts with information provision in real-time based on online communication.[90]

A considerable aspect is that the system represents an online service. All data is continuously transferred online. This means that each machine has to be connected by an Ethernet port. Further, the data may be vulnerable in terms of cyber security.

[90] Cf. Microsoft Newsroom (2016), online source [09.01.2017].

3.4 Conclusion of Literature Research and Potential for BRP

Industry 4.0 is characterised by the application of cyber-physical systems. The discussed topics declare the possibilities and benefits implementing these. With the further development of demarcated embedded-systems, new flexibility within the mechanical manufacturing is achievable. Flexibility that is highly relevant to face upcoming mass individualisation and manage volatile markets, as it causes challenges for the production of BRP-Rotax (see chapter 1.2).
With the use of a cyber-physical tool, the set-up processes are performable in less time. Also the data transmission is error unsusceptible and could lead to a better machine utilisation due to less downtime. But beside the economical benefits of using an automated identification system, a cyber-physical tool is a big step towards the goals of the Smart Factory. A digital illustration of the tool life cycle enables transparency over the tool use. This transparency can be used for further evaluations and concrete conclusions about which tool processed a specific part. The manufacturing literature gave insights into the state-of-the-art regarding AutoID systems. The data matrix code and the inductive variant with an RFID tag prevailed at this section. Depending on the specific application both offer advantages and disadvantages.
With the use of an AutoID-system, the paper flow within the mechanical manufacturing and around the tool handling at BRP-Rotax can be minimised. This can also save time when the tools are changed at the manufacturing machine. Further, transmission errors could be avoided. Another interesting issue is the transparency around the tools and their use. Exact information can be collected and evaluated. This leads to a huge amount of data (big data). If this data is used in the right way, prognoses about tool wear, upcoming tool use or tool purchase strategies could be made. But also correlations to other resources, for instance the used fixture or the manufacturing machine itself should be identifiable. In this way, predictive actions can be taken. For example, with all information about past and current manufacturing steps, abrupt tool wear could be detected preventively or avoided when the machine is monitored.
The use of cyber-physical systems offers a lot of potential in various sections for BRP-Rotax. Challenging is the implementation into existing systems and grown structures. Therefore, the following chapter focus on the practical research at the shop floor of BRP-Rotax.

4 Practical Research at BRP-Rotax

The following part of the thesis shows the practical approach of the elaborated aspects. As mentioned in chapter 1.2, the business unit CCZ is the pilot zone of the Smart Factory for taking a snapshot of the processes ongoing and creation of a suitable concept.
A major part of the practical chapter is a structured breakdown of the main process chain to discover the actual need for actions. Taking account of the located error sources, the relevant departments have been engaged in discussions with the approach to prevent future instabilities. Therefore the tool as a production resource, which particularly revealed weak points, was reconsidered and a concept for an efficient tool management has been conducted. This idea is based on the discussed topics of a cyber-physical tool.
The developed concept is proofed in terms of benefits for the production and economical aspects for BRP-Rotax afterwards. Furthermore, an implementation strategy completes the usability by considering the ongoing manufacturing for the introduction of new systems.

4.1 Approach

The methodological plan for the realisation at the shop floor was the Six Sigma roadmap for problem solving and process improvement. The key aspects and checkpoints have been aligned to the stages of the DMAIC plan (see Figure 4).

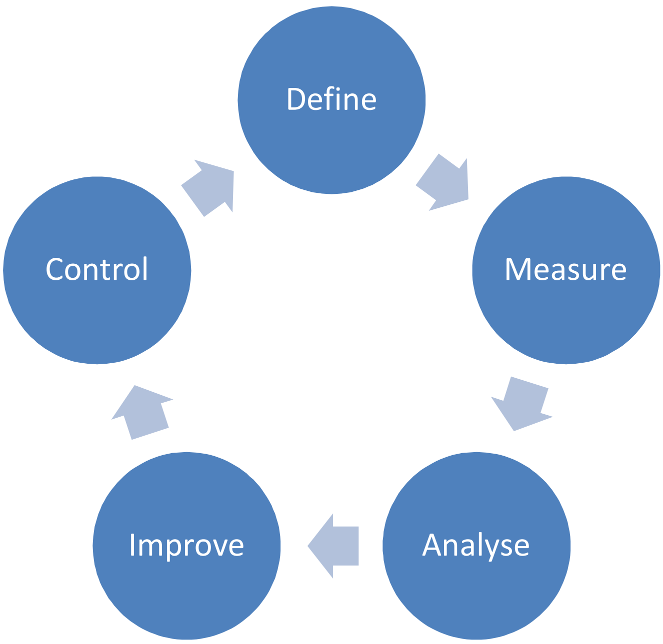


Figure 17: Six Sigma process improvement,
source: own representation, derived from Oriel (2016), online source [09.01.2017]

According to the Six Sigma roadmap, the project plan was created as represented by Table 1:

Define	• Problem definition • Delimination of the project • Declaration of project aims • Internal project kick-off
Measure	• Information acquisition by involvement of all affected parties • Collection and aggregation of relevant data • Evaluation of documented set-up processes
Analyse	• Mapping of the process chain and sub processes according to defined use-cases • Analysation of process models and deduction of potential errors • Detection of main reasons
Improve	• Declaration of key perfomance indicators • Concept development • Analyse ability for implementation
Control	• Target reconciliation • Development of an implementation strategy • Roadmap for internal use • Project documentation

Table 1: Six Sigma process steps,

source: own representation, derived from Furterer (2009), p. 23.

The roadmap represents the guideline for project and delivered the input for the written documentation. During the Define-stage the departments have been involved and clear project aims have been declared (chapter 4.2.1-4.2.5). The set-up process has been evaluated in the Measure-stage with the help of documented data about the times and problems during the reconfiguration (chapter 4.2.6 and 4.2.7). After that, the Analyse-stage delivered the base for the concept with a detailed analysis of the problematic tool management and the affected ongoing processes (chapter 4.3.2 and 4.3.3). The following

Improve-stage is discussed in chapter 4.4.1-4.4.5 and represents the conception for a new tool management system. In the end, the Improve-stage dealt with the proof of concept and the documentation of the project (chapter 4.4.6). Further, an outlook should point out the future steps for BRP-Rotax (chapter 5).

4.2 Current Situation

As mentioned in chapter 1.4, BRP-Rotax is confronted with new specifications on a modern manufacturing. Little lot sizes are required to react flexible on changing demands. The current instability within the process chain makes it even more difficult to react on short-term changes in production orders.
High stocks in raw material and semi-finished products as well as limited flexibility are the result of proactive manufacturing (see Figure 18). The production planning is forced to plan with this high work in progress since it takes selectively very long to adjust the manufacturing line for a new order.

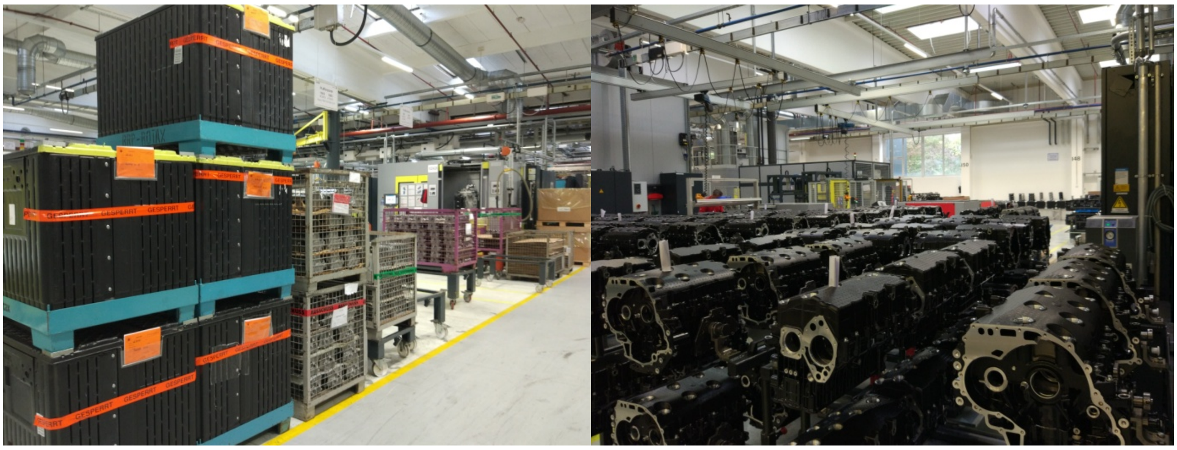


Figure 18: High stock in raw material, source: BRP-Rotax (2016), internal source

The following chapters describe the actual situation within the business unit CCZ. Chapter 4.2.1 and 4.2.2 cover background information about the department structure and the process classification. Afterwards, the process chain of the manufacturing is mapped and furthermore split into the single steps including the required set-up process.

4.2.1 Departments of BRP-Rotax involved in the Manufacturing Process

The following list (Table 2) contains all departments enrolled in the production process. A close cooperation is required to gain the necessary information, especially to perform a detailed process map.

Department	Subdivision	Area of Responsibility
Smart Factory		High-tech strategy for future projects Digitalisation in the manufacturing plant
Process Engineering	Tools	Calculation and evaluation of tool requirements
	CAM	NC programming Administration of tool data base Post processing NC program for work order
	Production Planning	FT-Order management Machine occupation
FT Manufacturing	Operator	Machine operator Execution of work FT-orders Changing tools if necessary Pre-setting of tools if necessary
	Technologist*	Receiving FT-orders Set-up machine ready for processing Equip machine with required tools and fixtures
	Pre-Setter	Tool pre-setting Tool assembling Tool management within the shop floor Preparing required tools ready for FT-orders
	Head	Supervisor of the business unit
Quality		Control produced parts in terms of geometry and quality
Shop floor-IT		Supervision of system landscape
Technical Service	Prototypes	Construction of prototypes
	Tool Construction	Provision of tools for the manufacturing
Procurement	Operating Materials	Execution of calculated tool demand

Table 2: Departments enrolled at BRP-Rotax, source: own representation

*Technologist is the internal description for the employees who are responsible for whole reconfiguration process of the manufacturing machines.

4.2.2 Process Classification

Depending on the specifications of the parts to produce the orders can be separated in two groups: Whether there are design changes at the part or there is an increase in demand of the assembling which requires a higher output without design changes. The time possible to use for producing is compared in Figure 19.

1. Design changes:
   - New product development (NPD)
     - Completely new work piece
   - Engineering design change
     - Existing product with significant design changes

2. No design changes:
   - Order to delivery (OTD)
     - Existing product
     - Change of quantity

Figure 19: Process classification, source: own representation

4.2.3 Process Chain

The below stated Figure 20 shows the entire layout of the production plant Gunskirchen. It is separated in two main sections. Section 1 represents the assembling and section 2 the manufacturing hall.
Two independent process chains are running through the pilot zone: The manufacturing of the cylinder crankcase and the manufacturing of the cylinder head which are then brought together and prepared for the assembling. The process chains within the relevant business unit are shown on an extract of the entire layout in Figure 21 followed by the described process steps in Table 3 and Table 4.

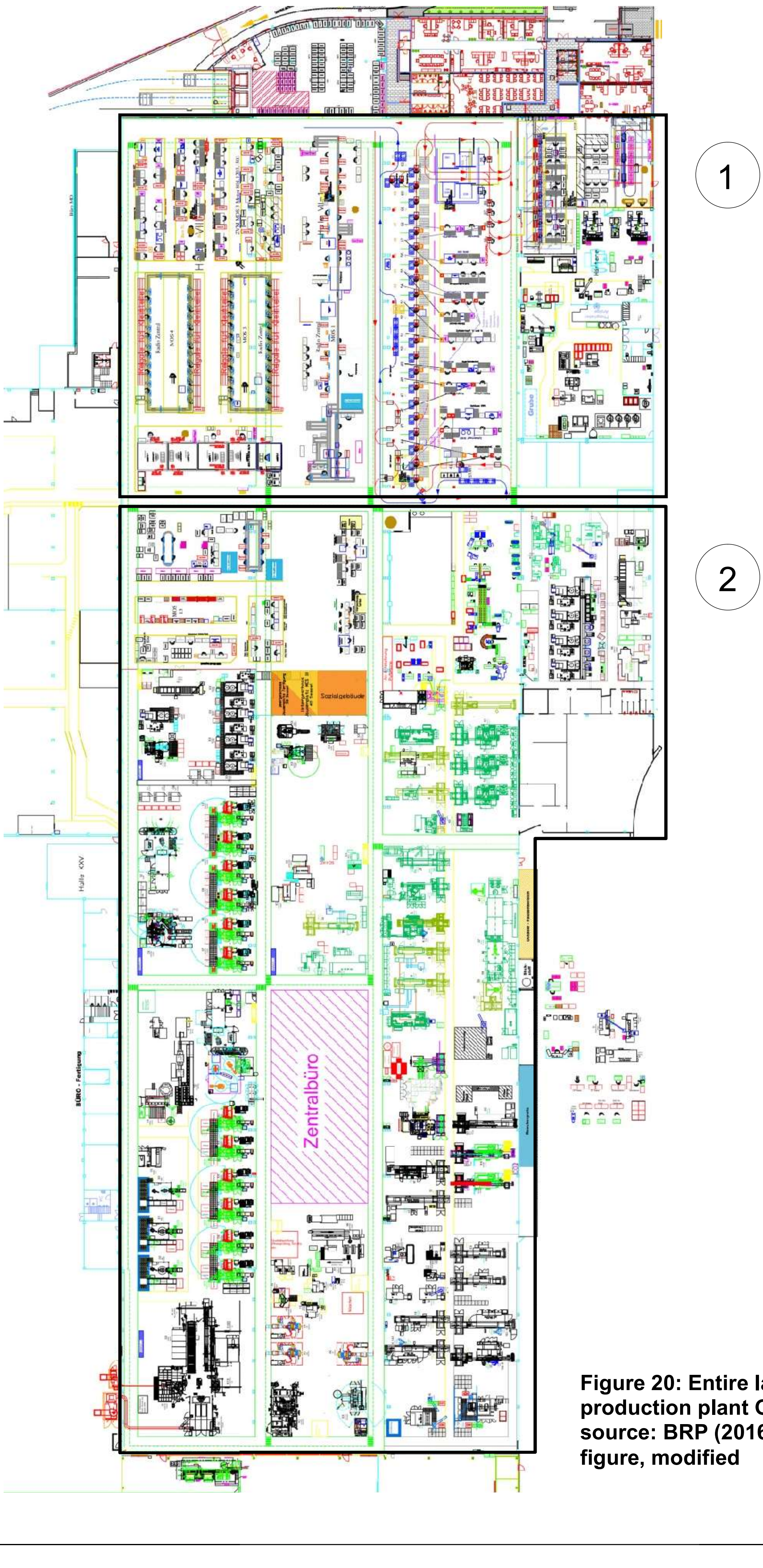


Figure 20: Entire layout of the production plant Gunskirchen, source: BRP (2016), internal figure, modified

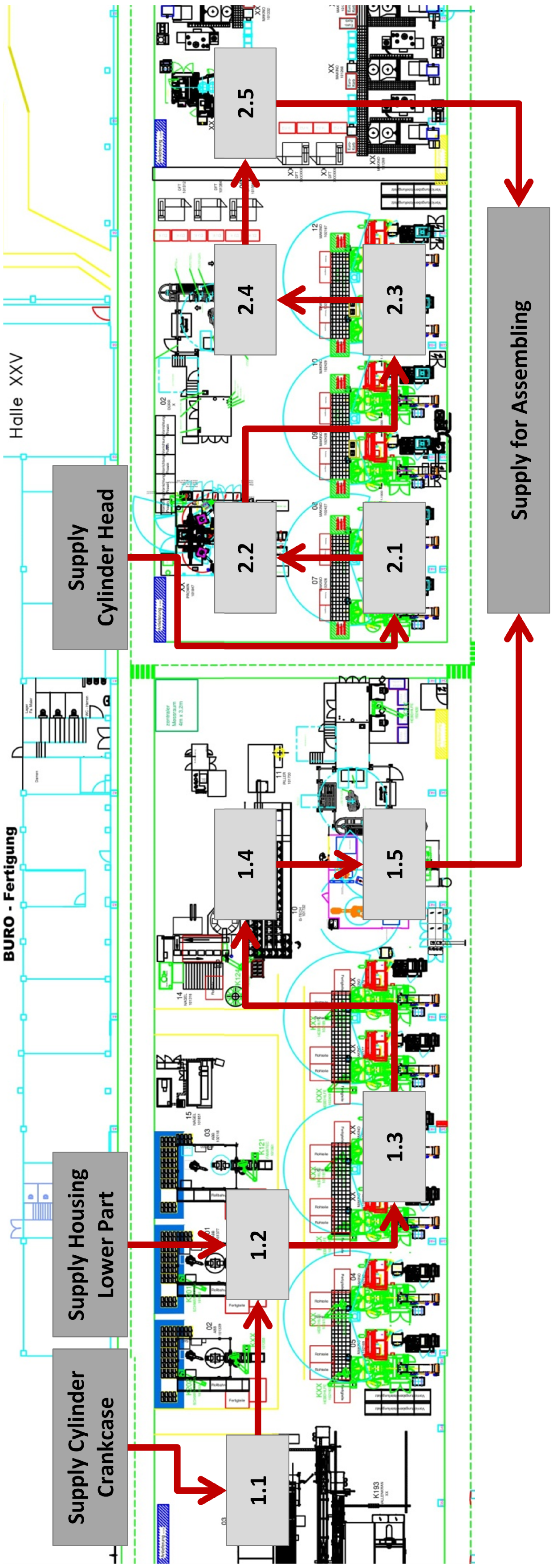


Figure 21: Process chains of the business unit CCZ, source: BRP (2016), internal figure, modified

Process Step	Description
Supply Cylinder Crankcase	Supply of the cylinder crankcase in the delivery zone next to the plasma coating system Supply of the lower part of the housing next to the automated screw station
1.1	Plasma coating of the cylinder bores
1.2	Automated mounting of crankcase and the lower part of the housing at the *ABB screw station*
1.3	Manufacturing with 1st and 2nd setting of the mounted crankcase at one of the six machining centres *Makino A61NX*
1.4	Vertical honing of the cylinder bores at the honing machine *Gehring* for two cylinder engines / *Nagel* for three cylinder engines
1.5	Deburring and washing at automated high pressure *Piller* deburring robot cell
	Supply for assembling

Table 3: Process chain of the cylinder crankcase production, source: own representation

Process Step	Description
Supply Cylinder Head	Supply of the cylinder head in the delivery zone next to the automated valve seat press-in system
1.1	Manufacturing with 1st and 2nd setting of the cylinder head at one of six machining centres *Makino A61NX*
1.2	Automated press-in operation of the valve seats
1.3	Manufacturing with 3rd and 4th setting of the cylinder head at one of six machining centres *Makino A61NX*
1.4	Deburring and washing at automated high pressure *Dürr* deburring robot cell
1.5	Tightness test
	Supply for assembling

Table 4: Process chain of the cylinder head production, source: own representation

For each production step, the work piece is mounted on the appropriate fixture that allows the assembly with a, for the relevant machine, suitable pallet. The machine is equipped with the required operating material and the matching control program. The machine is then ready to start the production.

On the basis of the business unit-production model different kinds of engine types are manufactured using the same machines. The parts produced vary from little changes in the revision until completely different aggregates. Hence, the set-up effort varies strongly as well. For little design changes, an alignment of the production program with the same fixture and operating equipment is enough. For the production of a different engine type, a complete new set-up is necessary.
To enable this enormous flexibility within the process chain, a set-up of each machine according to the production planning is required. This process is supposed to be achieved as fast as possible to provide a stable, subsequent production.

4.2.4 Set-up Process

Each single machine of the process chain has different specifications on the respective set-up process. For example, for the screw station it is enough to change the fixture and the program of the robotic control whilst a reconfiguration of a machining centre is a protracted activity. It takes several attempts until the quality control gives the final approval for the serial production.

The approach of the Smart Factory of BRP-Rotax is a flexible acting of the manufacturing line for the realisation of smaller lot sizes. Table 5 and Table 6 show the current set-up and cycle times for every production step of the pilot business unit. The two illustrations compare the average set-up times of each manufacturing step with the average cycle time per part.

The relation of set-up time to cycle time determines the economic lot size. For the realisation of an individual flow manufacturing, a drastic reduction and a levelling of the set-up times are prerequisite.[91]

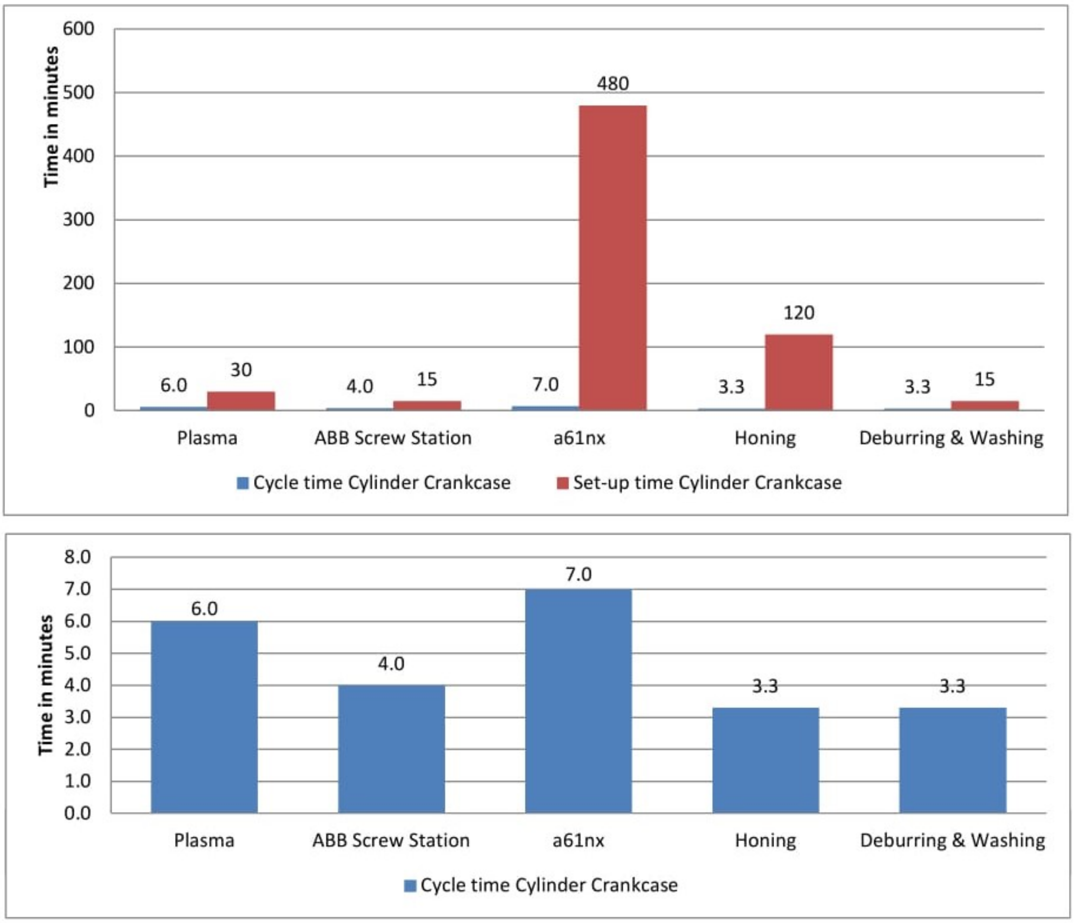
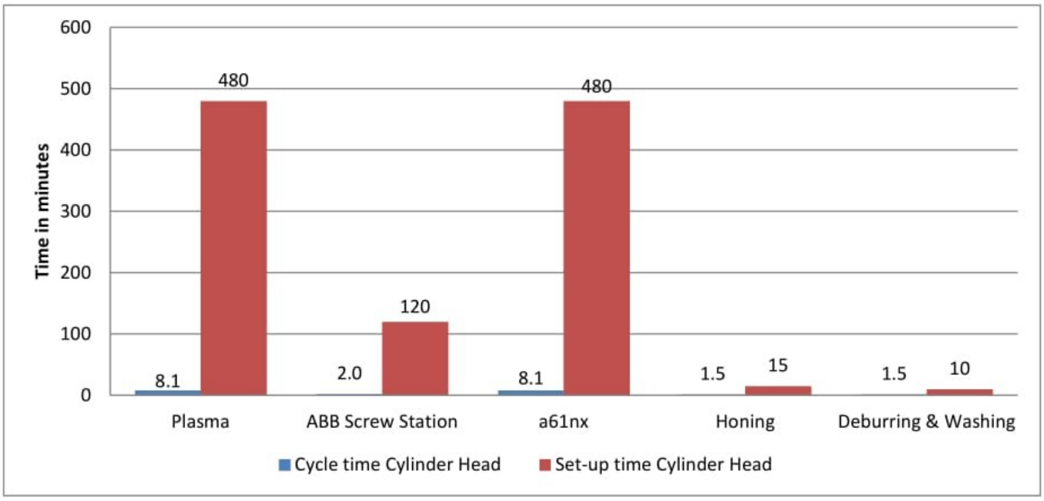


Table 5: Current set-up and cycle times of the cylinder crankcase manufacturing, source: own representation, based on BRP internal data

[91] Cf. Erlach (2007), p. 135 ff.



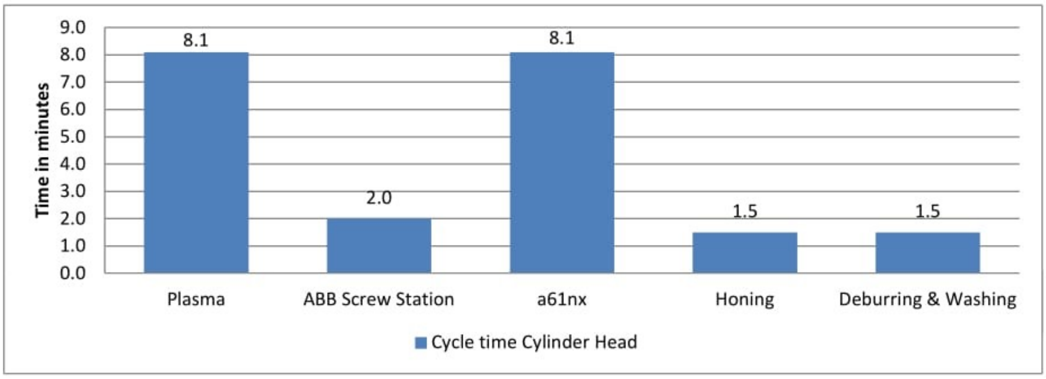


Table 6: Current set-up and cycle times of the cylinder head manufacturing, source: own representation, based on BRP internal data

A closer look at the set-up times and the comparison of single process steps shows substantial higher set-up times of the machining centres. Compared to the other production steps, the reconfiguration of a machining centre is an extremely accurate process. An average work piece is covered by 300 to 400 different measurement points with a tolerance of 0.01 mm. These reference points are checked by the quality control in an iterative loop after the first part is manufactured until the required tolerance can be achieved.

For producing a new work piece, the machine has to be equipped with several new components. The required tools have to be provided, the correct fixture for the work piece has to be placed in the machine and the right NC program has to be sent to the machine. After pre-setting the machine the manufacturing of a test work piece starts, whereby all these new influence factors have an impact on the work piece and its quality. After producing the quality control hands out the test report and the iterative alignment can start.

The pre-setting and the necessary readjustment is performed by the FT-Technologist who is responsible for operating the machine until the work piece is ready for serial production. The key elements of this procedure are illustrated by Figure 22.

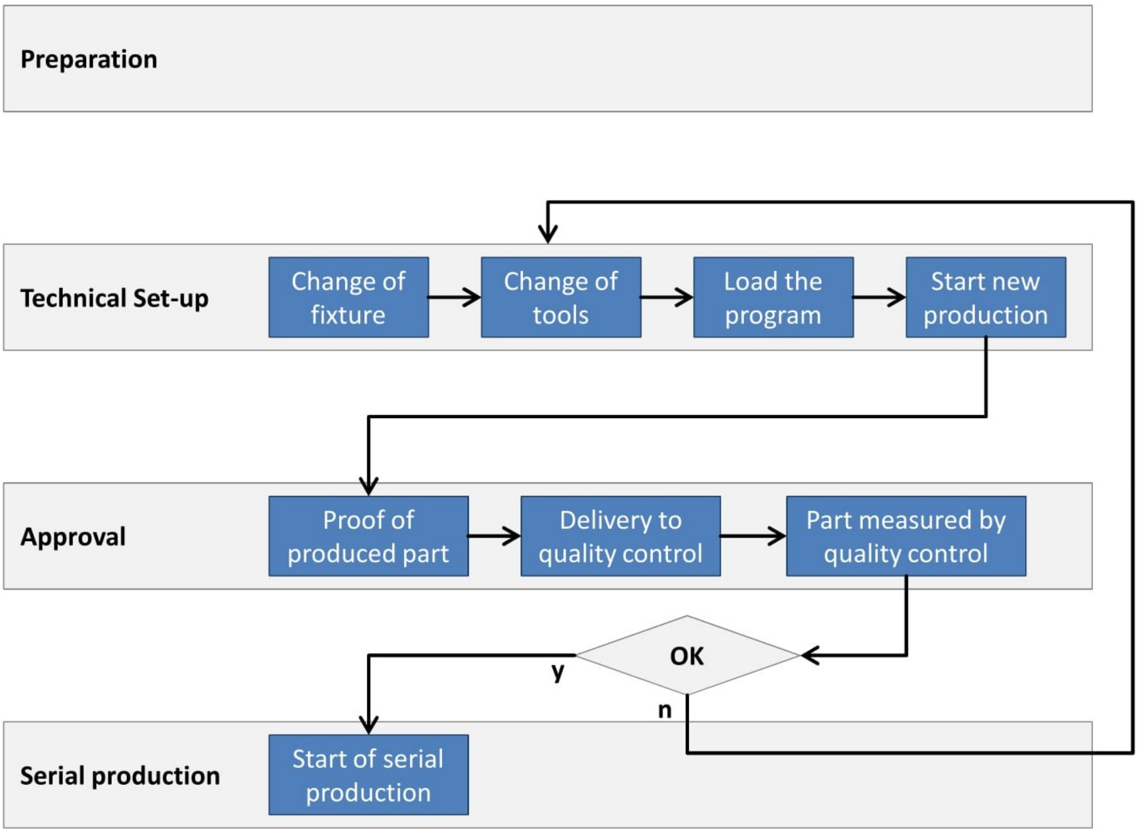


Figure 22: Block diagram of the key elements of the set-up process, source: own representation

4.2.5 Influence Factors on the Set-up Process

In general, a process is defined as stable when constant and predictable results are delivered from day to day, hour by hour.[92] Due to strong variations in the results of duration and quality, the current set-up process can hardly be termed as stable.
To demonstrate the detected influences, a relation between cause and effect based on the Ishikawa model was created. It should show the aspects in a rough way and furthermore be used for individual treatment of the appropriate factors. Therefore, the base structure of the diagram was modified and aligned to the major causes for the instability of the current set-up process.

[92] Cf. Dietrich/Schulze (2009), p. 219.

4.2.5.1 Ishikawa Diagram

The diagram was developed for the application in quality circles. Therefore, effect and cause are separated and clustered in main groups.[93]

The approach is to frame the problem as a question (Why is the process instable?). This is represented by the 'head of the fish' whilst the classified main causes are illustrated as the single fish bones. As classification serves the 6M-Method with the reference on[94]:

- Measurement
- Mother Nature
- Methods
- Man Power
- Material
- Machine

Figure 23 shows the modified cause-effect diagram was aligned on the set-up process.

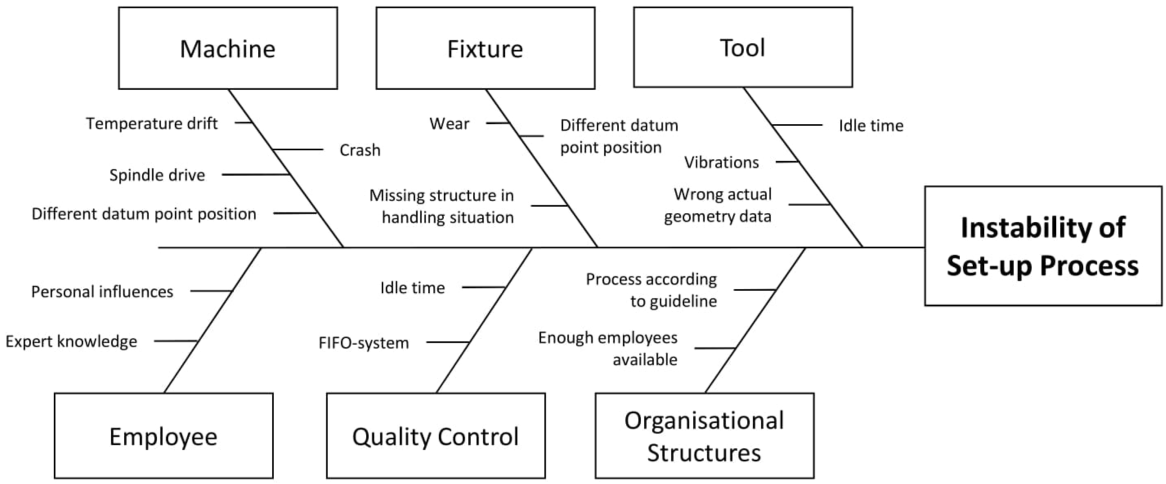


Figure 23: Influences on the set-up process, source: own representation

The major components can be divided into organisational issues, illustrated as the lower parts of the diagram, and technical issues, as the upper part. Their impact is discussed in the following descriptions:

[93] Cf. Kamiske and Brauer (2008) p. 251 f, cited in: Koch (2015), p. 159 ff.

[94] Cf. Lunau (2014), p. 167 ff.

Machine:

Currently there are twelve manufacturing machines from the type Makino A61 NX within the business unit CCZ in use. Aside from the new plasma coating machine, these machining centres are the most modern components of the process chain.

Despite the manufacturing process is taking place at machining centres that are identical in construction, each single machine has their own characteristics. This is caused for example by peculiarities of the spindle or the spindle drive, slightly different position of the datum point or a spindle offset because of a crash.
But the machines are also changing their behaviour over their lifetime e.g. caused by a temperature drift or the usual wear of the drive components.

Fixture:

As mentioned in chapter 4.2.3, the work piece has to be mounted on an appropriate fixture which is the link between the processed part and the pallet of the machining centre. Similar to the machine behaviour the fixtures are identical for the same engine type, but show significant differences among each other. This variation of actual geometry data results in different datum points of the fixtures and furthermore in protracted alignment processes of the machine on the fixture.
Another cause is the missing structure in the handling situation. The fixtures that are currently in use are only partially identified and listed in an MS-Excel file. The posting of the actual location is very inaccurate and can result in a protracted search for the required fixture.

Tool:

The technical influences of the tool on a normal production process are on the one hand geometry deviation by providing wrong actual data. On the other hand, surface quality problems can occur because of chattering or vibrations in terms of unsuitable cutting parameters.
An unusual, but also occurring issue is a machine crash in terms of tool problems. In general this is caused by wrong data or problems with the data. In the best case the FT-Technologist is able to intervene during the process or stop the machine. In the worst case the machine is creating a crash and has to be repaired. Beside the costs for repair at BRP-Rotax in Gunskirchen, it leads to a loss of production due to the machine downtime.
Approximately 4000 tools are presently enrolled in the production. Either in use at the machine or assembled waiting for an order. In addition the storage contains tools in form of raw material (single tools).

Employee:

The set-up process is performed by the technologist with the help of the pre-setter whose task is the provision of the required tools with the correct actual data.
The readjustment is an iterative loop, whereby the technologist has to align the manufacturing process step by step to fulfil the required quality specifications. Hence, the employee itself represents a major influence factor. The way he is creating the readjustment and the actions he is taking are decisive for the result of the next loop.
Hence a lot of expert knowledge is needed to perform the set-up.

Quality Control:

The task of the quality department is to measure the produced part and hand the measurement protocol over to the technologist. In average a test cycle of a cylinder head covers about 300 measurement points, a cylinder crankcase about 400 measurement points. According to this report the technologist has to find the reasons for the deviation and take actions to guarantee the correct geometry.
The time required to do the measurement is part of the machine downtime because the machine is waiting for the approval for serial production, which can take several attempts. Because there is no notification or planning when and which part is coming to the measuring room, the quality control has to deal with huge volatility. Therefore, the execution has to follow the FIFO-system (first in first out) with little consideration of priorities.
Hence, great idle time of the work piece can be the result as it has to wait for the other parts to be measured.

Organisational Structures:

Personnel troubles are currently increasing the difficulties at the shop floor. For performing the set-up process according to the internal SMED guideline (single minute exchange of die) two technologists are required. Therefore, it is essential to plan the utilisation of the machines carefully to ensure the availability of the employees needed for the set-up process.

4.2.6 Recording the Set-up Process

To clarify the influence factors on the set-up process, the responsible technologists recorded the progress of equipping a machine for a new order.
The document (attached in the appendix as a blank, see Attachment 1) delivers following information:

- Date and technologist
- Specific manufacturing machine
- Which work piece was and which is going to be manufactured
- If the process is carried out according to the internal SMED guideline
- Technical set-up time
- If a correction loop was required
- If the overall set-up time exceeds eight hours

The template in form of a table should be completed in the end of the respective set-up process. It should enable a transparent set-up and represent the driving key issues for the instabilities during the processes. This information about set-up times was gathered by the technologists during a period of 22 months starting in February 2013. With a total amount of 361 processes, the documentation is the most meaningful information about set-up procedures available in the company. The fact, that it is already a little outdated is not relevant because neither organisational nor technical changes have taken place in the meantime.
Considering the main issues demonstrated by the Ishikawa diagram in chapter 4.2.5.1 an evaluation of the collected data was conducted to provide a weighted illustration.

4.2.6.1 Technical Set-up Time:

The designation ‘technical set-up time’ refers to all activities performed by the technologist which are needed to equip the machine with the required utilities. Figure 24 shows the average time of the technical set-up. Usually, this consist tool change, fixture change, loading the program and starting the new production (see Figure 25).
Alarming in this diagram is the rising trend of times during this large period.

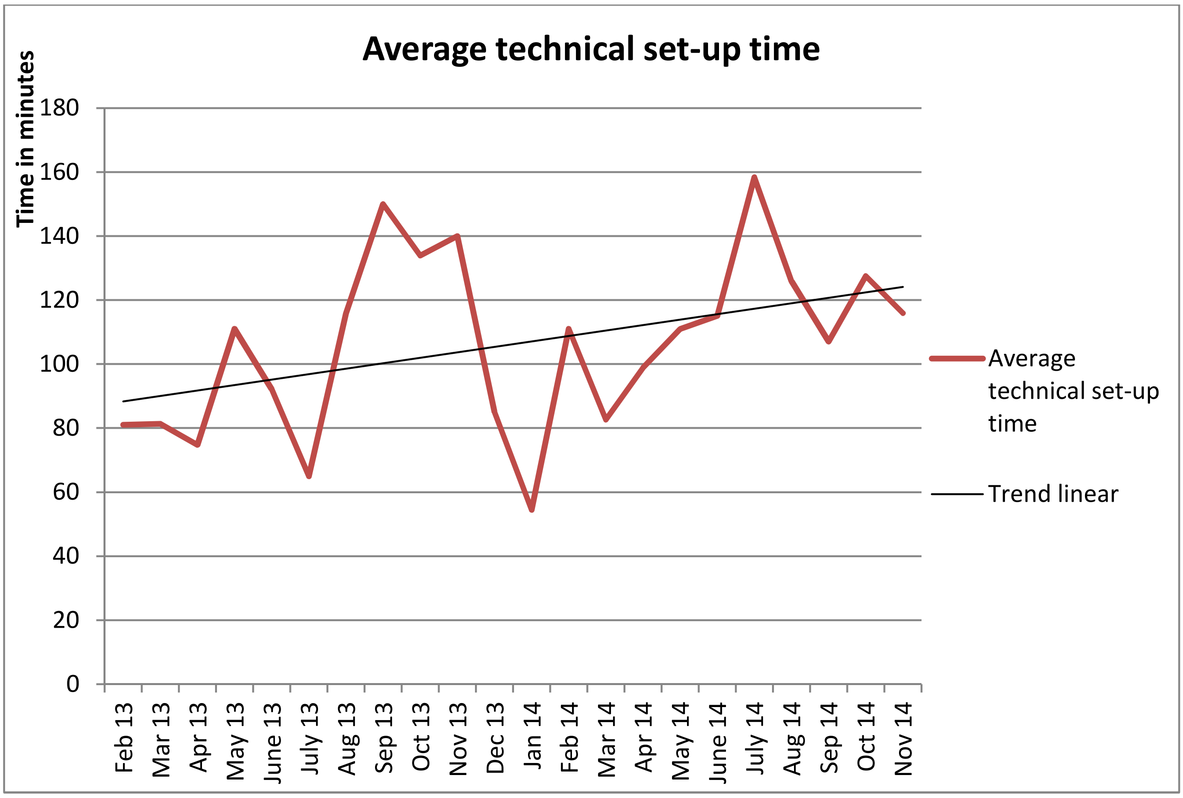


Figure 24: Average technical set-up time from Feb/13 – Nov/14, source: own representation, based on BRP internal data

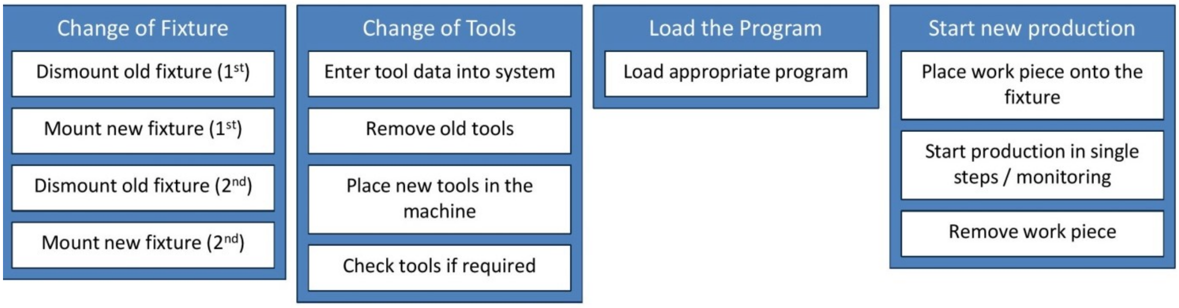


Figure 25: Elements of the technical set-up, source: own representation

4.2.6.2 Overall Set-up Time:

After the machine is equipped with the necessary resources and the technical process is completed, the quality control is able to start the approval process. As mentioned in chapter 4.2.4, it follows an iterative loop with alignments performed by the technologist. The ‘overall set-up time’ includes the whole process until the machine is ready for the serial production, as it is represented in Figure 22. The crucial limit for this process is a duration of eight hours. This period is the length of a shift, which means a new worker has to take on the open tasks of the previous shift if the set-up takes longer.
Considering the complexity of a work piece and the different influence factors that are adjusted, it is a very difficult procedure to hand over the job to the following worker. The technologist has to explain all undertaken actions depending on the result of the measurement report. Hence, an exceeding of the eight hour mark must be avoided under all circumstances to prevent an incomprehensive deliver of the task.

Figure 26 shows the percentage of the overall set-up durations that are exceeding the crucial eight hour mark over the relevant period. Like in the previous graph the rising trend is an alarming sign. The little amount of set-up processes in total in December 2013 explains the empty entry.

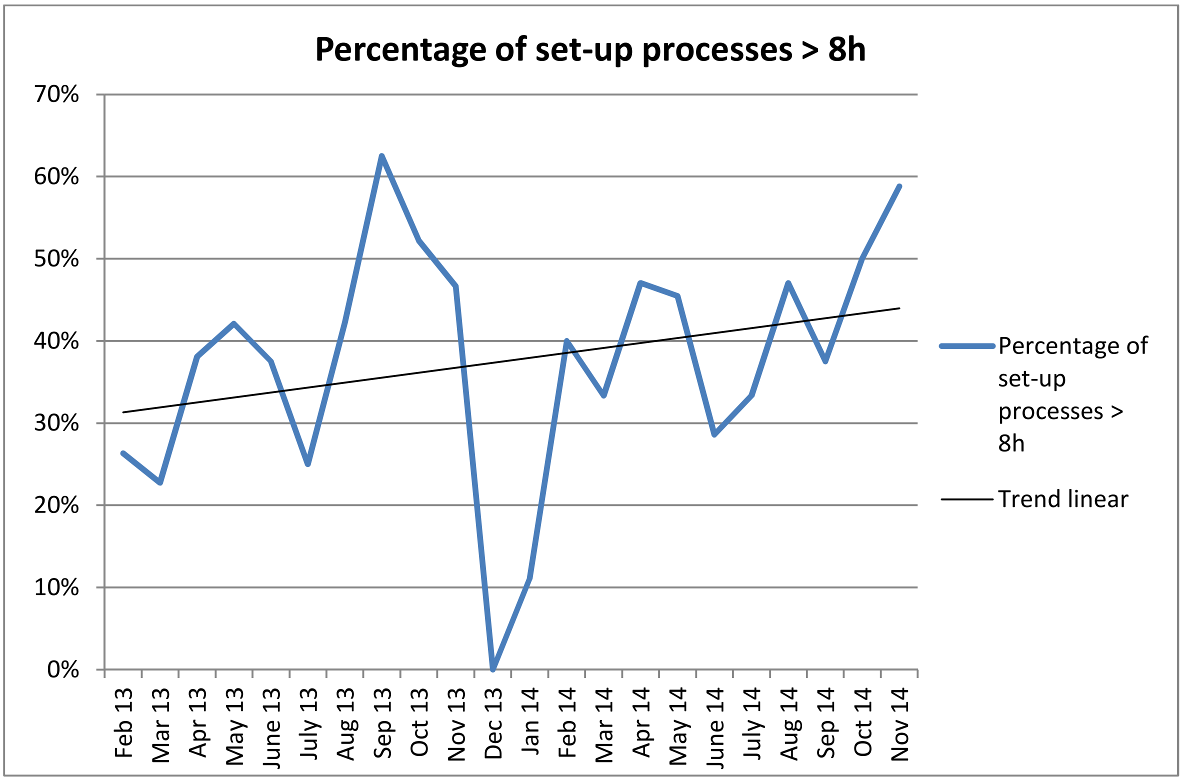


Figure 26: Percentage of set-up processes exceeding the limit of eight hours, source: own representation, based on BRP internal data

In the following Table 7, the responsible influences for long set-up processes are listed according to the set-up report.
The left part of the table shows how often a machine was newly equipped and how often this procedure was aligned to the SMED guideline. Furthermore the amount of processes which exceeded the eight hour mark is listed in total and in proportion. The technical set-up time delivers the required data for creating Figure 24.
On the right hand side, the table indicates the possible influence factors determined by the head of FT-Manufacturing. The number represents how often a special issue was responsible for process problems.
On the bottom right the sum of these problem drivers is listed. The gained results are discussed in descending order:

- Idle time of quality control (59 times):
  The measurement process follows a FIFO-system with only little consideration of priorities. Waiting time for the measured part and the related report extends the machine downtime.

- Several correction loops (50 times):
  The iterative set-up adjustment is a result of an instable set-up process. An adjustment by the technologist is necessary, if influence factors cause errors. So, the root causes that are responsible for several correction loops have to be detected to prevent an iterative adjustment (see Figure 23).

- Machine downtime (38 times):
  This issue comprises machine problems only occurring during the set-up process. Hence this is a special form of the downtime. Mostly this downtime is caused by problems of the NC-program or the tools which are then affecting the machine and lead to crashes in the worst case. Again, this issue represents not the cause, but the effect. This is also called a lagging factor.

- Tool problems (36 times):
  On the one hand, problems with tools can arise in terms of technical issues and influence the quality of the part surface or the geometry. On the other hand, a tool management, storage or provision problem may delay the setting-up.

- Fixture problems (21 times):
  The fixture is the part mostly responsible for geometric deviations. These problems can be remedied by changing the mounting method or aligning the NC program, for instance.

- NC-program (15 times):
  Troubles due to programming mistakes are occurring relatively seldom. The program is tested by the CAM division in terms of collisions. After pre-setting, the program runs through a test procedure. Little changes can also be done by the technologist at the machine.

- Missing 2nd technologist (5 times):
  For equipping the machine according to the SMED guideline, a 2nd technologist is required who is preparing the material needed. The technologists who are educated for these complex tasks are limited. So, if unplanned activities or problems with a manufacturing machine occurring, it leads to a personal bottleneck.

Months	# Set-up Proc.	# acc. to SMED	Ø min techn Set-up time	# overall Set-up >8h	% overall Set-up >8h	Influence Factors: Missing 2^{nd} Techn.	Idle Time of Quality Control	Machine Downtime	Tool Problem	Fixture Problem	Several Correction Loops	NC-Program Problem	other
February	19	19	81	5	26%		1		1		3		
March	22	22	81	5	23%		2	2	2	1			1
April	21	21	75	8	38%		4	1	2	2	2	1	2
May	19	18	111	8	42%		3	6			2		
June	24	22	92	9	38%	2	7	2	4	1	2		1
July	4	4	65	1	25%								1
August	26	24	116	11	42%		4	5	2		6	2	
September	16	12	150	10	63%		4	1	3	2	3	2	1
October	23	19	134	12	52%		5	1	5	2	2	2	2
November	15	11	140	7	47%	1	3	5	2	2	3		
December	4	4	85	0	0%								1
January	9	9	54	1	11%								
February	10	9	111	4	40%		1			1	2		
March	15	15	83	5	33%		2	1		3	4		
April	17	17	99	8	47%		2				3	1	5
May	11	10	111	5	45%		1				1		4
June	14	14	115	4	29%		2	1	1		2		
July	6	5	158	2	33%		2	2	1		2	1	
August	17	15	126	8	47%		2	2	1		2	1	4
September	32	30	107	12	38%	1	5	3	4	3	4	2	2
October	20	18	128	10	50%		5	4	4	2	3	2	
November	17	14	116	10	59%	1	4	2	4	2	4	1	
Total						**5**	**59**	**38**	**36**	**21**	**50**	**15**	**24**

Table 7: Result of set-up reports, source: own representation

4.2.7 Outcome of the Instability Investigation

Analysis of the documented set-up processes reveals on the one hand difficulties in technical matters, because of outdated systems or components. On the other hand, organisational structures are a cause for ineffective procedures.
The driver with the highest ranking is an organisational problem of the measurement strategy and the communication between the shop floor and the measuring room. This is not affecting the technical set-up in its base structure and so it is not relevant for new manufacturing methods on the shop floor.
Further the report consists of root causes and the subsequent effect. These aspects are comparable to leading and lagging business indicators. Basically a lagging issue is only a result driven by other (leading) factors.[95] The two remaining influences are representing such resulting aspects. Both the correction loops and the machine downtime are definitely drivers for the overall set-up time but each aspect is influenced by other leading factors. The root causes are illustrated in the cause-effect diagram of Figure 23.
Considering this, the problem in most cases according to the reports of chapter 4.2.6 is the tool and the tool handling situation. Occurring problems are affecting directly the technical set-up time. Mostly idle time is the result of searching the right tool or troubles regarding the tool data. Indirectly, they represent an influence on the amount of correction loops by quality losses or delivering wrong geometry data. Also the machine downtime is affected by the tools especially the downtime during the set-up. This may happen if the geometry data deviation is so large that a machine crash is the result.

The tool management comprises all activities around handling and organisational issues of the tool as a resource for the production. Its enormous importance is declared in the literature research in chapter 3.3. The following chapter 4.3 discusses the tool management at the shop floor of BRP-Rotax as well as the reasons for the high ranking at the problem documentation.

[95] Cf. Lannon (2014), online source [09.01.2017].

4.3 Tool Management

The tool as part of the influence factors (see Figure 23) has several impacts on the set-up process as well as on the serial process stability. Therefore, it is a central operating resource of the mechanical manufacturing at BRP-Rotax. But before the tools can be used for manufacturing, a lot of preparation in terms of NC-programming, pre-setting, purchase etc. is necessary. This information linkage and handling regarding the tool is called tool management.[96]

The effect on the process stability of the tool occurs as an operating material in terms providing the required quality issues. Further, the handling and management of the tools requires a well thought system and has to follow strict rules to avoid idle time and waste regarding suboptimal usage as mentioned in Chapter 4.2.7. Figure 27 separates the mentioned issues as key influences on the process stability in groups.

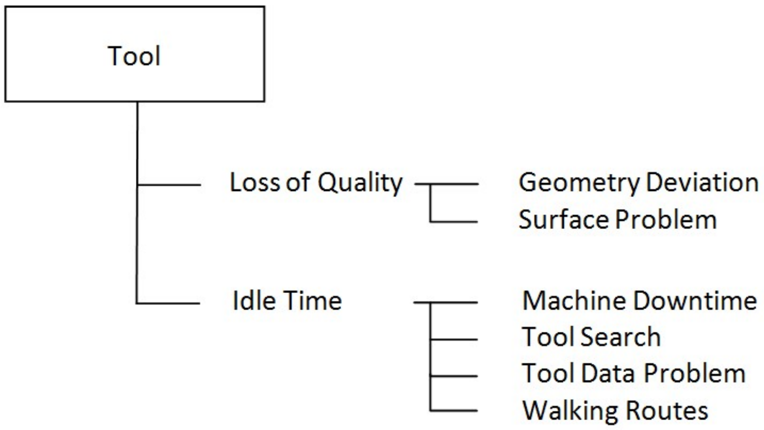


Figure 27: Separation of key influences, source: own representation

4.3.1 Involved Departments for the Tool Management at BRP-Rotax

To point out all activities that are affecting the tool management, a clear description of the use-cases was elaborated. This stepwise analysis is important to understand the different processes that are ongoing and interacting within the production. Depending on the department, the activities around the tools and the requirements on the tools vary significantly.

1. Production Planning:

The production planning receives the drawings and files of a part and is responsible for preparing and planning of the processes. Their actions regarding the tools are:

- Tool creation
- Tool database maintenance
- Tool purchase and order strategy

[96] Cf. Kief/Roschiwal/Schwarz (2015), p. 466 f.

2. FT-Manufacturing:

The FT-Manufacturing represents the employees enrolled at the shop floor and the production activities. It starts with the order for a new part production or an increasing demand in existing parts. In terms of tool handling the affected activities are:

- Tool storage
- Tool pre-setting and tool provision
- Machine set-up and/or tool change

4.3.2 Process Mapping of Use-Cases

The application of different process analysis tools was required to examine the specific use-cases of the previous chapter. The overall process description, starting with the drawing of the R&D department, is attached in the appendix in form of a diagonal matrix (see Attachment 2). As mentioned in chapter 4.2.2, the processes are distinguished whether there are design changes regarding the part or not. Either way the physical tool life cycle follows the illustration in Figure 28. The digital cycle occurs only if new tools are required.

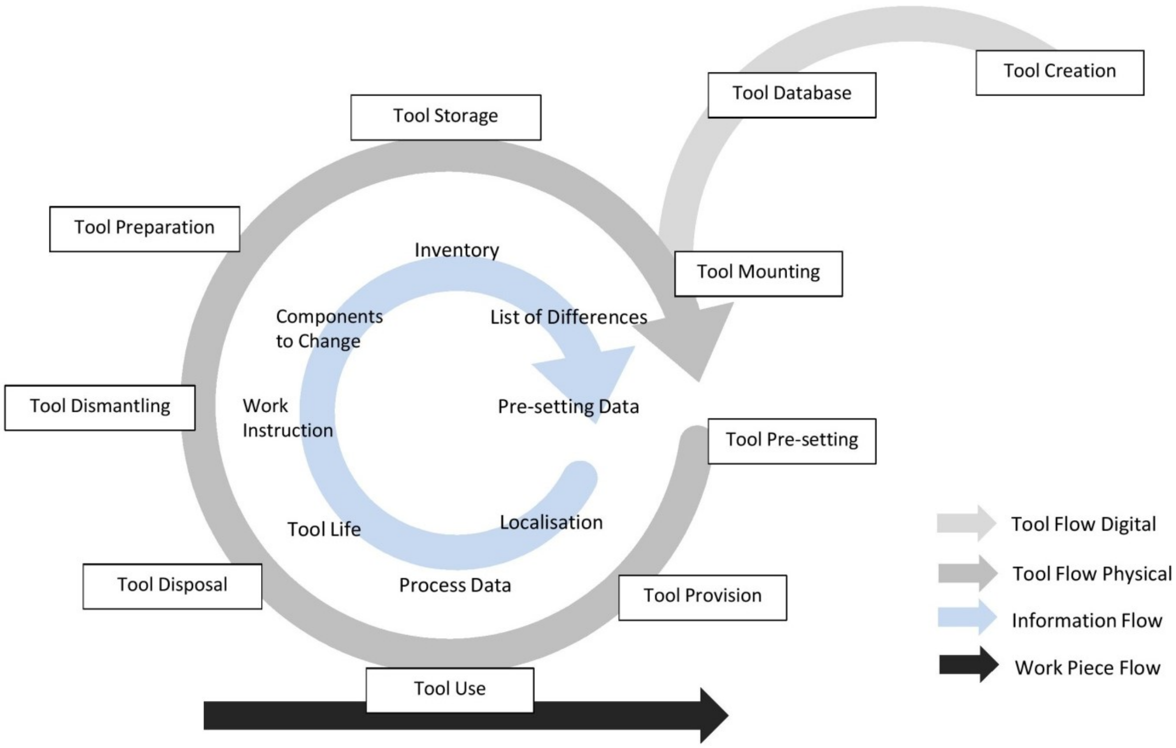


Figure 28: Different flows regarding the manufacturing tool at BRP-Rotax, source: own representation, derived from Sauer/Grosch/Abele (2014), p. 542.

Following the cycle, the tool passes several different software systems. This heterogonous data structure is represented by Figure 29 and Figure 30 which distinguish between design changes. The two figures demonstrate the systems from the construction to the shop floor.

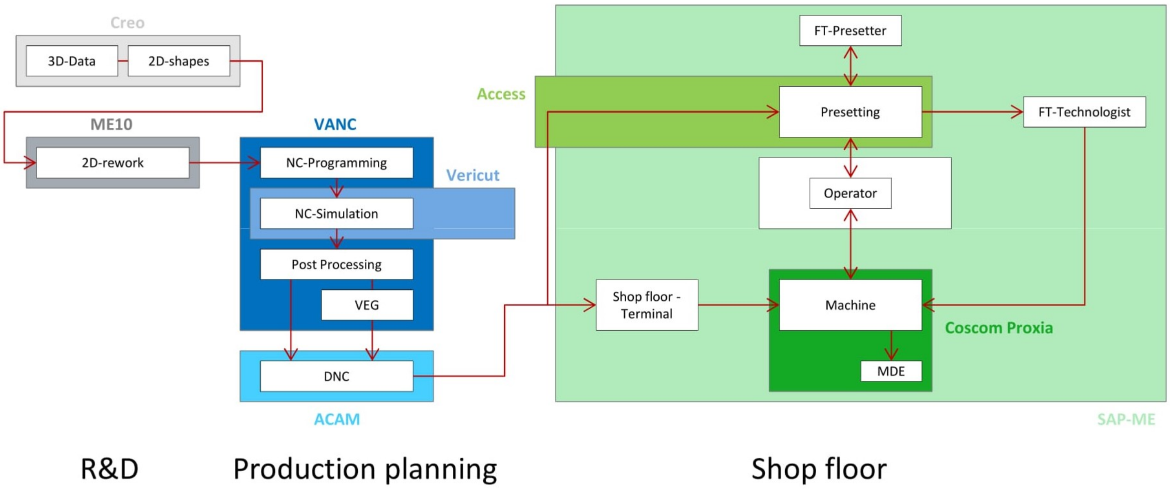


Figure 29: Information flow – New product development & engineering design change, source: own representation

In Figure 29, the information flow of a new product or a product with significant design changes is described. The part is created by the research and development department and the data is transferred to the production planning. This department is responsible for the creation of an appropriate NC program, considering all required operating material. After a crash-simulation, the program is post-processed for the relevant usage. On the one hand, the DNC (direct numerical control) converts the program for the use at the specific manufacturing machine. On the other hand, the resources of the program are provided for the pre-setter, for instance tools or the required auxiliary material.

The shop floor-terminal serves then as a connection to the machine which is operated by the technologist. Also at the shop floor, different systems are interacting between the single steps.

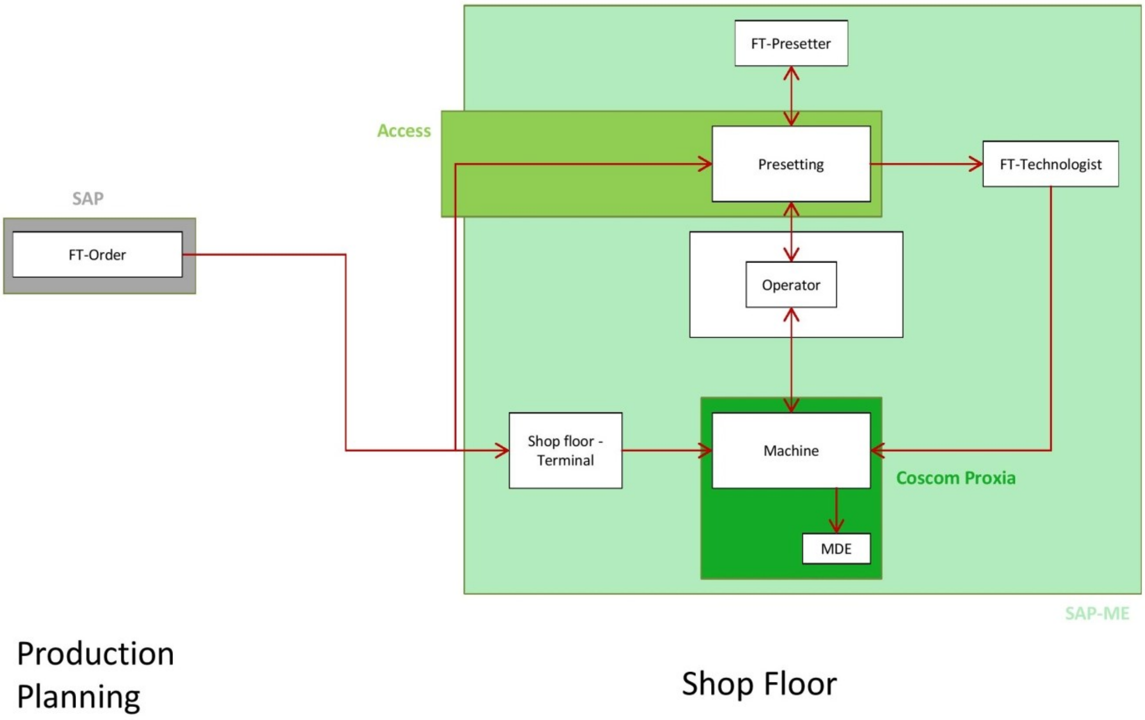


Figure 30: Information flow - Order to delivery, source: own representation

Figure 30 on the contrary, shows the information flow if a production increase of an existing part is required. Therefore, no changes regarding the design and, as a consequence, no adjustment of the NC-program occur. However, the operating materials, such as tools, have to be provided for the relevant production order.
According to this, the pre-setting machine and the shop floor-terminal receive the information directly, so the tool pre-setting and the machine set-up can be performed immediately.

4.3.2.1 Tool Creation

The tool creation is part of the production planning department, more precise, of the CAM division. New part drawings are received and the rough planning of the production takes place by determination of required operational resources and proper machines.
If new tools are required, the CAM division starts during the NC-programming to create the new tools by compiling the tools with the suitable holder in the database. For both the programming and the database the VANC CAM-system is in use. VANC is a CAM-system by Magna Inc., former by voestalpine, which is responsible for the abbreviation (voestalpine numerical control).
Figure 31 shows a newly created tool with the appropriate holder. Afterwards the information is put into the tool database (Figure 32).

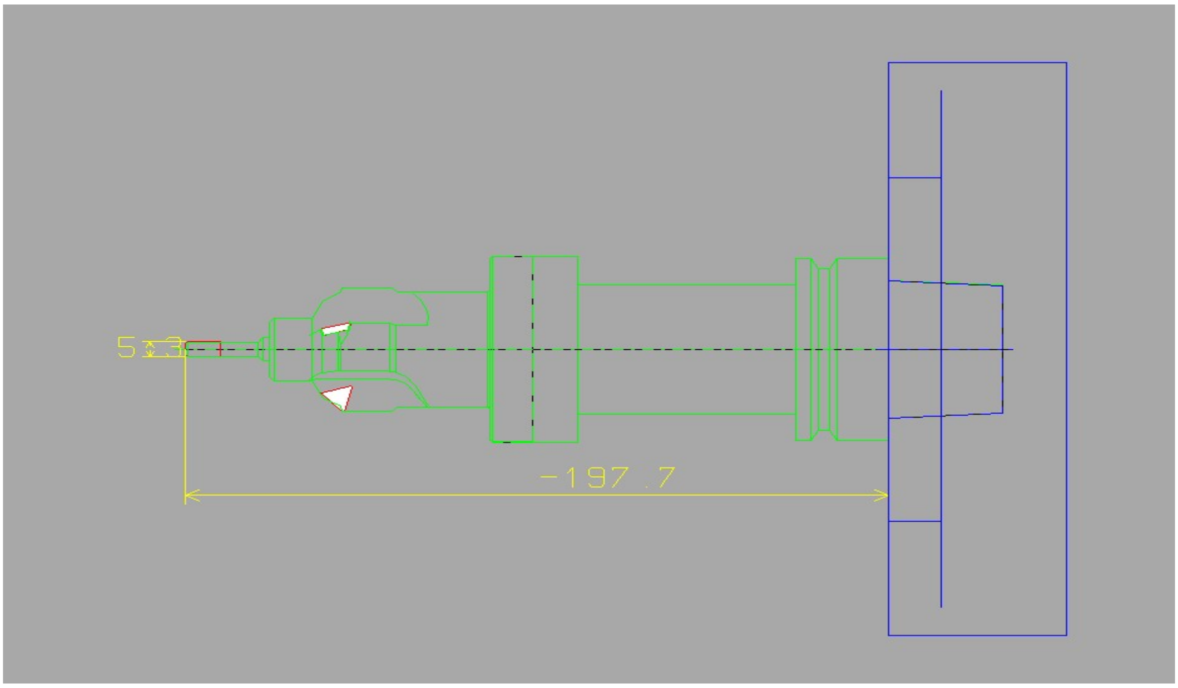


Figure 31: CAM tool creation, source: BRP (2016), internal figure

Figure 32: CAM tool database, source: BRP (2016), internal figure

4.3.2.2 Tool Database Maintenance

Tool data which is provided in the database of the CAM program needs to be maintained continuously. After dropping the new tool in the database, the regarding entry should contain the information and provide access for the enrolled parties. Hence, a proper management of the systems interfaces is indispensable to ensure information transfer for the further activities (e.g. purchasing by using the ERP system).

Currently the database contains about 6000 tools in digital form whereas approximately 4000 tools are in use or stored at various locations at the shop floor physically. This difference is a result of inconsequent maintenance caused by limited human resources.
The following figure gives an overview about the data structure and the existing interfaces (Figure 33).

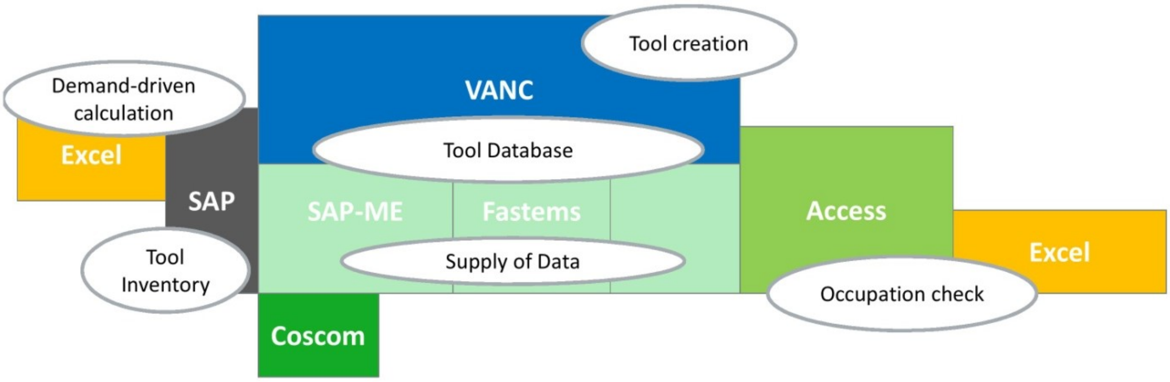


Figure 33: Interconnection of the tool database, source: own representation

For a neat production planning and optimisation of the tool use, a lot of information about the operating material in use is required. Due to this grown heterogeneous structure of software in use, data regarding the tool is stored at different locations. Central, e.g. on severs or decentral, e.g. on local computers.
In the following Table 8, the relevant tool data is listed with the appropriate current system and storage location.

Type of Data	Sub	Description	System	Storage	Side Note
Identification		Consecutive Number for tool identification	VANC SAP SAP-ME	Network	Available through system Different software
Specification	Master data	Basic data e.g. length, diameter, etc.	VANC SAP-ME	Network	Available through system
	Special data	Specific data e.g. inner cooling, oversize, etc.	SAP-ME	Network	Determined by technologist
Geometry correction		Actual dimension of the tool	SAP-ME	Network	Printed on sticker Technologist types data into system
Tool life		Nominal time of possible tool use	Excel	Network	Input by technologist
Remaining tool life		Remaining time	SAP-ME	Network	Calculated by system
Warning limit		Time limit until the appropriate tool is worn	SAP-ME	Network	
Use	Machine	Inf. about the machine that is using the tool	SAP-ME	Network	Inf. partially available
	Finishing part	Inf. about the part the tool is working on	-	-	No inf. available
	Process step	Inf. about the processing step the tool is involved	-	-	No inf. available
Localisation		Accurate information about the tools position	-	Network	SAP-ME inf. only for active or passive use
Components	Mounting inf.	Instruction for assembling the compound tools	Excel	Local PC	Local file of pre-setter
	Single parts	Inf. of components used for the tool	Excel	Local PC	Partial by pre-setter
Reason for change		Inf. about problem type	Excel	Local PC	Information in separate file
Slot occupancy	Possible machines	For the production suitable machines	Access	SQL	Requires separate data maintenance
	Possible slots	For the use suitable slots	-	-	Occupancy determined by technologist
	Set-up advice	For the use suitable tool allocation	-	-	Strategy determined by technologist

Table 8: Relevant tool data and current situation, source: own representation

4.3.2.3 Tool Purchase and Order Strategy

As illustrated in Figure 33 the activities regarding the inventory management are taking place using the internal ERP-system SAP. The logical aspect behind it is a demand-driven calculation of the tools needed. If the amount of a specific tool falls below the minimum stock level, an order for procurement is going to be placed.

This strategy is not possible for purchasing tools for the manufacturing of new products or existing products with significant design changes because of potential, new required tools. Since there is no information about the exact tool use, employees of the work preparation have to estimate the approximate requirement in advance using an MS-Excel sheet for their calculation based on past manufacturing steps.

4.3.2.4 Tool Storage

The tool storage is separated into the initial tool inventory, responsible for administration and provision of new ordered raw material and the tools interim storage, or pre-setting area, where the tools are assembled and stored for the following use.
If required, the pre-setter has to pick the raw material from the inventory for mounting it with the appropriate tool holder ready for the manufacturing process. The assembled parts are then stored in the interim storage of the pre-setting area. This depot contains passive tools and replacement tools (see Figure 34).

Figure 34: Interim tool storage at the pre-setting area, source: BRP-Rotax (2016), internal source

Passive tools are tools which have already been in use and are taken out of the manufacturing machine for providing their slots to other tools used for the production of another part. These tools are temporarily stored at the pre-setting area. Currently, there is an amount of 1000 tools booked as passive and can be taken out for production at any time. A green label is used to mark the relevant passive tools (see Figure 35). The information about these tools is provided by the ME-system where their data implemented by a responsible technologist.

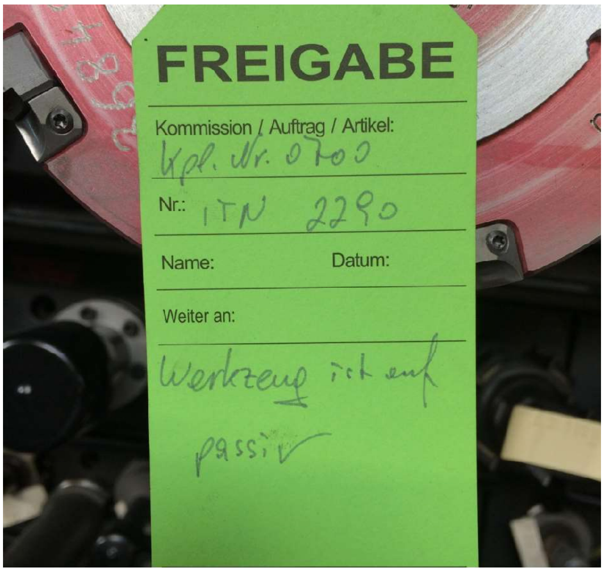


Figure 35: Tag of a tool booked passive, source: BRP-Rotax (2016) internal source

Replacement tools have just been assembled by the pre-setter out of initial tool and the proper tool holder. These tools are as well fully prepared and ready for use. Their correct geometry data is on a sticker providing information for the technologist (see Figure 36).

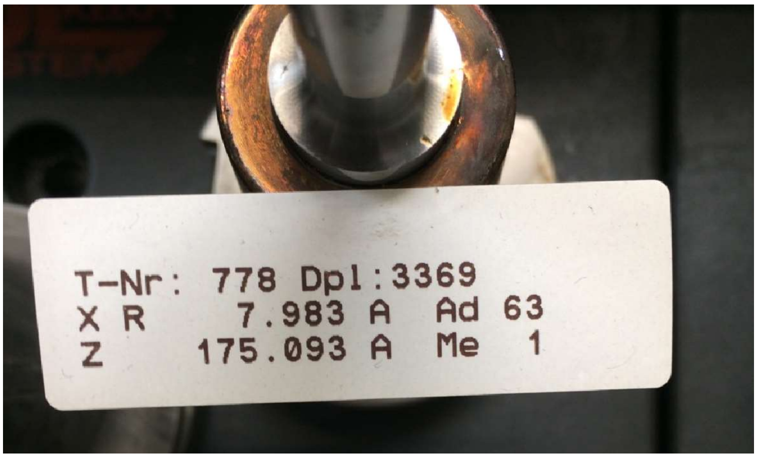


Figure 36: Geometry correction printed on a sticker,
source: BRP-Rotax (2016) internal source

4.3.2.5 Tool Pre-setting and Tool Provision

New FT-orders are placed in the ERP-system delivering information about the required tools. This order is received by the technologist who is responsible for the machine set-up. Hence, the tool requirement list for the new order is handed over to the pre-setter.

At the pre-setting area, the actual needed tools are determined by double checking the requirement list with the difference list of the SQL database. Access to the VANC CAM-system provides information about the target state of the tool. According to this, the pre-setter assembles the raw material and the tool holder using an MS-Excel list for work instructions based on previous cases. The precise measurement of the mounted part is performed by experienced personal to guarantee the actual data. This information is then printed out on a label and attached to the tool (see Figure 36). With the sticker on it, the tools are sorted into the interim storage. If the tools are needed, a cart with the required material is provided for the technologist.

4.3.2.6 Machine Set-up / Tool Change

With the list of the tools needed for the new order the technologist is able to equip the machine with correctly.
First step is an alignment of the slot occupancy with the current store room of the machine. To enable the quickest tool change for the machine, the slots are occupied beginning with the side which is closest to the spindle. This minimises the distance which the spindle has to move when a tool is taken from the store (see Figure 37).
The consideration of the special data is therefore essential. E.g. an oversize tool, which requires more space, has to be put in a slot surrounded by free slots. Furthermore, the handling of this tool has to be kept in mind. For the changing procedure, the spindle takes the tool through the slot. Hence, for an oversize tool a slot in the upper row is needed to enable a lifting of the tool over the store. All this unique specifications have to be considered by the technologist who is preparing the machine.

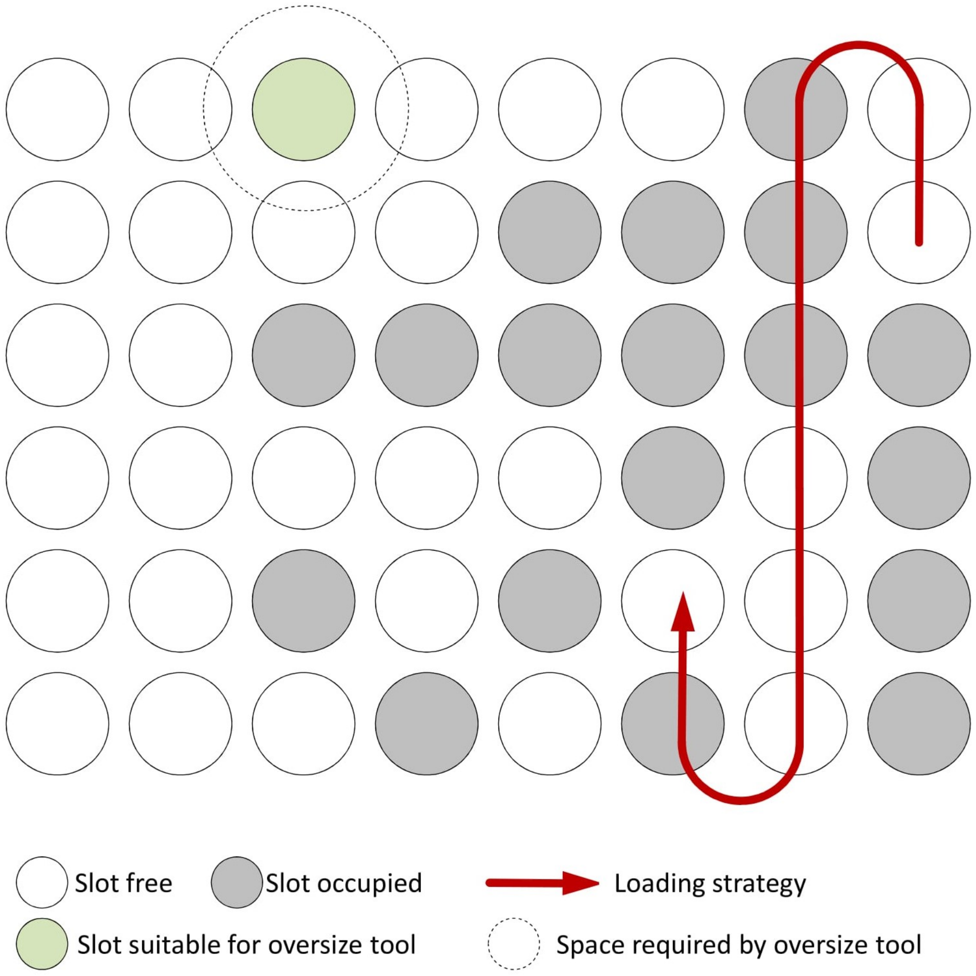


Figure 37: Slot occupancy of the machines store, source: own representation

After the tools are provided, the technologist carries the cart to the shop floor-terminal to type in the tool data from the sticker into the ME-system. Afterwards the tools are brought directly to the machine and are put into the previously determined slot. When the slots are confirmed, the machine is ready to start.

If a tool comes to its end of life or is broken, the machine operator is responsible for changing it. The tool is handed over to the pre-setting area with the information on a piece of paper. In this area the dismantling and tool preparation take place. The information about the change is typed into a MS-Excel sheet to evaluate untypical material use or wear.

This whole procedure is illustrated by Figure 38. For a better understanding, the single steps are listed:

- FT-order: The technologist receives the order that a specific part is going to be produced. The list for all tools required is attached.
- Information about tool requirement: The actual needed tool is calculated by the pre-setter who checks the equipment of the machine via a SQL database.
- Tool geometry on sticker: The pre-setter provides the actual required tools with a sticker for the correct geometry data on it.
- Information about tool slot occupancy: The technologist checks the slot occupancy of the relevant machine and creates a strategy for the occupation.
- Tool data into system: The technologist creates an entry in the SAP-ME database for each specific tool and enters the correct master and special data.
- Tool slot conformation: The tools are then put into the machine and the slot position is confirmed.
- Broken/ end of tool life: If it is necessary, the tool is changed by the operator.
- Information about required tool change: The operator fills in a form for tool change and hands it over to the pre-setter.

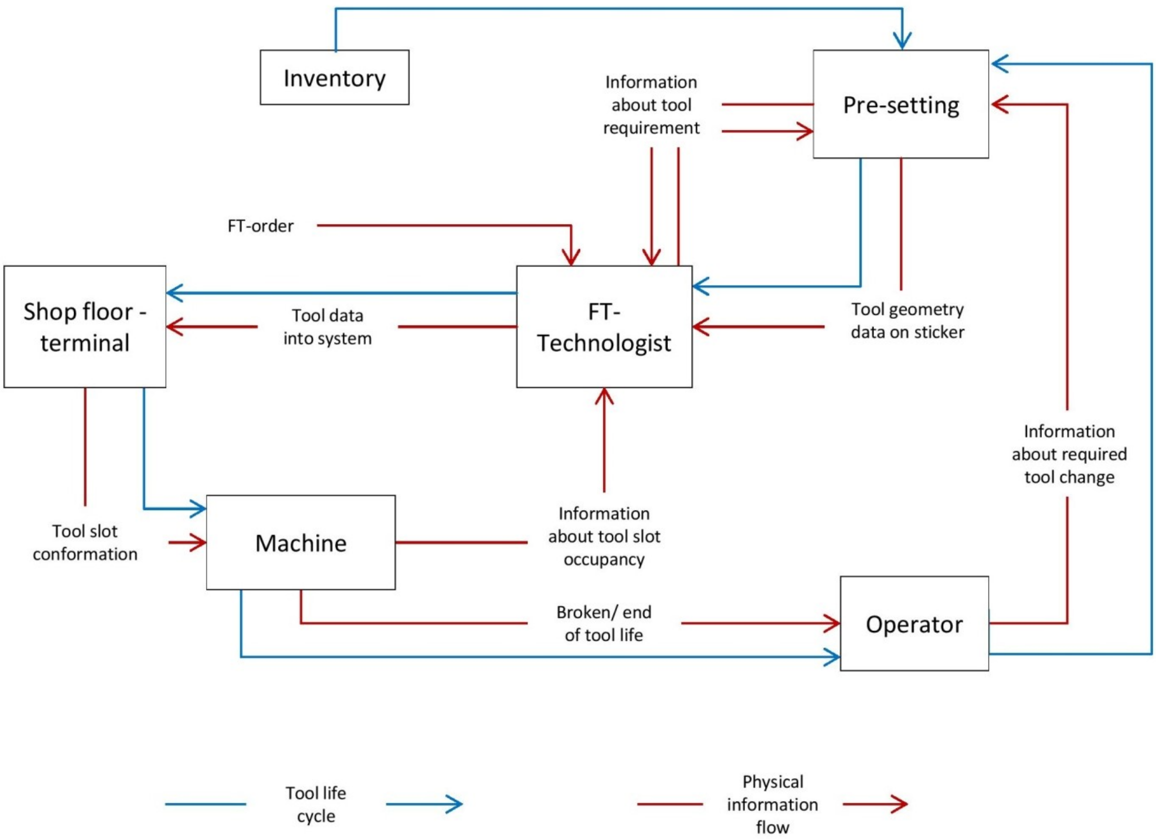


Figure 38: Tool life cycle and information flow, source: own representation

4.3.3 Evaluation

A critical view at the different sub processes around the tool handling revealed several conspicuous issues according to the seven types of waste of lean manufacturing. These categories are defined as follows:[97]

- Transport
- Inventory
- Motion
- Overproduction
- Overprocessing
- Defects

These types of waste will be discussed in the following paragraphs.

<u>Transport:</u>

Figure 38 reveals the whole physical flow accompanied by the technologist. The actual transport way varies, depending on which is the relevant machine but the single working steps remain the same. Waste in terms of transport occurs by:

- Realignment of the technologist and pre-setting area
- Required occupation check of the machine
- Carrying the cart to the shop floor terminal to enter the tool data

Also information transport represents a waste factor:

- The outdated tool database lead to a lack of information and limited access

<u>Inventory:</u>

The tool storage covers a huge amount tool in replacement or passive use. Waste regarding unused or not efficient tools arises because of:

- Unsystematic tool storage
- Tool required for a new order are taken from replacement section rather than from the passive section

But inventory scopes also administrative waste:

- Redundant information stored at local PC because of missing central access
- Unnecessary physical information flow by printing stickers and papers
- A confusing database because of unused digital tools

[97] Cf. Lunau (2014), p. 196 f.

<u>Motion:</u>

Due to the required conformation of the tool at the terminal, waste in terms of motion is caused by:

- Time-consuming data input procedure
- Idle time because of waiting for the conformation of the system for each tool which is entered

<u>Defects:</u>

In general a defect of the product is a non-achievement of the required quality. According to the discussed use-cases, the main causes of such a defect, influenced by the tool, are:

- Tool assembled in a wrong way due to a lack of information between CAM and pre-setting division
- Unreadable or missing tool data sticker
- Problematic data transmission caused by a mistype
- Mismatch between the digitally booked tool and the actual location

The process mapping of the use-cases gives a detailed insight into the tool and the tool management situation. The output of these use-cases is then aligned onto the different types of waste of lean manufacturing.
According to this waste classification, different problems have been detected. First, the current in use CAM-system and the related database are very old software versions. These systems do not offer the required transparency to achieve a data patency, such as accessibility for the shop floor. This leads to physical and administrative waste, because a lot of information is stored redundantly. Also an efficient organisation of the tool storage is not possible because of the missing transparency.
Further, the current tool handling requires a lot of transport of the tools and walking routes for the technologist. This is mainly caused by the physical information flow (Figure 38) and the used data transmission in form of stickers. Defects at the produced part or even a machine crash may occur due to unreadable stickers or mistypes, apart from the protracted machine set-up.
The next chapter focus on a stepwise creation of a concept which should eliminate the mentioned aspects. Therefore the elaborated topics of the literature research (see chapter 3) deliver the knowledge about the newest technologies. Again, a close cooperation with the employees which are involved in the processes was required for the development of the concept.

4.4 Methodical Approach for Modern Tool Management

According to the analysis of the tool management in chapter 4.3, a concept was conducted to minimise or avoid the critical issues. This proposition is based on clear defined key performance indicators (KPIs) to demonstrate the benefit (see chapter 4.4.1). For the conduction of the concept a system framework delivers an overview of the affected activities and components (see chapter 4.4.2). The approach for the conception is illustrated in the following Figure 39.

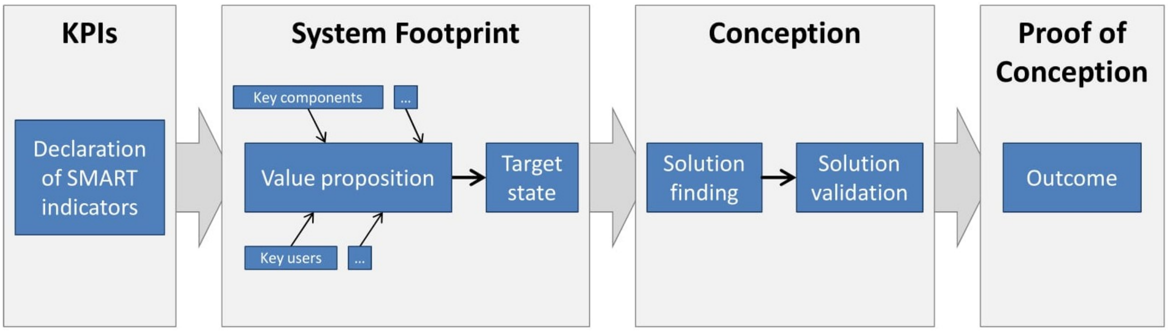


Figure 39: Illustration of the different conception stages, source: own representation

4.4.1 Declaration of Key Performance Indicators (KPIs)

A key performance indicator (KPI) is a clear defined value which refers to a quantifiable measure and should demonstrate how effectively a company is performing to meet its strategic and operational business objects.[98] KPIs vary between companies and industries, depending on their specific priorities and area of application.[99] The factors can also change over time as the business evolves, achieves old goals and sets new ones.[100]
Further, different types of indicators can be distinguished. E.g. leading and lagging KPIs. A leading indicator measures activities that have a significant effect on future performance. They drive the performance of the outcome measure and serve as a predictor of success and failure. On the contrary, a lagging indicator reflects the success or failure after an event has been consumed. Most of the times financial KPIs are such lagging indicators.[101]
These types of indicators can be compared with the relation of cause and effect (see chapter 4.2.7).

For the detection of suitable key performance indicators, a look at the evaluation of chapter 4.3.3 is necessary. It shows inefficiencies and losses at the shop floor. A

[98] Cf. Investopedia (2016), online source [09.01.2017].
[99] Cf. LinkedIn Slideshare (2016), online source [09.01.2017].
[100] Cf. Investopedia (2016), online source [09.01.2017].
[101] Cf. LinkedIn Slideshare (2016), online source [09.01.2017].

challenging task is to measure these errors and lead them to quantifiable indicators. Since the amount of indicators is enormous and the particular value is affecting different areas, the detection has to be aligned on the goal which is wanted to reach.

A key performance indicator has to be SMART, which is an abbreviation for specific, measurable, achievable, result-oriented and time-bound. More specific, a good KPI has to be connected to the corporate goals and should be easy to understand. Further, it should represent a leading indicator of performance.[102] To fulfil these requirements, a separation of leading and lagging factors and a consideration of the goals of the Smart Factory of BRP is required. Here, the focus is to increase the following three aspects:

- Quality
- Agility
- Efficiency

Figure 40 shows the main goals with a common influence. According to the discussed classification of KPIs, the goals represent lagging indicators. These goals have a stable process in common. If a stable and quick set-up process can be achieved, the quality is going to be higher because of fewer defects at the produced parts. Further, the manufacturing is more flexible and the machine utilisation is going to be higher if less time is needed for the unproductive set-up.

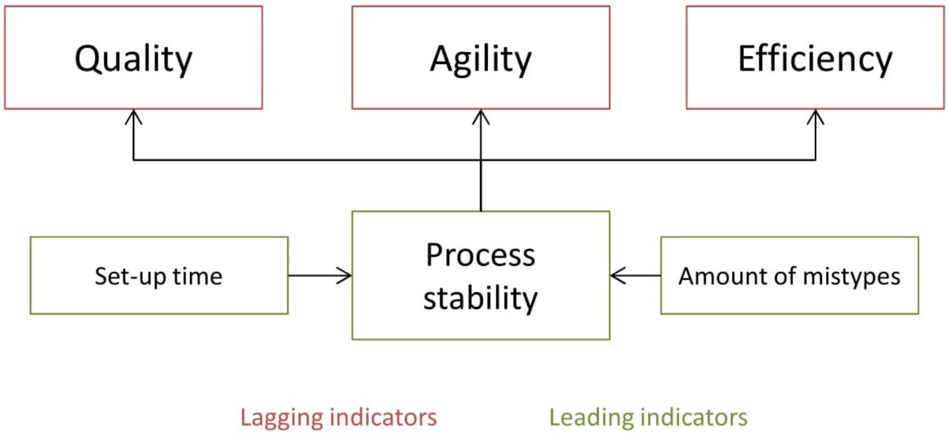


Figure 40: Connection of leading and lagging key performance indicators, source: own representation

To create the set-up process more stable, errors that occur during the procedure have to be avoided. From the view of the mapped use-cases, SMART indicators that are influencing these errors are:

- Set-up time [min]
- Amount of mistypes [n]

[102] Cf. LinkedIn Slideshare (2016), online source [09.01.2017].

4.4.2 System Footprint[103]

The System Footprint is a framework which is supposed to visualise all affected components involved in a process. It shows the structure of the current tool management system and specifications for the new system by delivering information about:

- Who is using the system?
- What are the use-cases?
- What are the key functions?
- What are the components the system consists of?
- What are the deliverables of the new system?
- What are the interfaces within the system?
- Which technical constraints are to consider?
- Which stakeholder constraints are to consider?

Aligned on the instruction for creation the System Footprint, the figure was completed using the relevant information of the tool management situation (see Figure 41).
The value proposition of the new system is located in the middle of the System Footprint. Under this aspect the framework indicates a concept as proposal for the new system by considering all the surrounding influences which is described in the following chapter.

[103] Cf. Pfingsten (2016), p. 44 ff.

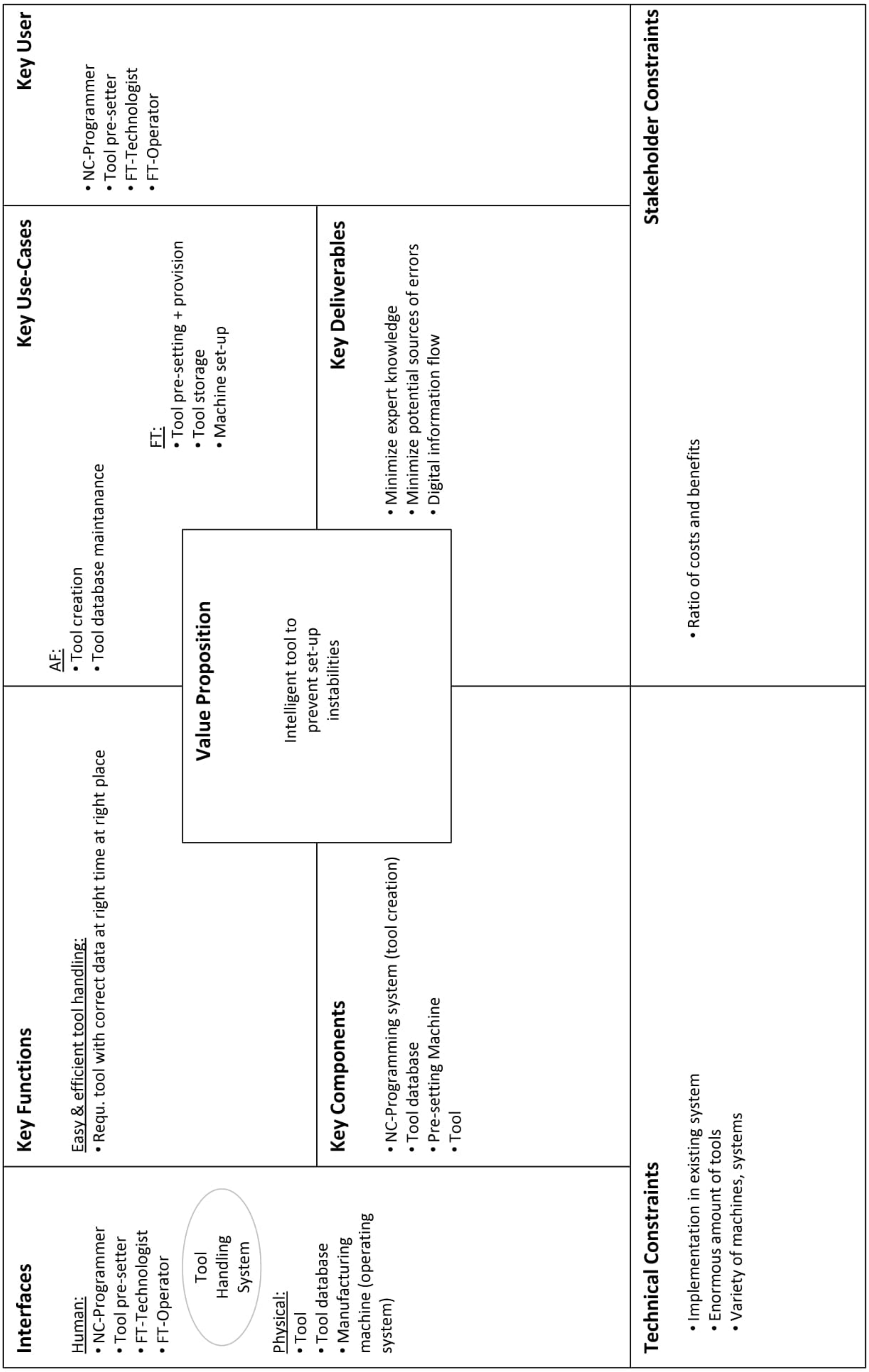


Figure 41: Illustration of the System Footprint for a new tool management, source: Pfingsten (2016), p. 47.

4.4.3 Value Proposition

Looking at the main reasons for instabilities regarding tool handling, evaluated in chapter 4.3.3, the value proposition should point out a proposal to minimise or avoid these causes. The input of the key users was required to create the value proposition. This concept should be based on the elaborated topics of the literature research of an intelligent tool (see chapter 3).

4.4.3.1 Brainstorming

In accordance with the Six Sigma guideline Brainstorming represents a very easy and efficient creativity method. A clear defined problem is important for a neat solution finding procedure. Then the participants are asked to post ideas which are noted and later categorised.[104]

Some rules should be considered for an efficient creating of the brainstorming:[105]

- Every speaker is able to finish speaking
- Any input is going to be documented
- All participants are going to be involved
- Quantity before quality
- Setting a proper time frame

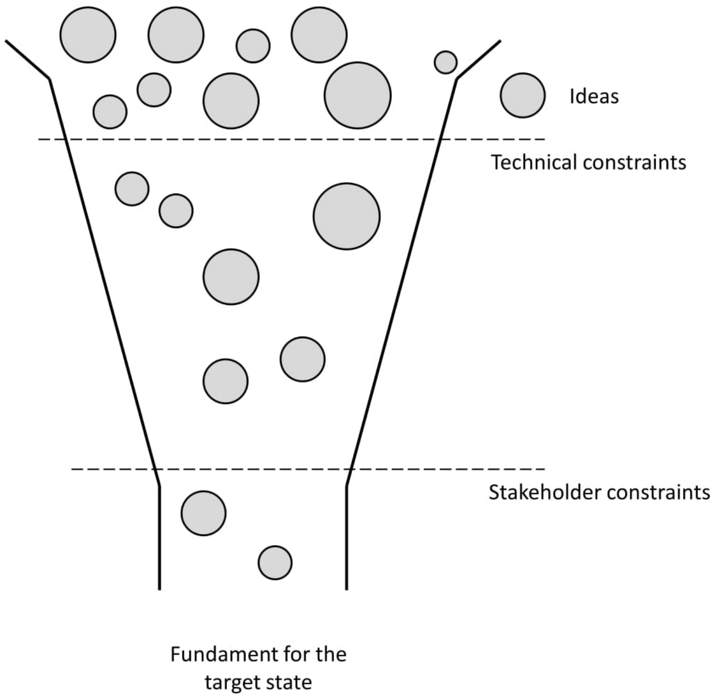


Figure 42: Visualisation of the Brainstorming activity, source: own representation

[104] Cf. Alisch (2004), p. 519.

[105] Cf. Lunau (2014), p. 303 f.

The brainstorming creativity technique was performed with several key users. Therefore a NC-programmer of the CAM division, the tool pre-setter and a FT-technologist have been involved. Mentioning the key problems the participants were asked to give their definition or vision of an intelligent tool. The input was clustered to declare the key components of the system. Further, a theoretical target process regarding the tool handling was created and should serve as guideline which indicators are to be examined.

Figure 42 represents the procedure of this activity. The Brainstorming helped a lot to declare the specifications of the employees, who are going to use the elaborated system (key users). The ideas, recorded on post-it, have been filtered according to the restrictions, mentioned in the System Footprint. To filter the input in terms of technical constraints, the shop floor IT was involved. The stakeholder constraints have to be calculated in terms cost and benefit for the company.

The result of the Brainstorming serves as fundament for the declaration of target state.

4.4.3.2 Target State

To create a virtual situation how the target process should look, it is important to visualise the defined process improvement. In this way, all enrolled employees can recognise and understand the impacts on the current process.[106]

The target state is the result of the brainstorming activity and serves as specification sheet for the new system. For the categorisation, the specifications are separated in software and hardware. The software comprises the digital management of the tools, whereas the hardware covers properties about the physical tool itself.

Software – Tool management:

- Consistent data linkage between the key components (see Figure 41)
- Data collection and preparation for subsequent analysis about the tool
- Maximise the transparency for key users in terms of data supply and accessibility
- Communication with existing systems

Hardware – Cyber-physical tool:

- Consistent and uniform identification of the tool (physical and digital)
- Information about the localisation and use of the tool
- Maximise the digital information flow parallel to the physical tool
- Providing data about the tool and ability for communication

[106] Cf. Lunau (2014), p. 326 f.

A third additional component has to be considered for a feasible realisation – the scalability of the concept. The ability to use the system in other business units than the pilot zone is essential to guarantee a homogenous structure. So the system has to be scalable in terms of:

- Application area: Starting within the pilot zone; ability for implementation in other business units
- Functionality: Allowing further extension levels; object intelligence, system connection

4.4.4 Conception

The conception phase examines how the target state can be achieved. Therefore, technical and stakeholder constrains should be considered. On the technical side, the most important issue is the ability to implement the new system in the existing structure. So a communication with the current machines, their control unit and the software is essential. Another condition is the roll-out to other machines. This is basically mentioned by the scalability of the application area. Nevertheless, this represents a huge restriction considering the enormous variety of machines and systems at the shop floor.

The stakeholder conditions are represented by the management specifications regarding the investment details. For this purpose, a cost benefit analysis is supposed to point out the financial potential of the future concept (see Chapter 4.4.6).

4.4.4.1 Morphological Box

Aligned on the key components of Figure 41, indicators of the current system have been determined. These indicators serve as components and show technical interventions needed to reach the future state of the tool management.

To create an overview about the indicators and their relevant solution alternatives, a Morphological Box serves as visualisation (see Table 8). This creativity technique is used for solution finding and comparison of ideas. Basis is a separation of the entire aspect in its key elements (indicators). Appropriate alternatives are then listed and compared. Aim of the Morphological Box is to show possible solution interactions und consideration of restrictions between the different alternatives and indicators.[107]

[107] Cf. Schawel (2012), p. 174 f.

		Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Software	**CAM System**	Existing system		New system		
		VANC	VANC upgrade	Coscom Tool Director	Creo	
	Tool Database	Existing system		New system		
		VANC	VANC upgrade	Coscom Tool Director	Walter TDM	Zoller TMS
Hardware	**Pre-setting Machine**	Existing device		New device		
		Kelch Kalimat a	Kelch Kalimat a upgrade	Kelch Kali-tec		
	Manufacturing Machine	Existing operation	Machine external read/write operation	Machine internal read/write operation		
		Manual entering	External device	Machine upgrade		
	Tool ID	Engraved number	DMC	RFID		

Table 9: Morphological Box for the solution finding regarding tool management, source: own representation, derived from Schawel (2012), p. 174.

4.4.4.2 Description of Indicators

CAM-System and Tool Database:

VANC is the current CAM system in use. It is a system from ECS – Engineering Center Steyr which is a subdivision of Magna International and combines NC programming and the tool database called ‘Werkzeugkatalog’. The current version is from 1996 and according to Magna International the last system in use within a company. Since this version constitutes no central database, it is not possible to enable interfaces between the different systems. This leads to constraints regarding the accessibility for different departments and the accompanying lack of information.

Restrictions:
The implementation of a new NC-programming software leads to a changeover of the whole CAM division. In addition, new software requires much more instruction and training rather than an upgrade of an existing system. Hence, the priority in the first place was an investigation about the current system and the ability to upgrade.
Furthermore, the amount of different systems is supposed to be kept low following the principle ‘as little interfaces as possible’.[108] Beside the effort each interface requires for maintaining, potential problems between the systems may occur. E.g. using a new tool for the NC-programming requires a creation of a proper tool in the database in advance. A foreign database covers only standard tools, which is problematic considering that approximately 70% of the tools in use are special tools.

Options:
1. VANC – Using the existing CAM program and the appropriate tool database
2. VANC upgrade – Software upgrade of the CAM program and tool database
3. Coscom Tool Director – Implementation of a new CAM system and tool database
4. Creo – Changeover of the CAM system with a foreign system

Pre-setting Machine:

The pre-setting consists of shrinking and measuring of the tool, which takes place at two different devices. A Kelch Kalimat a device is in use for the measurement of the tools. The year of construction of the machine is 1999.
For the measurement, a teach-in program is created which is appropriate for each single tool when it is measured for the first time. Using this information, the machine is able to find the reference point chosen by the NC programmer automatically. Despite the existing Ethernet port this geometry data is then printed on a sticker.

[108] Cf. Schlick (2001), p. 44.

Restrictions:
According to the manufacturer, the internal application of a tag reading/writing system is only possible by upgrading the device.
Furthermore the teach-in data is programmed at the Kelch device for each single tool in use. These programs are aligned to the Kelch operating surface and not usable

Options:
1. Kelch Kalimat a: Using the existing, 17 years old device
2. Kelch Kalimat a upgrade: Software and hardware upgrade of the device
3. Kelch Kali-tec: New pre-setting device with integrated shrinking station

Manufacturing Machine:

The Makino A61NX machining centre is the most modern device within the process chain. The machine is connected with the shop floor terminal by the Ethernet port. The terminal is used for providing the entered tool data. The ME-system serves as interface between terminal and machine.

Restrictions:
When the Makino A61NX was ordered in 2013 BRP-Rotax declined ordering an integrated reading writing system due to the missing infrastructure and no intension to implement an AutoID system. In retrospect this upgrade would cost approximately € 21 000 (see Appendix, Attachment 3).

Options:
1. Manual entering – Stick to the existing operation of typing tool data into the shop floor terminal
2. External device – Tool identification at the machine by using an separate device
3. Machine upgrade – Automated tool identification by occupying the tool pot of the machine

Tool ID:

The identification of the tool is enabled by an engraved number called 'ITN number'. Information flow on paper is necessary next to the physical tool flow (see Figure 38). Based on the results of the literature research, the AutoID systems which prevailed are compared below.

Restrictions:
Regarding the identification, a write- and readability at any machine at the shop floor is essential. Hence, elder machines which are offering only serial ports are to be considered as well, not only on the modern Makino A61NX.

Options:
1. Engraved number: Sticking to the existing system with additional, necessary information flow
2. DMC: Tool identification via a data matrix code; information stored in a database
3. RFID: Tool identification via a RFID chip

4.4.4.3 Solution Correlations

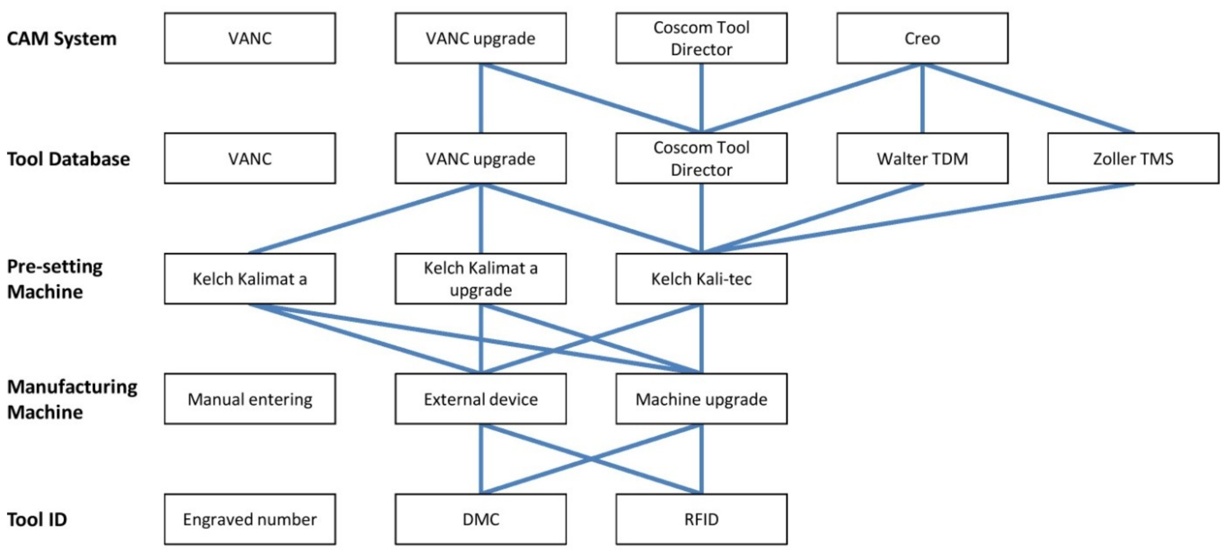


Figure 43: Possible solutions aligned on the Morphological Box, source: own representation

Figure 43 demonstrates all possible correlations that are realisable in terms of system interconnection. The elements of the current situation are listed as well according to the Morphological Box. Key criterion for representing a solution alternative is the ability to meet the key specifications as listed in the target state of chapter 4.4.3.2. In order to that, the current procedure represents no possible solution.

4.4.4.4 Utility Analysis

To lead the complex interactions of the different variants to possible solutions a stepwise analysis of the indicators is necessary. Therefore a utility analysis compares the various alternatives of the indicators according to defined criteria. The criteria have been aligned on the relevant indicator because of deviating priorities.
The utility analysis was conducted according to the VDI guideline for product and process design which suggests following approach[109]:

- Check mandatory criteria
- Definition of criteria relevant for valuation
- Weighting of criteria
- Valuation of alternatives
- Calculation of partial utility
- Calculation of total utility

The following utility analyses have been validated in cooperation with the employees of the corresponding department. E.g. the employees of the CAM division compared the characteristics of the relevant software according to their requirements on the system and assessed the single alternatives. Further, the research in modern manufacturing literature (see chapter 3) delivered knowledge to grade other non-quantifiable aspects. The financial criteria have been validated on the base of supplier's offers which are referenced in the relevant sections.

CAM-System and Tool Database:

		VANC UPGRADE		COSCOM TOOL DIRECTOR		CREO CAM + FOREIGN SYSTEM	
Criteria	Absolute weighting	Valuation (max. 10)	Partial utility	Valuation (max. 10)	Partial utility	Valuation (max. 10)	Partial utility
Changeover effort	0.6	8	4.8	4	2.4	3	1.8
Interface communication	0.4	10	4	10	4	8	3.2
TOTAL	**1**		**8.8**		**6.4**		**5**

Table 10: Utility analysis of the CAM-system and tool database, source: own representation

[109] Cf. VDI - Gesellschaft Produkt- und Prozessgestaltung (2011), p. 149.

The criteria of the utility analysis of Table 10 have been aligned on the specifications of the CAM division of BRP-Rotax. As mentioned in chapter 4.4.4.2 the changeover, as well as the matching of CAM software and tool database, are the driving factors.
Considering the fact, that all functions demanded by the CAM division are delivered by upgrading the VANC software, sticking to the well-known software is the most purposive decision. The offer, containing a package of software and database, represents with a price of € 31 510 a reasonable investment (see Appendix, Attachment 3-8).

Pre-setting machine:

		KELCH KALIMAT A		KELCH KALIMAT A UPGRADE		KELCH KALI-TEC	
Criteria	Absolute weighting	Valuation (max. 10)	Partial utility	Valuation (max. 10)	Partial utility	Valuation (max. 10)	Partial utility
Costs	0.4	9	3.6	5	2	4	1.6
Probability of downtime	0.3	5	1.5	5	1.5	10	3
Simplification for employee	0.2	4	0.8	5	1	10	2
Changeover effort	0.1	10	1	8	0.8	6	0.6
TOTAL	**1**		**6.9**		**5.3**		**7.2**

Table 11: Utility analysis of the pre-setting machine, source: own representation

Table 11 offers the result of the utility analysis. Since a new pre-setting machine costs about € 70 000 (according to an offer from the company Kelch, see Appendix, Attachment 9-10) the financial aspect represents the first priority. On the other side, this device is essential for the whole mechanical manufacturing, so a downtime is indispensable.
The simplification for the employee represents a direct impact on the technical set-up time. The effort for performing a changeover is a minor factor due to the existing infrastructure.
Investment in a new pre-setting machine is, considering the year of constriction (1999) of the present device, is definitely recommended. The new device offers a huge simplification of the pre-setting procedure due to an integration of the external shrinking station. Since a new investment represents a huge cost factor a temporary solution by using the current machine with an external computer could be an option to split the capital required. However, a strict dissuasion of performing the upgrade is confirmed by the relevantly little cost difference between the upgrade and the new machine (see Appendix, Attachment 9-10, or Attachment 11-12).

Manufacturing Machine:

		EXTERNAL DEVICE		MACHINE UPGRADE	
Criteria	Absolute weighting	Valuation (max. 10)	Partial utility	Valuation (max. 10)	Partial utility
Simplification for employee	0.5	7	3.5	10	5
Costs	0.4	9	3.6	5	2
Changeover effort	0.1	9	0.9	8	0.8
TOTAL	**1**		**8**		**7.8**

Table 12: Utility analysis of the manufacturing machine, source: own representation

The handling of the tool effects directly the technical set-up time. Hence, the simplification represents major priority, followed by the costs for implementation. Whether by using an external device or upgrading the machine, the changeover effort is very limited since the machine remains the same.

The calculation of Table 12 shows the external device for tool identification as most suitable solution. This represents an option for existing machines due to high upgrade costs. For new purchased manufacturing machines, the optional function of an integrated reading/writing procedure is, with an additional price of € 6 000, much more economical (see Aappendix, Attachment 13). In this way a recommendation for ordering forthcoming manufacturing machines can be confirmed.

Tool Identification:

		DMC		RFID	
Criteria	Absolute weighting	Valuation (out of 10)	Partial utility	Valuation (out of 10)	Partial utility
Readability	0.4	6	2.4	8	3.2
Simplification for employee	0.3	9	2.7	9	2.7
Costs	0.2	8	1.6	5	1
Changeover effort	0.1	7	0.7	8	0.8
TOTAL	**1**		**7.4**		**7.7**

Table 13: Utility analysis of the tool identification, source: own representation

The two options (DMC and RFID) of the utility analysis in Table 13 represent the state of the art of tool identification in modern tool management[110]. Decision base for the criteria was in the mainly the consistent usage of the new system. Therefore the tag has to be easily readable for any machine in use. Further, the new identification is supposed to simplify the work for the employee, which has a direct impact on the set-up time. The costs of a single tag are to be considered (according to Balluff GmbH € 15 per piece, see Appendix, Attachment 14-17) because of the multiplication factor of 4 000 tools in use. Attaching the tag on the tool is a simple work step – it has to be either laser engraved (DMC) or bonded and balanced (RFID).

The two compared options are very similar regarding the future process flow. The calculation shows slightly better values for the RFID tag in spite of the higher investment costs. This is caused by consistent reading properties. The data matrix code is read optical what lead to potential error sources in terms of e.g. lubricant residues, dirt or a damage of the code (see chapter 3.2.2 and 3.2.3).

4.4.4.5 Best Practice[111]

A business trip to the company ENGEL Austria GmbH, located in Schwertberg, Upper Austria, showed a practical example of the tool handling using RFID identification.

With the manufacturing of injection moulding machines the company's focus is completely different, but the organisation of the mechanical manufacturing is in certain points comparable with BRP-Rotax. ENGEL also has to handle a huge amount of mechanical tools and is due to a very little lot size forced to enormous flexibility. Currently, there are approximately 12 000 mechanical tools at the shop floor in use.

The system landscape is in its variety similar to the structure of BRP-Rotax. A Siemens software serves as CAD+CAM system. The tools are managed centralised using the Coscom Tool Director which is supposed to provide the digital tools for all locations of ENGEL worldwide.

The tool itself is identified via a *Balluff Bis M* RFID tag. Only a consecutive identification number is stored at the tag – this number is engraved at the tool holder as well. The remaining tool data is stored at the database of the Coscom Tool Director and provided the relevant manufacturing machine via network when the tool is put into the machine.

After measuring the tool at the pre-setting machine the device sends the actual data back to the pre-setting terminal, where the Coscom Tool Director is managing the data. Because of the large store of the manufacturing machine the tool change is performed by a sluice, which provides seven changing slots at once. No additional entering of any tool data is necessary. The machine scans the RFID tag during the change procedure and the relevant tool data is provided by the network connection. The slot occupancy is performed as well by the manufacturing machine using the data of the tool director.

[110] Cf. Röschinger et al. (2015), p. 61.

[111] ENGEL Austria (2016), internal sources.

At this point it should be mentioned, that ENGEL does not equip any manufacturing machine in retrospect. Only new ordered machines are providing an automated reading system. The reason for that are the huge additional costs for the retrofit.

In general, ENGEL focus on another manufacturing strategy, due to complete different products. Lot sizes towards one and extreme long cycle time require different specifications. Nevertheless, the motives of the company to implement an AutoID-system for the tool identification have been similar. Unnecessary paperwork protracted the tool handling situation and information transmission errors took place more and more because of the increasing amount of tools and tool changes.

ENGEL implemented a read-only system. In this way the transparency about the actual data is easier to achieve, since the information is stored in a database. The Coscom Tool Director serves as a tool database and enables the connection to the machine. This connection is supposed to be enabled by the ME-system at BRP-Rotax. The reason for this is the existing integration of the SAP-ME system as tool provision software. Anyway, all the information about the tool should be delivered by this connection, so the operator does not have to enter any kind of master or special data manually.

Another interesting point is the connection of the pre-setting machine. This device is operating completely separately. Only a computer is connected to this machine, which provides the data transmission of the tool data. This solution would offer the possibility that an elder pre-setting device can remain in use.

All in all, the information exchange with ENGEL gave a very good insight in their motivation for implementing the RFID-system.

4.4.5 Finalisation of the Concept

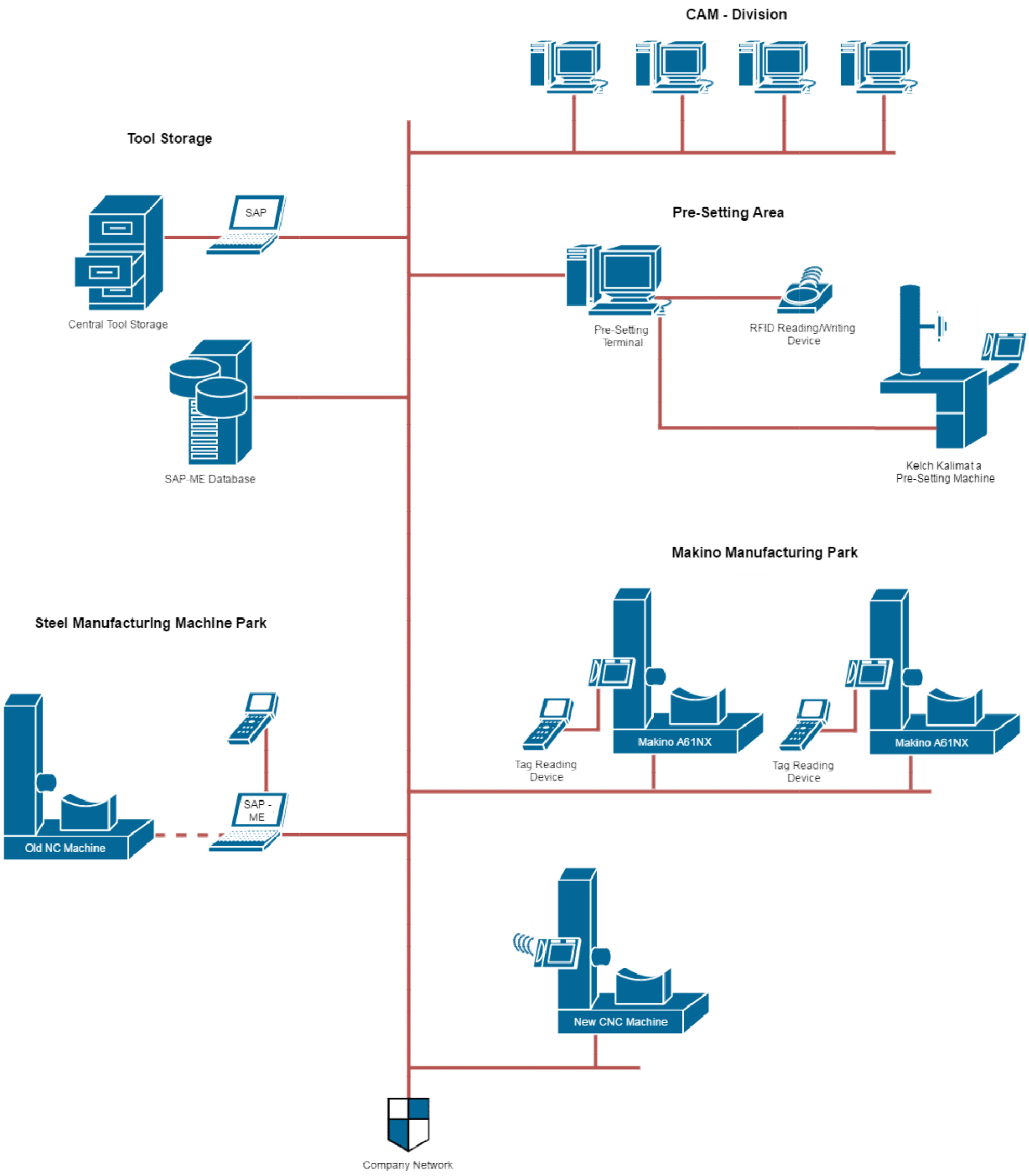


Figure 44: Structure for implementation of a tagging system, source: own representation

Based on the results of the utility analysis, a landscape with the relevant options has been developed (see Figure 44).The diagram has been created by running an online, open-source tool called draw.io.[112]

[112] Draw.io (2016), online diagram tool [09.01.2017].

4.4.5.1 Strategy

Core element of the concept is the new handling system. Therefore, the tools are equipped with an RFID-tag that is storing the tool identical number. This is the only information stored at the tag. The remaining data of the tool which is belonging to the appropriate identification number is deposited in the SAP-ME tool database. In this way, redundant information about a tool, stored at the tag and the database, is prevented.
As declared in chapter 3.2.3, the readability was the decisive argument for the RFID tag, since the DMC is read optically.

Connection of the CAM-Division:

The CAM division remains using the VANC programming software with the appropriate tool database TRP (Tool Resource Planning). This database stores the nominal tool data specified by the NC programmer. Furthermore, it provides access for the pre-setter who is then able to check the nominal data with the relevant mounting instruction.

Connection of the Pre-Setting Area:

The pre-setters responsiveness is the adjustment of the nominal data to the actual geometry data, using the existing ME-system as interface between the tool database and the manufacturing machine.
The pre-setting area disposes of an RFID reading and writing device. This component is used to assign the unique tool identification number when the tool is assembled for the first time. Since the identification number remains the same this procedure takes place only once. Engraving the same number at the tool holder is a hedge against losing information.

Connection of the Makino Manufacturing Park

The business unit CCZ consists of twelve Makino manufacturing machines. These machines dispose of a network connection as well as of a supply of the ME-system SAP-ME. This ME-system is used for transferring the tool data to the machine as soon as the relevant tool is identified by the RFID reading device.
By tagging the tool, the manufacturing machine calculates the ideal slot for the tool, considering the information provided by the ME-system. The technologist does not have to consider any special information about the tool when putting it into the feeder.
Due to the high costs of a belated machine upgrade the connection is provided by an external tagging device. This consists of a reading head, a processor unit and the connection cable to the machine.[113]
New ordered manufacturing machines are already equipped with the option of an integrated RFID reading possibility.

[113] Cf. Balluff (2016), p. 20.

Connection of the Steel Manufacturing Park

The connection to the steel manufacturing is part of the roll-out to other business units. But since the requirement for the concept is to represent a holistic approach, possible for the usage on other machines then the pilot zone, the scalability has to be reconsidered.
Especially in this section of the manufacturing elder machines without a network connection are in use. The control unit is fed with the CNC-program by using a serial port of the type RS232. Using this port as well for connection a processor unit with the control of the machine would be theoretically possible. But to realise this connection individual software aligned on the specific machine would have to be programmed.
A different option is to implement the chip in this section as well but using a computer as terminal which is providing the tool data. Then the machine operator has to type in the tool data and update the system manually. In this way a digital information flow to the terminal is enabled and the SAP-ME database is completed.

4.4.5.2 Required Components

The necessary components for performing a tagging operation have been discussed in the previous chapter 3.2.3 and are listed below:

- The reading head
- The processor unit
- The connection cable to the machine
- The appropriate RFID tag suitable for the hole of the tool holder

To retrofit the current machines, all single components are required for each machine. Therefore, prerequisite is the controls ability to assimilate the fed information.

4.4.5.3 Specifications on the Manufacturing Execution System

To pursue the strategy of chapter 4.4.5.1, the expansion of the current in use ME-system is required. These specifications should be considered by introducing new functions of the SAP-ME.

ME-System as a Connective Link

The VANC tool database (TRP) provides the nominal data of the tool. A consistent interface leads this information to the ME-system by using the input of the pre-setter about the actual geometry data. In this way, the ME-system provides the data for the manufacturing machines and keeps the information transparently in the database. Thereby a neat interface between the TRP and the SAP-ME database is essential.

Further Information about the Tool and the Machine

The ME-system is supposed to hold the specific data about the tool in addition to the standard geometry and tool life data. Additional arrays of the database should provide the necessary information to perform an automated equipping procedure (see Figure 37). Furthermore a similar database has to keep information about every single manufacturing machine in use.

Therefore information about following issues is required:

- Any specific data about the tool such as
    - Oversize
    - Overweight
    - Inner cooling
    - Breakage control
- Location of the tool
    - Which machine
    - Which specific pot at the machines store
- The current slot occupancy of the machines store

Slot Occupancy Strategy

The machine has to follow the strategy of minimising the spindle distance (see Figure 37). Hence, the ME-system is supposed to deliver the information about the slot occupancy to the control unit. Then the machine control is able to put the tool into the optimal slot.

Connection to the Machine Control Unit

The MES database is providing the information for the machine control unit. Therefore a connection between SAP-ME and the control unit is essential. Table 14 provides an overview about the different control units in use.

Again, the steel manufacturing park has to be considered. The different control units are listed in the following table as well.

Manufacturing machine	Business unit	Control unit
Makino A61 NX	CCZ	Fanuc 31 iB5
Makino A61	CCA	Fanuc 31
Makino A55	CCS	Fanuc 16 iM
SW 400	CCS	Siemens Sinumeric
Matsuura	CCK	Yasnag
Monforts RCN4	CCK	Fanuc 10-T

Table 14: Overview about different control units in use, source: own representation

4.4.6 Proof of Concept

In this case, the proof of the concept represents an analysis of the developed strategy. According to this, an evaluation should point out the economical benefit of the project. Furthermore, an experimentation zone was arranged so the physical components of the concept can be tested in the future.

For the evolution, a comparison of the current process and the future state was conducted. According to the declared KPIs (see chapter 4.4.1) the result shows the measurable benefits of the new concept.
Beside these, the implementation of an AutoID system enables, in combination with a central database, transparency about the tool location, the tool life and the tool use. But this additional value is very difficult to quantify. At this stage of the project only assumptions about cost savings could be considered. Hence, the calculation bases on measurable indicators and excludes profit in terms of transparency, or a later, potential occurring decrease of inventory needed.

4.4.6.1 Outcome

The outcome of the virtual process is described by a Gantt Chart. This chart demonstrates the total amount of time the tool change procedure takes.
The Gantt Chart is a diagram which should help to visualise the relation of facts to time. The principles of the chart are equal divisions of time at the abscissa and varying amount of work at the ordinate.[114] In this way, the Gantt Chart has been applied most extensively to industrial production.[115]
Two Gantt Charts have been created:

- Changing the tools in the conventional way (see Figure 45)
- Using RFID tags as identification (see Figure 46)

Therefore, prerequisite is the implementation of the software components in advance. Data input for the tool change was a recording of a tool change of 32 tools to set-up a machine. The virtual process was aligned on the technical specifications discussed.

[114] Wallace (1923), p. 3ff.
[115] Wallace (1923), p. 17.

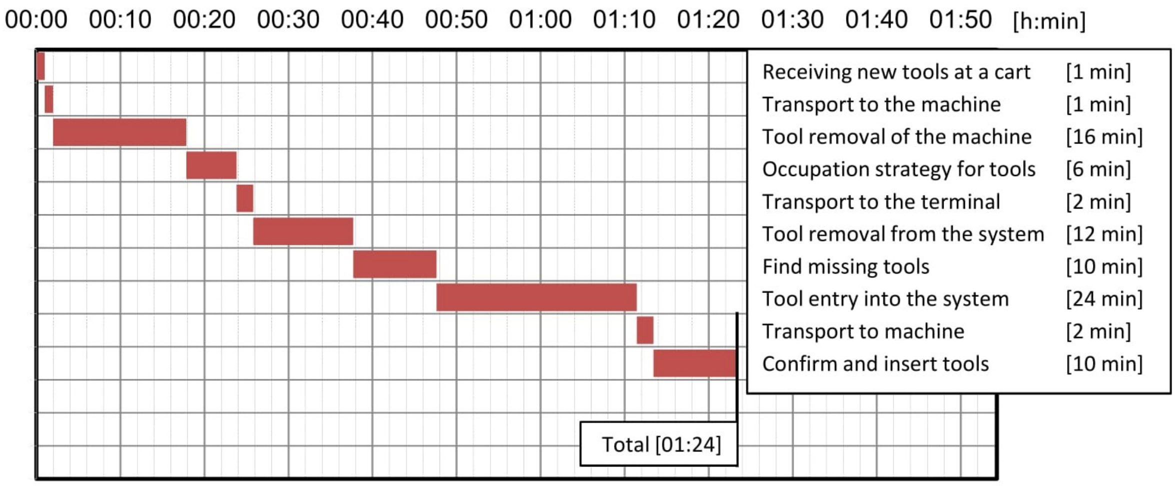


Figure 45: Gantt Chart of tool change in the conventional way, source: own representation

Figure 45 illustrates a recorded tool change. The single steps with the related amount of time are listed in each line.

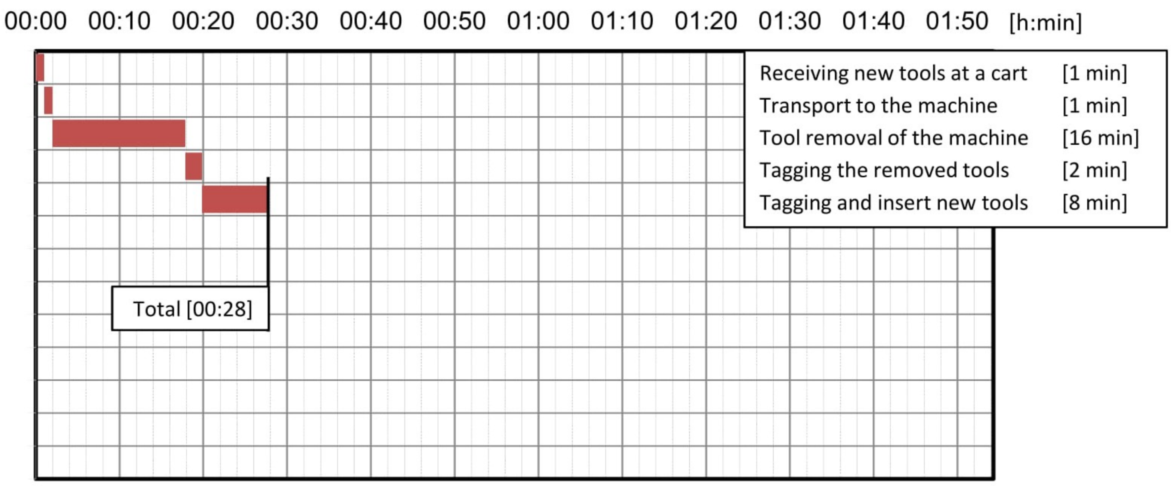


Figure 46: Gantt Chart of tool change using RFID tool ID, source: own representation

Figure 46 illustrates a virtual tool change using an RFID-tagging system for the tool identification. A couple of work steps can be eliminated in this way. As mentioned, the prerequisite for the usage is a connected database. Then, additional transport to the shop floor terminal is not necessary anymore. Also the protracted operation of the system input can be replaced by a fast tagging operation. In sum, a time saving of nearly 1 hour can be achieved in this way.

The whole tool change operation is represented by the following Figure 47. Aligned on Figure 38, it should point out the minimisation of physical information flow. The technologist is now able to put the tools directly into the machine store. The required information is then provided by the connected database (SAP-ME).

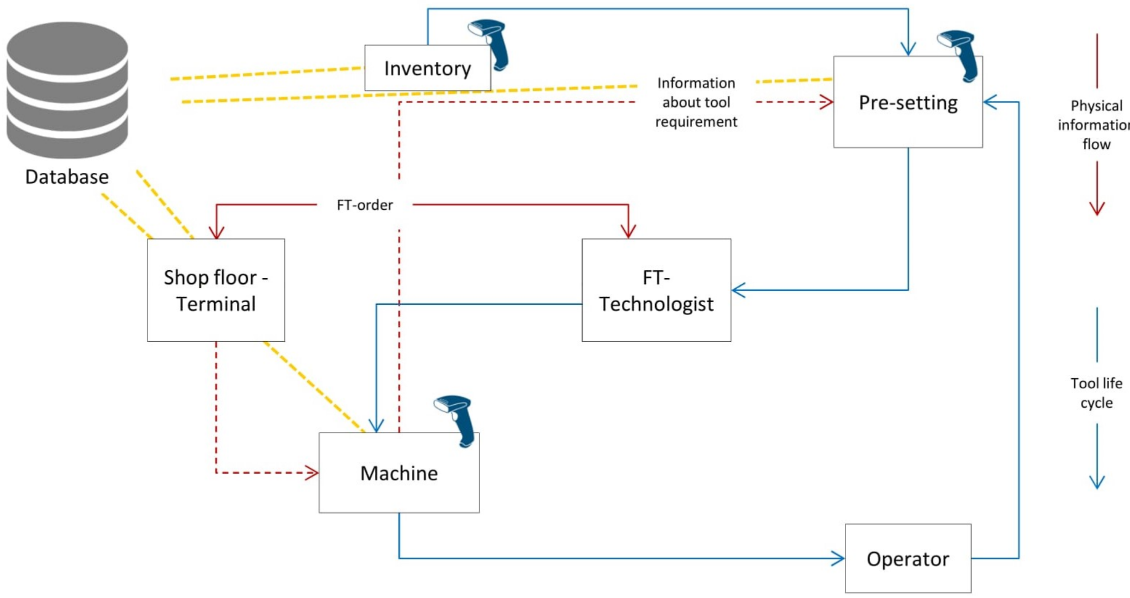


Figure 47: Conceptional tool life cycle and information flow with the use of AutoID, source: own representation

Further, a data transmission error can be prevented completely. Since the tools are uniquely identified and the information is stored within a database, no manual data entry has to be performed. The estimated errors due to mistypes or problems with the tools occur, according to the Smart Factory manager of BRP, two times a week. In the most no substantial damage occurs. But approximately two times a year, the machine is down for a week because of a crash caused by these data transmission error.[116]

Hence, a comparison of the determined KPIs looks a follows (see Table 15):

KPI	PRESENT SYSTEM	ELABORATED CONCEPT
Set-up time for the tool change [min]	84 min	28 min
Number of mistypes [n]	2	0

Table 15: Comparison of the determined key performance indicators, source: own representation

[116] BRP (2016), internal sources.

4.4.6.2 Cost-benefit Assessment

The outcome which is discussed in the previous chapter leads to benefits for the workers and the company. The advantages for the BRP-Rotax, in terms of financial aspects, are elaborated and compared with the investment costs.
According to Abele et al. the RFID investment is separated into three categories:[117]

- Investment in RFID-Chips
- Investment in additional tool holder
- Investment in reading units and software for the manufacturing and pre-setting machine

At this section it has to be mentioned, that in the following calculation the costs for the CAM extension is headed, but not considered by the cost-benefit assessment. This is because the CAM system has to be upgraded anyway, no matter which tool handling system is going to be used. A different point is the additional investment caused by the MES expansion. This is quantified with 20 man-days, with an hourly rate of € 120, for the implementation of the new features, according to the shop floor IT of BRP. This lead to implementation cost of approximately € 24 000.

COMPONENT	QUANTITY	COSTS PER UNIT [€]	TOTAL COSTS [€]
RFID-Chips	1 000	18	18 000
Read / write head	13	200	2 600
Processing unit	13	1 050	13 650
Connection to the machine	13	50	650
MES expansion	1	24 000	24 000
Total investment costs			**58 900**

Table 16: Investment costs for an RFID tool identification system, source: own representation, data attached in the appendix

The financial benefit of the considered aspects is listed in the next Table 17. The total amount of set-up processes is calculated with 2.5 per week for each section of the business unit (cylinder crankcase, cylinder head). This lead to a total amount of 250 processes a year. The total machine downtime is 240 hours a year, considering a total breakdown of a week for two times. Since the machine is in shift operation the weekly amount of available production hours is 120.[118]

[117] Cf. Abele/Hueske/Albrecht (2010), p. 49.

[118] BRP (2016), internal source.

KPI	BENEFIT	AMOUNT A YEAR [HOURS]	HOURLY RATE [€]	TOTAL BENEFIT [€]
Set-up time for tool change	1 hour	250	40	10 000
Number of mistypes	2 times less a year	240	43	10 320
Yearly benefit				**20 320**

Table 17: Financial benefit for BRP-Rotax by implementing an AutoID system, source: own representation

On the base of this rough cost-benefit analysis a return on investment can be achieved in two years and 11 months. The problem is the difficult quantification of influence factors and benefits.[119] But also with no consideration of positive side effects, such as more efficient tool usage because of a transparent handling system, a positive calculation can be represented. Considering the calculated indicators a break-even diagram illustrates the comparison of investment and monthly benefit (see Table 18).

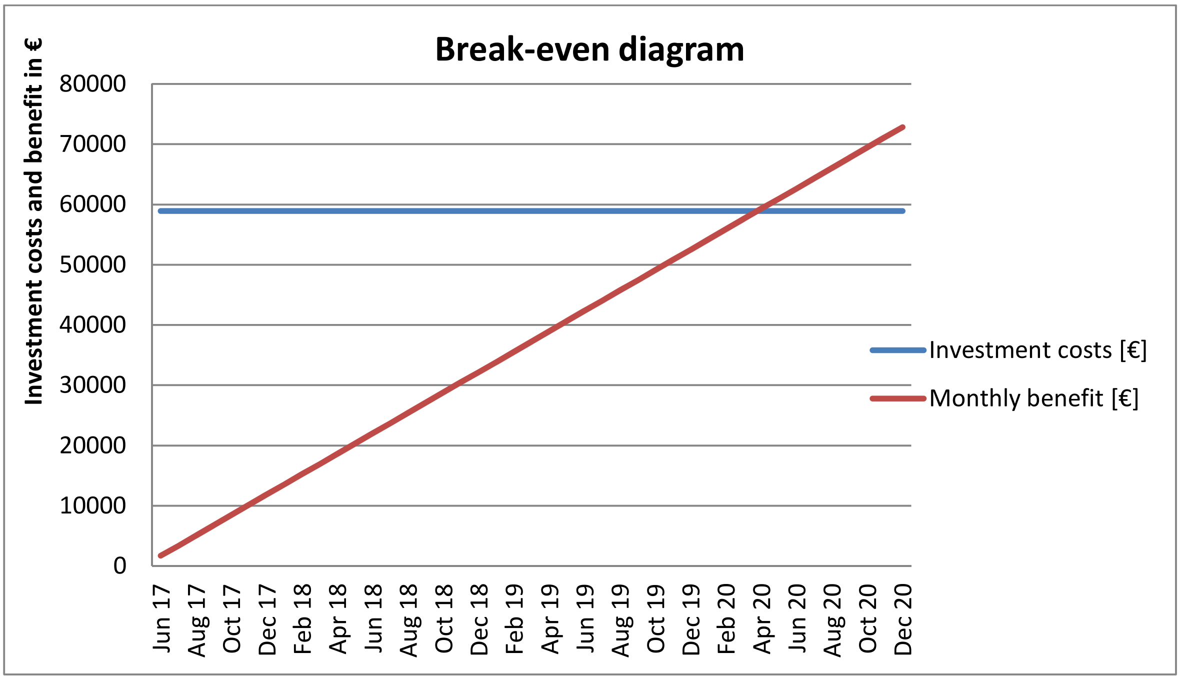


Table 18: Break-even diagram of investment costs and benefit, source: own representation

[119] Cf. Abele/Hueske/Albrecht (2010), p. 49.

4.4.6.3 Testing and Experimentation

The business unit cylinder crankcase and cylinder served as the base for the process analysis and the calculation of investment costs. But before implementing the new tool handling system into the manufacturing machines of this business unit, the concept has to be tested in terms of manageability. Only if an error-free procedure can be warranted the system is ready for implementation. For testing the components of the RFID-system and simulation of tool change situations, resources at a manufacturing machine are needed. These possibilities can be made available at the business unit Turbo. With one Makino A61 manufacturing machine, this business unit is the smallest at the production plant. The testing zone has been already arranged. The next step is now an implementation of the physical components at the business unit to simulate tool change situations.

Figure 48 shows the process chain of the business unit turbo. The following manufacturing steps take place until the turbo housing is ready for assembling:

1. Manufacturing at the Makino A61 manufacturing machine
2. Deburring at the robotic cell
3. Washing
4. Tightness test

Relevant for testing the RFID-tool system is the manufacturing step which takes place at the Makino A61. Currently only one type of turbo housing is produced within the business unit, which means that no machine set-up takes place at the machine. Hence the tool changes have to be simulated at first.

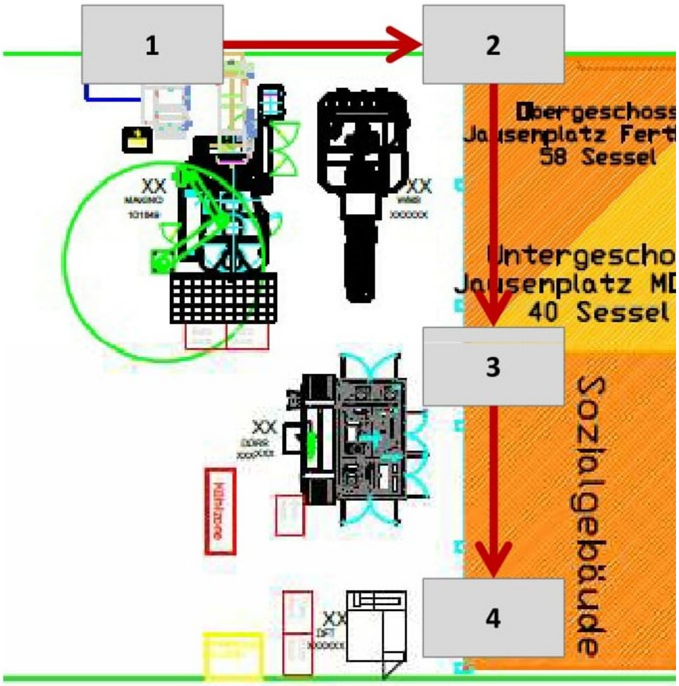


Figure 48: Process chain through the business unit turbo, source: BRP (2016)

The necessary resources to enable realistic tool change situations at the testing zone are as follows:

- External reading device for the manufacturing machine
- External reading / writing device for the pre-setting machine
- RFID-tags for the tool holder

Due to the existing MES connection, the physical tool change can be simulated with the mentioned components. For the demonstration of the target situation the software requirements have to be provided as well (see chapter 4.4.6.4, step 1-3).

4.4.6.4 Implementation Strategy

A strategy for the roll-out of the tested RFID-system was conducted to realise a neat implementation. If an error-free tool handling can be warranted, the system is ready for a realisation at the business unit cylinder crankcase and cylinder head. Aligned on the current situation the steps are proposed as follows:

1. Upgrade and new creation of the tool database:

The database upgrade comes hand in hand with the CAM upgrade and represents the first step required for the implementation. Despite the enormous additional expense, the tool data base should be created completely newly in its structure. The advantage of it is the elimination of meaningless data. Currently, the tool database stores approximately 2000 unused digital tools (see chapter 4.3.2.2). Another benefit for the database is the definition of a homogonous cluster for all tools, which is currently not the case.
Using the new structure, the tools have to be marked with a consecutive identification number available for each access. Furthermore an integrated assembling guideline has to be provided for the pre-setter. According to this, the accessibility has to be warranted for the ERP-, ME- and CAM-system, as well as for the pre-setter.

2. Expansion of the MES:

The current in use ME-system is SAP-ME. This system is already linked to machines but an expansion is required to enable local posting of the tool and providing this information on request. Also an interface between the MES and the new database is necessary to enable an information exchange regarding master and special data of the tool (see chapter 4.4.5.3).

3. Investment in a new pre-setting machine

Tagging the tools with an external reading device should just represent an interim solution for the testing zone. Since the current pre-setting machine is already 17-years, old a new investment is not only regarding the new tool id-system (see chapter 4.4.4.2). A new pre-setting offers benefits for the pre-setter as well. An automated tagging is quicker, rather than tagging the tool by an external device. Further the pre-setter is able perform the shrinking procedure and pre-setting in one step. According to this, a new pre-setting machine is strongly recommended.

4. Manufacturing machine

The existing MES connection provides an interface to the new tool database. In this way the ME-system can be used for location posting and stores all data about the tool in use. For the existing machines an external reading device can be used for tagging and identification of the tools. A retrofit of the machine costs about four times more than the initial, optional costs when the machine is ordered. Hence, existing machines should be equipped with an external device. New ordered machines should be delivered with an integrated reading unit.

5. Tool identification

The last step is the mounting of the RFID chip at the tool. The consecutive number of the tool database is the identification number which is stored digitally at the RFID chip. Further the tool holder is engraved with the same number as a hedge against data loss.

4.5 Conclusion of the Practical Research

The investigation of the process chain revealed weak points regarding the reconfiguration process of the manufacturing machine. This complex machine set-up has a lot of influence factors which are responsible for this instability. Especially the tool handling situation has a huge impact on the set-up time, as shown on internal records about the set-up process.

The tool management is a broad issue which is affecting several different departments. Therefore, the analyses of relevant use-cases gave insight in the detailed processes which are ongoing. A lot of paper flow and redundant information which is stored on decentral computers complicate the tool change for the workers. Further, the current data transmission represent a huge error source has a significant influence on the protracted set-up process. With the gained information a concept was conducted to avoid the revealed weak points. The cooperation with the employees of the appropriate department was therefore essential.

The concept’s base is an AutoID system with the use of RFID-tags for the tool identification. The tool data is stored in a database and is provided by the existing MES connection on request of the machine. In this way, a time saving of nearly one hour per set-up process can be achieved. Further, the data transmission errors can be avoided because no manual entering of the tool data in necessary.

The developed concept is now ready for a testing phase within the business unit turbo.

5 Conclusion and Outlook

Industry 4.0 offers a lot of possibilities to create a modern manufacturing line more flexible. This broad topic was discussed and aligned on the practical situation of the BRP-Rotax shop floor in order to show the potential at the ongoing manufacturing.
The precise process analysis of the relevant business unit cylinder crankcase and cylinder head revealed weak points and instabilities within the process chain where tool management is only one necessary part for it. Nevertheless this topic is of enormous importance for a stable production, as it is confirmed by modern manufacturing literature as well. The tool management situation at BRP-Rotax is characterised by paperwork and redundant or missing information. This leads to protracted tool change situations and errors caused by instable information flow. Also the CAM system and the related tool database behind the tool management are very old versions of the software. For the development of a concept which is ready to face the current instabilities, an intensive research in the area of cyber-physical systems and their application was necessary. On this occasion, the definition of object intelligence was discussed and further aligned on the tool within a mechanical manufacturing. A tool handling controlled by an AutoID-system is not only state-of-the-art of a modern tool management, in fact, it represents a support to prevent human errors and impede redundant information within the tool cycle. But the core element is the software controlling the tool handling system: The tool database. At this section, BRP-Rotax is compelled to act to enable a data and information patency and thusly provide accessibility for all involved parties.

The conducted concept combines the advantages of both discussed AutoID systems which prevailed in the area of tool identification. On the one hand the readability of the RFID system and on the other hand the central data storage within the connected ME-system (Read-only-system) to gain transparency about the tools in use. After the testing phase, which is planned to take place at the business unit turbo, the system is ready to be rolled out at the process chain for the manufacturing of cylinder crankcase and cylinder head. Therefore, an implementation strategy represents a guideline for the realisation at the shop floor. Prerequisite for introducing the system is the new database with the appropriate interface for the ME-system that serves as connection to the manufacturing machine. Hence, a strict compliance to the single steps and their order is essential.

Although not all economic advantages of an AutoID system can be quantified and are consequently not considered by the cost-benefit calculation, the potential of the new system is enormous. Less transmission errors of the tool information and faster processes are the result of digital information flow. This leads directly to a decrease of machine downtime and a more stable set-up process. Furthermore, the employees can be relieved and are able to focus on other activities.

With a successful implementation of the new tool management, a further milestone towards a paperless and flexible manufacturing is achieved. The concept strengthens the base for full transparency within the cycle of resources for the production. This is important to achieve the set goals of the Smart Factory. The gained transparency and collection of process data is the base for big data analyses and predictive maintenance. The evaluation of these gained information leads to data which is applicable for the detection of linkages between the tool and the surrounding area. With the identification of these correlations, predictive actions can be taken. For example, tool changes because of unusual tool wear detected by a variance of the machine torque. In this way, the creation of unique factory objects within the mechanical manufacturing and the evaluation of the collected data regarding these objects represent the characteristic of the Smart Factory.

This master thesis delivers a completed and though-out concept which is ready for the implementation. The benefit covers the implementation costs in the foreseeable future, whereas also other areas profit from the investment. Further, the approach for a modern tool management is essential for the transparency as it is required by the Smart Factory of the future. A timely realisation is therefore recommended.

6 List of References

Abele, Eberhard; Hueske, Benjamin; Albrecht, Florian (2010): *Zerspanungswerkzeuge Werkzeugorganisation ohne Zettelwirtschaft*, in: MM Maschinenmarkt - Das Industriemagazin, issue from 29/03/2010, p. 46-49

Abele, Eberhard; Reinhart, Gunther (2011): *Zukunft der Produktion – Herausforderungen, Forschungsfelder, Chancen*, Carl Hanser Verlag, München

acatech (ed.) (2011): *Cyber-Physical Systems. Innovationsmotoren für Mobilität, Gesundheit, Energie und Produktion (acatech POSITION)*, Springer Verlag, Heidelberg

acatech (ed.) (2012): *agenda CPS*, acatech, Berlin

Alisch, Katrin; Winter, Eggert; Arentzen, Ute (2004): *Gabler Wirtschafslexikon*, 16th Edition, Gabler Verlag, Wiesbaden

Arnold, Dieter; Isermann, Heinz; Kuhn, Axel; Tempelmeier, Horst; Furmans, Kai (2008): *Handbuch Logistik*, 3rd Edition, Springer Verlag, Berlin-Heidelberg

Balluff GmbH (ed.) (2016): *Industrial Identification*, Neuhausen auf den Fildern

Balluff GmbH (ed.) (2016): *Tool Identification with Industrial RFID*, Neuhausen auf den Fildern

Barr, Michael; Massa, Anthony (2006): *Programming Embedded Systems with C and GNU Development Tools*, 2nd Edition, O´Reilly Media Inc., Sebastopol

Coscom (ed.) (2016): Werkzeugverwaltung ToolDIRECTOR VM, Ebersberg

Denkena, Berend; Litwinski, Kai M.; Dahlmann, Dominik; Boujnah, Haythem; Kiesner, Johann; Kürger, Max; Schmidt, Justin; Neff, Thomas (2014): *Industrie 4.0 in der Zerspanung*, in: ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb, issue 7-8/2014, p. 537 - 541

Erlach, Klaus (2010): *Wertstromdesign – der Weg zur schlanken Fabrik*, 2nd Edition, Springer-Verlag, Berlin Heidelberg

Eversheim, Walter (1989): Organisation in der Produktionstechnik Band 4: Fertigung und Montage, 2nd Edition, VDI-Verlag, Düsseldorf

Federal Ministry of Science, Research and Economy (ed.) (2016): *Economic Report 2016*, Vienna

Furterer, Sandra L. (2009): *Lean Six Sigma in service: applications and case studies,* Taylor & Francis Group, Boca Raton

GTAI – Germany Trade and Invest (ed.) (2014): *Industrie 4.0 – Smart Manufacturing for the Future*, Berlin

Heath, Steve (2003): *Embedded Systems Design*, 2nd Edition, Newnes, Oxford

Hameed, Bilal; Durr, Frank; Rothermel, Kurt (2011): *RFID based Complex Event Processing in a Smart Real-Time Factory*, Expert discussion: Distributed Systems in Smart Spaces

Kagermann, Henning; Wahlster, Wolfgang; Helbig, Johannes (2012): *Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0*, Büro der Forschungsunion im Stifterverband für die Deutsche Wissenschaft e. V., Berlin

Kamiske, Gerd F.; Brauer, Jörg-Peter (2008): *Qualitätsmanagement von A - Z: Wichtige Begriffe des Qualitätsmanagements und ihre Bedeutung*, 6th Edition, Hanser, München

Kärkkäinen, Mikko; Holmström, Jan; Främling, Kary; Artto Karlos (2003): *Intelligent products - a step towards a more effective project delivery chain*, in: Computers in Industry, Volume 50 Issue, p. 141-151

Kief, Hans B.; Roschiwal, Helmut A.; Schwarz, Karsten (2013): *CNC-Handbuch 2013/2014*, Hanser, München

Kief, Hans B.; Roschiwal, Helmut A.; Schwarz, Karsten (2015): *CNC-Handbuch 2015/2016*, Hanser, München

Koch, Susanne (2015): *Einführung in das Management von Geschäftsprozessen*, 2nd Edition, Springer Verlag, Berlin-Heidelberg

Lunau, Stephan (ed.); Meran, Renata; John, Alexander; Staudter, Christian; Roenpage, Olen (2014): *Six Sigma + Lean Toolset*, 5th Edition, Springer Verlag, Berlin-Heidelberg

Lucke, Dominik; Constantinescu, Carmen; Westkämper Eengelbert (2008): *Smart factory - a step towards the next generation of manufacturing*, in: Manufacturing Systems and Technologies for the New Frontier, Springer, p. 115–118

Madu, Christian N.; Kuei, Chu-Hua; Aheto, John; Winokur, Dena (1994): *Integrating total quality management in the adoption of new technologies*, in: Benchmarking for Quality Management & Technology, vol.1 no. 3, p. 52–66

Maehnz, Andreas (2007): RFID-Einsatz in metallischer Umgebung, Fraunhofer Instiut (ed.): Workshop »Identifikationstechnologien & Sensorik – Stand und Anwendungen«, Magdeburg

McFarlane, Duncan; Sarma, Sanjay; Chirn, Jin Lung; Wong, Chien Yaw; Ashton Kevin (2003): *Auto id systems and intelligent manufacturing control*, in: Engineering Applications of Artificial Intelligence, issue 16(4), p. 365-376

Meyer, Gerben G.; Främling, Kary; Holmström, Jan (2009): *Intelligent Products: a survey*, in: Computers in Industry, issue 60 (3), p. 137–148

Pfingsten, Maik (2016): *Erfolgreich Lastenhefte schreiben: Eine Schritt-für-Schritt-Anleitung aus der Praxis eines Troubleshooters*, 2nd Edition, BoD – Book on Demand, Norderstedt

Radziwon, Agnieszka; Bilberga, Arne; Bogersa, Marcel; Madsenb, Erik Skov (2013): *The Smart Factory: Exploring Adaptive and Flexible Manufacturing Solutions*, in: Procedia Engineering, Vol. 69, p. 1184-1190

Röschinger, Marcus; Kipouridis, Orthodoxos; Lechner, Johannes; Günther, Willibald A. (2014): *AutoID-Konzept für ein cloud-basiertes Werkzeugmanagement*, in: ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb, issue 1-2/2015, p. 59-62

Sauer, Markus S.; Grosch, Thomas; Abele, Eberhard (2014): *Smart Tool*, in: ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb, issue 7-8/2014, p. 542 – 545

Schawel, Christian; Billing, Fabian (2012): *Top 100 Management Tools*, 4th Edition, Springer Gabler Verlag, Wiesbaden

Schlick, Gerhard H. (2001): *Projektmanagement – Gruppenprozesse – Teamarbeit*, 4th Edition, expert Verlag, Renningen-Malmsheim

Syska, Andreas (2006): *Produktionsmanagement*, Dr. Th. Gabler GWV Fachverlage GmbH, Wiesbaden

VDI - Gesellschaft Produkt- und Prozessgestaltung (ed.) (2011): *Wertanalyse – das Tool im Value Management*, 6th Edition, Springer Verlag, Berlin-Heidelberg

Wallace, Clark (1923): The Gantt Chart – A Working Tool of Management, 2nd Edition, The Ronald Press Company, New York

Westkämper, Engelbert; Spath, Dieter; Constantinescu, Carmen; Lentes, Joachim (2013): *Digitale Produktion*, Springer Verlag, Berlin-Heidelberg

Wong, Chien Yaw; McFarlane, Duncan; Zaharudin, Alia Ahmad; Agarwal Vivek (2002): *The intelligent product driven supply chain*, in: Systems, Man and Cybernetics, 2002 IEEE International Conference

Yoon, Joo-Sung; Shin, Seung-Jun; Suh, Suk-Hwan (2012): *A conceptual framework for the ubiquitous factory*, in: International Journal of Production Research, vol.50, no. 8, p. 2174–2189

Zipper, Brigitte (1994): *Das integrierte Betriebsmittelwesen — Baustein einer flexiblen Fertigung*, Springer Verlag, Berlin-Heidelberg

Zoller Inc. (ed.) (2016): *TMS Tool Management Solutions*, Ann Arbor

Zuehlke, Detlef (2010): *Smart Factory — towards a factory-of-things*, in: Annual Reviews in Control, vol.34 no. 1, p. 129–138

Weblinks

BRP-Rotax (2016): *Production plant in Gunskirchen, Austria*
https://www.rotax.com/files/project/userdata/content/unternehmen/Unternehmen-Gunskirchen-3.jpg [Accessed on 09.01.2017]

BRP-Rotax (2016): *Company homepage*
https://www.rotax.com/en/company/about-us.html [Accessed on 09.01.2017]

DFKI (2011): *Industrial revolution steps*
https://www.nrwinvest.com/en/industries-nrw/industry-4-0/ [Accessed on 09.01.2017]
Fastems (2016): *Tool management automation*

https://www.fastems.com/tool-management-automation/ [Accessed on 09.01.2017]

Draw.io online diagram tool (2016)
https://www.draw.io [Accessed on 09.01.2017]

Investopedia (2016): *Key Performance Indicators - KPI*
http://www.investopedia.com/terms/k/kpi.asp [Accessed on 09.01.2017]

Lannon (2014): *Lagging vs. Leading Business Indicators - Do you know the difference?*
https://www.projecttimes.com/articles/lagging-vs-leading-business-indicators-do-you-know-the-difference.html [Accessed on 09.01.2017]

LinkedIn Slideshare (2016): *Key Performance Indicator*
http://www.slideshare.net/speedcars/key-performance-indicator-11582069 [Accessed on 09.01.2017]

Microsoft Newsroom (2016): *Fertigungsoptimierung mit ValueFacturing: Neue Cloud-Lösung spart Zeit und Geld*
http://news.microsoft.com/de-de/fertigungsoptimierung-mit-valuefacturing-neue-cloud-losung/#iWJUQUHbSubiZ0cQ.99 [Accessed on 09.01.2017]

McKinsey & Company (2013): *The Internet of Things and the future of manufacturing*
http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/the-internet-of-things-and-the-future-of-manufacturing [Accessed on 09.01.2017]

Oriel Stat a Matrix (2016): *Six Sigma DMAIC*
http://www.orielstat.com/practice/six-sigma-dmaic-consulting [Accessed on 09.01.2017]

Produktion - Technik und Wirtschaft für die deutsche Industrie (2013): *Industrie 4.0-Award: Herzlichen Glückwunsch nach Regensburg!*
https://www.produktion.de/spezial/industrie-4-0-award-herzlichen-glueckwunsch-nach-regensburg-349.html [Accessed on 09.01.2017]

TDM Systems (2016): Production equipment - multi plant management
https://www.tdmsystems.com/en/products/software-for-production-equipment-management/tdm-multi-plant-management/ [Accessed on 09.01.2017]

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8 List of Tables

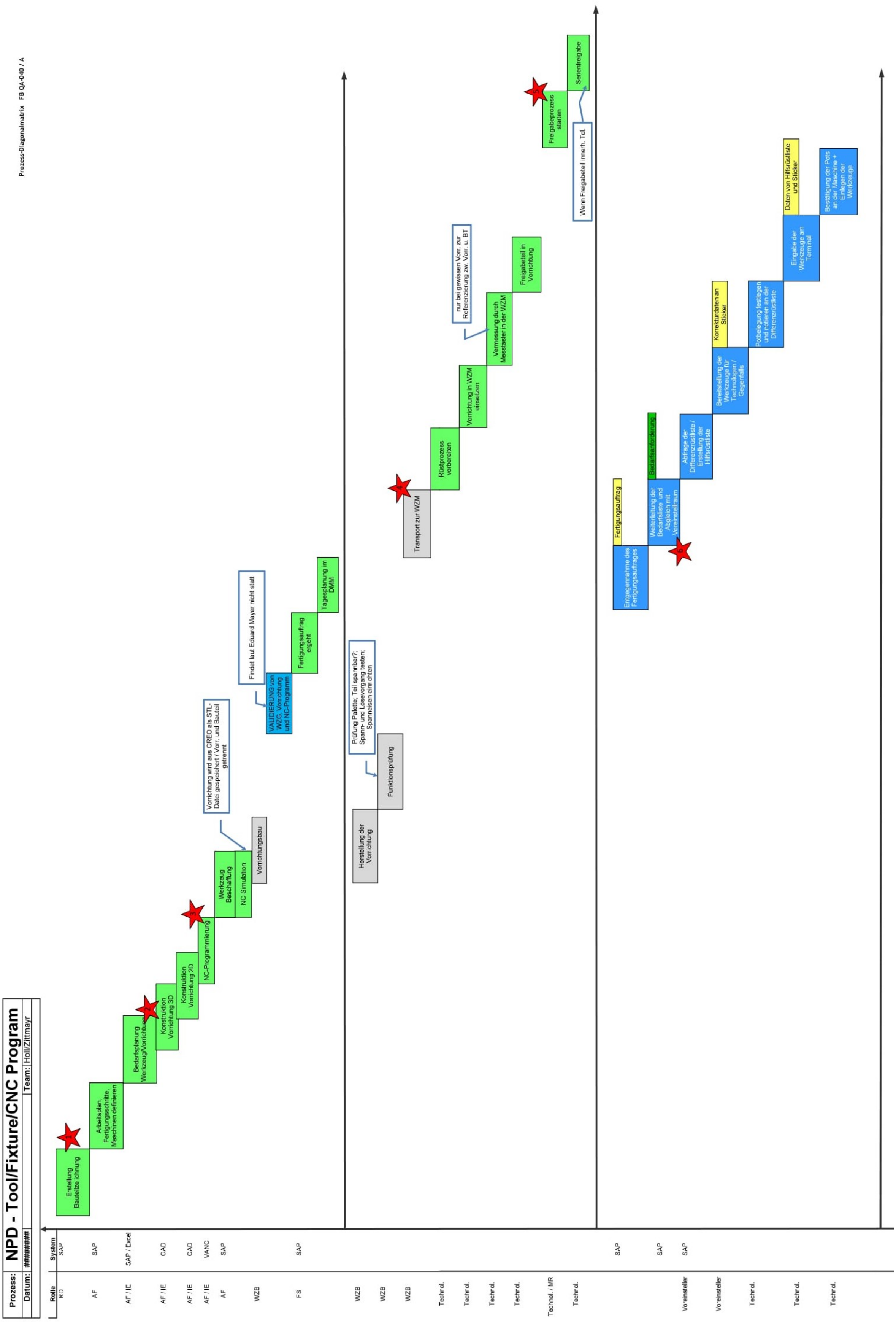
Appendix

Erstrüsten

Rüsten Makino nach SMED 4-TEC ALU November

Anzahl	Datum	Rüster	Makino	Von Teil	Auf Teil	Rüstzeit (Zeit in Min)	SMED (1 od. 2 MA max 180min)		Begründung Rüst und Freigabeprozess länger als 8h kein 2ter Rüster (1) Liegezeit Messraum (2) Maschinenausfall (3) WKZ-Probleme (4) Vorr. Problem (5) mehrere Korrekturschleifen (6) Bearbeitungsprogramm N.I.O (7)	Korrektur schleife		Rüst + Freigabeprozess in 8h		Erststückfreigabe I.O	Maschine läuft auf anderen Bauteil weiter
							JA	NEIN		Ja	NEIN	Ja	NEIN		

Attachment 1: Blank of the document for the set-up recording, source: BRP Rotax (2016), internal sources



Attachment 2: Diagonal matrix used as overall process map, source: own representation

STEINDL Service GmbH

A–8561 SÖDING/Graz
PACKERSTRASSE 177
TEL.: +43-(0) 3137–27224–0
FAX.: +43–(0) 3137–27224–6
E-Mail: info@steindl.at
http://www.steindl.at

Steindl Service GmbH, Packerstrasse 177, A-8561 Söding
Firma
BRP-Rotax GmbH & Co KG
z.Hd. Herrn Florian Zittmayr
Rotaxstraße 1
4623 Gunskirchen

Datum:
16.12.2016

Kundennummer: 200205	**Lieferzeit:** ca. 5 Monate	**Sachbearbeiter:** Kevin Vodovnik	**E-Mail:** vodovnik@steindl.at
Kunden-UID-Nr.: ATU53018309	**Angebot gültig von:** 15.12.2016	**Angebot gültig bis:** 31.01.2017	
Maschine: a61nx	**Maschinen Nr.:** a61nx__80-a61nx-0094	**Anfrage Nr.:**	

A N G E B O T 2160578

Wir bedanken uns für Ihre Anfrage recht herzlich und bieten Ihnen wie folgt an:

Pos	Artikel	Bezeichnung	Menge	Einh	Preis	Gesamt	
1	ToolIDnx	Balluff Tool ID (with Operation Panel)	1,00	Stk	16.431,66	16.431,66	EUR
2	Technikereinsatz	Technikereinsatz Steindl Geschätzte Kosten. Abrechnung erfolgt nach tatsächlichem Aufwand.	1,00	Stk	4.500,00	4.500,00	EUR
			Nettobetrag			**20.931,66**	EUR
			+ 20,00% USt. von		20.931,66	**4.186,33**	EUR
			Gesamtbetrag			**25.117,99**	EUR

Attachment 3: Statement of retrofit costs for an AutoID system at the Makino A61NX, source: Steindl Service GmbH

MAGNA

Magna Powertrain
Engineering Center Steyr
GmbH & Co KG
Steyrer Strasse 32
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Legal Form: Kommanditgesellschaft
Register Office: St. Valentin
Register of Firms No.: FN 222001Y
Commercial Court:
District Court St. Pölten
DUNS No.: 30-060-2377
Bank Account:
Raiffeisen Bank International AG
Acct. 1-04.077.038, Bank Code 31000
IBAN: AT66 3100 0001 0407 7038
Swift Code / BIC: RZBAATWW
UID-Nr. / VAT ID: ATU 54112605

Engineering Center Steyr GmbH & Co KG, Steyrer Strasse 32, 4300 St. Valentin, Austria

BRP-Powertrain GmbH & Co KG
z.H.: Herrn Andreas Pylypiw
Rotaxstraße 1
A-4623 Gunskirchen, Austria

Fax:

Ihr Zeichen	Unser Zeichen	☎ Telefon	Telefax	St. Valentin,
	E-TS/ELJ-KAL	07435/501-2279	07435/501-2255	20.10.2016

Betreff: Angebot Nr.: EC16_0140-A

Sehr geehrter Herr Pylypiw !

vielen Dank für Ihre Anfrage zur Angebotslegung. Wir erlauben uns ein Angebot für Software und Dienstleistungen durch die MAGNA POWERTRAIN / ENGINEERING CENTER STEYR GmbH & Co KG (ECS), basierend auf den allgemeinen Verkaufsbedingungen des ECS wie folgt zu unterbreiten.

1.1 1x 3-5 Achsen Paket Simultan Fräsen .... € 9.500.-

<u>3 Achsen:</u>

- 3D Schruppbearbeitungen
- Automatisches 3D Restmaterial Schruppen
- Automatische Bearbeitung von ebenen Bereichen
- Automatische Restbearbeitung von ebenen Bereichen
- Projektionen von Werkzeugbahnen, Radial, Zirkular und über 2 Kurven
- 3D Profilschlichten mit Rauhigkeitskontrolle
- 3D Abzeilen
- Projizieren von NC-Bearbeitungen auf beliebige Freiformflächen
- 3D Gravieren
- 3D Konturfräsen
- NC-Bearbeitung Freiformflächen "

5 Achsen:

- "Beinhaltet die volle Funktionalität des 4A Simultanmoduls plus 5A Simultanbearbeitungen auf Solids und Flächen.
- 5 Achsen flächenübergreifendes Fräsen,
    - mit einer Steuerkurve,
- zwischen zwei Steuerkurven
- 5 Achsen Besäumungen
- Mantelflächenfräsen (Swarf Cutting)
- Verwendung von Haltepunkten, Haltekurven oder fixiertem Anstellwinkel
- Kontrollflächen und 5 Achsen Werkzeugbahnkontrolle mit Kollisionsüberwachung und Kollisionsvermeidungs- Strategien
- volle 5A simultane Maschinenraumsimulation"
- Unterstützung von konischen Werkzeugen

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Attachment 4: Statement of costs for CAM system upgrade and tool database TRP (1/5), source: Magna Powertrain

MAGNA

1.2 1x VANC™-Maschinensimulation.. € 3.000.-

- Kollisionsüberprüfung
- Prüfung des Verfahrbereichs
- Manuelle Achsensteuerung und –kontrolle
- Kollisionserkennung: Werkzeug, Schaft, Halter
- Überprüfung der Werkzeugwege nach Vorschub und Eilgang
- Rohteil-Visualisierung
- Messung des bearbeiteten Rohteils

Hinweis:
- Bei einer kompletten Arbeitsraumsimulation muss das Maschinenmodell in einem neutralen Format zur Verfügung gestellt werden.

1.3 VANC™- Werkzeug „Korrekturpostprozessor"

Um die gemessenen Werkzeug- Ist Daten im entsprechenden Steuerungsformat zu erzeugen, wird pro Maschine ein „Korrekturpostprozessor" benötigt.
Im Standardformat stehen pro Werkzeug die VANC- Primärdaten und pro Werkzeug- Indexpunkt (WIP) folgende Daten zur Verfügung:
Werkzeug- Ist – Länge (L-Maß)
Werkzeug- Ist-Durchmesser oder Quermaß (beim Drehen)
Werkzeug- Schneidenradius
Werkzeug- Lage

Prinzipiell wird angenommen, dass bei den Maschinen das jeweilige Steuerungs – Standardformat verwendet wird. Falls Sonderformate (z.B: auf Grund einer Werkzeugverwaltung) benötigt werden, bieten wir Ihnen den Mehraufwand nach Spezifikation bei Bedarf gerne an.

Nachfolgende Liste beinhaltet die Maschinen, die von der VEG- Software unterstützt werden sollen. Dabei wurden für steuerungsähnliche Formatausgaben Paketpreise gebildet.

1.4 *VANC™- Werkzeug Korrekturpostprozessoren pro Maschine/Steuerung*...€ 750.-

1.5 1x VANC™-Advanced Feature Recognition .... € 2.000.-

- Automatische Erkennung von Bearbeitungsgeometrien
- Featurebearbeitung mittels Sprache
- Interaktive Bearbeitung

- Bohrbearbeitungen mittels AFR
  - Halb- automatisches Bohren
  - Automatische Bohren

- Prozedurmanager
  - Zum Erstellen und Bearbeiten von automatisierten Bohrstrategien.
  - VANC Prozedurmanager nutzt die jeweils besten Eigenschaften der regel-, wissens- und Featurebasierten Bearbeitung und kombiniert diese in einer schnellen, zuverlässigen und hochautomatisierten Lösung für die Bearbeitung von Volumenmodellen.
  - Somit werden die erzeugten Bearbeitungen ganz auf die firmenspezifischen Anforderungen zugeschnitten.

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Attachment 5: Statement of costs for CAM system upgrade and tool database TRP (2/5), source: Magna Powertrain

MAGNA

2 Dienstleistungen

2.1 VANC™- Überführung der Werkzeugdaten aus Ihrem bestehenden VANC Werkzeugkatalog in die Betriebsmitteldatenbank TRP.

Der bisherige Werkzeugkatalog steht nun als firmenübergreifende Betriebsmittel- Datenbanklösung unter der Produktbezeichnung TRP (Tool Resource Planning) zur Verfügung. Dieses Produkt ermöglicht mit geringem Einführungsaufwand das Management aller Betriebsmittel mit automatischer Werkzeugsynthese und Anbindung an das NC- System.

Durch das Update des Werkzeugkataloges steht Ihnen die Betriebsmitteldatenbank **TRP** zur Verfügung.

Im Rahmen der Dienstleistung werden die Daten aus Ihrem NC- Werkzeugkatalog in die Betriebsmitteldatenbank TRP überführt. Bei dieser Konvertierung werden nach Zusendung der entsprechenden Files an ECS von unseren Supportmitarbeitern alle Daten übernommen. Bis auf vereinzelte Anpassungen der Dialogtexte an die neue Eingabetechnologie sind vom Kunden keine weiteren Aufwendungen notwendig.

Hinweise:

- Voraussetzung für eine einwandfreie Funktion der Betriebsmitteldatenbank TRP ist eine MS-ACCESS Lizenz (vorzugsweise MS- Access 2000 oder höher) auf dem entsprechenden Arbeitsplatz bzw. Microsoft SQL Server 2014
- Die Übernahme von Werkzeugdaten ins VANC- System ist in der Basislizenz beinhaltet.
- Exportmodule für Fremd CAD- oder PPS- Systeme sowie Importschnittstellen für herstellerspezifische Daten werden gerne projektbezogen angeboten.
- Bei Auswahl der Klasse Messerkopf können nicht automatisch die dazugehörigen Wendeplatten (Folgeteil) geladen werden

2.2 VANC™- Dienstleistung Installation und Einweisung TRP vor Ort

Zum effizienten Hochlauf der neuen Werkzeugdatenbank empfehlen wir eine Anwendereinführung, sowie eine Unterweisung für jene Personen, die bisher mit der Wartung und Betreuung des bestehenden Werkzeugkataloges beauftragt waren.
Für diesen Hochlauf empfehlen wir inklusive Installation und Einspielung der überführten Altdaten 2 Manntage.

2.3 VANC™- Dienstleistungen Update und Einweisung DBF V11

Damit eine optimale Integration und durch eine Unterweisung der Mitarbeiter eine effiziente Anwendung der Version V11 in Ihrem Betrieb gewährleistet ist, empfehlen wir zwei Tage Dienstleistung vor Ort. Darin ist auch die Updateinstallation DBF enthalten.

2.4 Überführung Gesamtwerkzeuge

Um Gesamtwerkzeuge vom alten WZ-Katalog in den TRP zu überführen, muss ein DBF-Bauteil(e) mit Gesamtwerkzeugen zur Verfügung gestellt werden wo diese entnommen werden können.

2.5 Überführung der Werkzeugdaten aus ihrem bestehenden Werk-……€ 4.900.- -zeugkatalog in die Betriebsmitteldatenbank

2.6 VANC™- Dienstleistung Einweisung TRP 2 MT vor Ort………………€ 2.300.-

2.7 VANC™- Dienstleistung Einweisung DBF V11 3 MT vor Ort…………€ 3.450.-

2.8 VANC™- Dienstleistung Überführung Gesamtwerkzeuge……………€ 2.300.-

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Attachment 6: Statement of costs for CAM system upgrade and tool database TRP (3/5), source: Magna Powertrain

SpaceClaim Engineer Einzelplatz...€ 3.310.-

Standard Funktionen

Import von 2D Zeichnungen aus DWG/DXF Format
als Grundlage zur Erstellung von 3D Modellen oder
zur Änderung von bestehenden Geometrien.
Konstruktion von Flächen- und Volumenmodellen
sowie Baugruppen.

2D Zeichnungsableitung inklusive Stücklistenerstellung.
Vermessen und Analysieren von Solid- und Flächenmodellen.

Beinhaltet ein Plug-In für die direkte Integration in Rhinoceros

Wiederverwendung von bestehenden Flächen und CAD Daten
für die Erstellung korrekter Volumenmodelle für nachfolgende CAD Bearbeitungen

gängige Austauschformate (Engineer)

ACIS, STEP, IGES, ECAD, Rhinoceros®, CGR, DWG, DXF,
STL, OBJ, XAML, VRML und
3D PDF (benötigt Adobe® Acrobat® 9 Pro Extended)
Optional sind noch weitere Module für den Import nativer CAD-Daten verfügbar

SpaceClaim Doctor

automatische Reparaturfunktionen für Flächen-
und Volumenmodelle

Sheet Metal Modul

Mit dem Sheet Metal Module können Sie Blechteile
sowie Baugruppen importieren, erzeugen und bearbeiten

API Schnittstelle

zusätzlich eine Heim-Lizenz (nur mit gültigem Wartungsvertrag)

Sie erhalten zusätzlich eine "Watermarked Home Edition".
Diese Version können Sie auf Ihrem Heim-PC verwenden und
dort Bearbeitungen an SpaceClaim- Dateien fortsetzen.
Es stehen Ihnen dabei alle SpaceClaim Funktionen zur Verfügung,
allerdings können sie keine Volumenmodelle anderer Formate einlesen.

Internetanschluss

SpaceClaim benötigt zur Freischaltung einen
Internetanschluss mit Zugriff auf die SpaceClaim Webseite.

Brief-16

Seite 4 von 6

Attachment 7: Statement of costs for CAM system upgrade and tool database TRP (4/5), source: Magna Powertrain

MAGNA

Wartung/Jahr

01	VANC™-3-5 Achsen Paket Simultan Fräsen	€	1.710,00
01	VANC™- Maschinensimulation	€	540,00
01	VANC™- Werkzeug Korrekturpostprozessoren	€	135,00
01	VANC™- VANC™-Advanced Feature Recognition	€	360,00

1 ALLGEMEINES:

Das Angebot ist 30 Tage ab Angebotsdatum gültig.

Lieferung: 6 Wochen nach Eingang der schriftlichen Bestellung bzw. nach Absprache.
Zahlung: innerhalb von 30 Tagen ab Fakturadatum ohne Abzug.

Die Preise verstehen sich ab Werk, in EURO exkl. der gesetzlichen MWSt und exkl. Reisekosten und Spesen.

Im Übrigen gelten sinngemäß die Liefer- und Verkaufsbedingungen für die Kraftfahrzeugindustrie (auch Anhänger- und Karosseriebauende Industrie) – vom 01. Jänner 1969 in der Fassung vom 15. Februar 2010 und bei Softwareaufträgen die Allgemeinen Lieferbedingungen des Fachverbandes der Elektro- und Elektronikindustrie Österreichs, Ausgabe Oktober 2012.

1.1 Bestelladresse

ENGINEERING CENTER STEYR GmbH & Co KG
z.H. Fr. Ulrike Gradischnig
Teamassistentin Vertrieb
Steyrer Straße 32
A-4300 ST. VALENTIN
Tel.: +43 7435 501 2251
FAX: +43 7435 501 2255
E-Mail: ulrike.gradischnig@magna.com

Wir hoffen, dass dieses Angebot Ihrer Erwartung entspricht, und würden uns über ein gemeinsames Projekt sehr freuen

mit freundlichen Grüßen

MAGNA POWERTRAIN
ENGINEERING CENTER STEYR GmbH & Co Kg

iA Edin Ljubuncic
Manager Manufacturing Solutiond
Tel.: +43 7435 501 2279
Fax: +43 7435 501 2255
e-mail: edin.ljubuncic@magna.com

Alfred Höller
CAM Consulting & Support
Tel.: +43 7435 501 2268
Fax: +43 7435 501 2255
e-mail: alfred.hoeller@magna.com

Brief-16

Attachment 8: Statement of costs for CAM system upgrade and tool database TRP (5/5), source: Magna Powertrain

KELCH

BRP-Rotax GmbH & Co. KG
Herr Florian Zittmayr
Rotaxstr. 1

A – 4623 Gunskirchen

Bearbeiter: Massimo Brandone
Telefon: +49 (0) 7151/20522-23
E-Mail: Massimo.Brandone@kelchgmbh.de

Angebot Nr.: **AN16/003549**
Datum: 06.09.2016/Pa

Ref.: Alternativ zu Umrüstung Kalimat A56 #5169

Pos. Nr.	Artikelnr.	Beschreibung	Preis in €	*Alternativ Optional*
1	VK-V956-S	**VERTIKALES WERKZEUGEINSTELLGERÄT** **und Schrumpfgerät KENOVA set line V958-S** Messbereich: X = - 50 bis Ø 530 mm Z = 600 mm Grundgerät inkl. - CNC in X, Z und C-Achse - 4. messende Achse automatische Längeneinstellung - PC-Messelektronik EASY 24“ TFT Monitor - Bildverarbeitung MegaVision - Picture Start Workshop - MPS-Spindel Basismodul - Kühlmodul mit 3 Stationen - Kühleinsätze für i-tec Wekzeugschäfte Ø 6-32 mm	69.500,00	
2	1043288	Dampfabsaugung mit Aktivkohle-Ölabschneider		5.700,00
3	10387xx	Einstelladapter im Set Ø 6-32, 10 Stück	1.700,00	
4	1038730	TUL-Träger für Einstelladapter	98,00	
5	1044025	Längeneinstellpin PIN 1, HSK 63/80/100 Ø 14-32	90,00	
6	1044024	Längeneinstellpin PIN 2, HSK 63/80/100 Ø 6-12	90,00	
7	1044023	Längeneinstellpin PIN 1, SK40/SK50 Ø 14-32		90,00
8	1044022	Längeneinstellpin PIN 2, SK40/SK50 Ø 6-12		90,00
9	313.704	Aufnahmeflansch i-tec HSK 63	41,50	
10	313.712	Aufnahmeflansch i-tec SK 50		41,50
11	1041728	MPS-Einsatzmodul mit Segmentauflage HSK 63 A/C	1.900,00	
12	1041730	MPS-Einsatzmodul mit Segmentauflage SK 50		1.600,00
13	1028174	EASY Megavision: Reiben	2.100,00	
14	1033954	EASY Megavision: Teach In	3.500,00	
15	1064509	Postprozessor EASY, 2 Stück á € 600,-	1.200,00	
16	1066539	2. Monitor 17“ für separates Schneidenbild		1.500,00
17	1043443	Etikettendrucker Dymo	189,00	
18	1068123	Laserdrucker	390,00	
19	1067480	MPS-Handgriff	85,00	

Kelch GmbH·Werkstraße 30·71384 Weinstadt·Tel.: +49 (0)7151 / 20522-0·Fax +49 (0)7151 20522-11·E-Mail: info@kelchgmbh.de
Geschäftsführer: Dipl..-Betriebswirt Frank Wildbrett · HRB 733 476 Stuttgart · USt-IdNr. DE269897911· Steuer-Nr. 90493/40070
Volksbank Schwäbisch Gmünd · BLZ 613 90140· Konto 112460003 · SWIFT Adresse: GENO DES1VGD · IBAN: DE98 6139 0140 0112 4600 03

Attachment 9: Statement of costs for new pre-setting machine of the company Kelch (1/2), source: Kelch GmbH

KELCH

20	1007543	Scheidkantenreiniger	9,50	
21	127.100	TUL-Träger für MPS-Einsätze, 2 Stück	90,00	
		Gerätepreis	**80.983,00**	
		Gerätepreis abzgl. 20 % Rabatt	**64.786,40**	
		Dienstleistungen		
22	D-1002	Inbetriebnahme des Einstellgerätes 1 Tag beim Kunden vor Ort	1.280,00	
23	D-1006	1 Tag Schulung am Folgetag der Inbetriebnahme	1.100,00	
		Endpreis	**67.166,40**	

Seite 2 von 10 Angebot-Nr. AN16/003549

Kelch GmbH·Werkstraße 30·71384 Weinstadt·Tel.: +49 (0)7151 / 20522-0·Fax +49 (0)7151 20522-11·E-Mail: info@kelchgmbh.de
Geschäftsführer: Dipl..-Betriebswirt Frank Wildbrett · HRB 733 476 Stuttgart · USt-IdNr. DE269897911· Steuer-Nr. 90493/40070
Volksbank Schwäbisch Gmünd · BLZ 613 90140· Konto 112460003 · SWIFT Adresse: GENO DES1VGD · IBAN: DE98 6139 0140 0112 4600 03

Attachment 10: Statement of costs for new pre-setting machine of the company Kelch (2/2), source: Kelch GmbH

KELCH

KELCH GmbH Postfach 21 20 71380 Weinstadt-Endersbach

BRP-Rotax
GmbH & Co. KG
Anton Stranzinger-Mayrhauser
Rotaxstraße 1
4623 Gunskirchen
Österreich

Seite 1/3

Angebots-Nr.:	**AN16/003994**
Datum:	07.10.16
Kunden-Nr.:	1113787
USt-IdNr.	ATU53018309
Ihr Verkäufer:	Brandone, Massimo
Telefon:	+49(7151)20522-23
E-Mail:	massimo.brandone@kelchgmbh.de

Angebot
Bestell-Nr.:
Referenz: Email 06.09.16 / Kalimat A56 #5169

Pos.	Artikel-Nr. Bezeichnung	Termin Warenausgang	Menge/ME	Preis/ME EUR	Rab. %	Gesamt EUR
10	**SONDER EG** Sonderartikel EG Upgrade Kalimat A56 #5169, Baujahr 2000 Neuer PC, Software update und neue Firewire Kamera inkl.: - Softwareupdate von Easy V5.1.0 auf Easy V7-Win7 - Update Picture Start Workshop - Update Picture Start Reiben - IPC i3-3220, 2x3 Ghz, 4 GB, Win7 - 24" TFT Monitor inkl. Halterung - Tastatur, Maus, Stick, Dongle - Zählerkarten f. X, C, Z-Achsen - Umrüstkit Antriebsbox f. X, Z, C-Achsen - Neue Firewire Kamera inkl. Halterung . Alte Messabläufe können zwar übernommen werden, sind ausführbar, aber nicht mehr änderbar und nur in der vorherigen Kameraauflösung 4x4 mm Messfenster. Die Messfenster müssen manuell, bei jeder Messung neu angepasst werden, oder alle Messabläufe müssen neu erstellt werden! Teachin ist notwendig. Erst dann können neue in der Kameraauflösung im 7x7mm Messfenster erstellt werden. .		1 ST	20.450,00		20.450,00
20	Option **1033954** Easy-Teach In		1 Stück	(3.500,00)	(20,00)	(2.800,00)
30	Option **1013821** IS-Balluff Hardwareteile A5 2Kanal inkl.1xLesekopf+V-24 Leitung+		1 Stück	(4.000,00)	(20,00)	(3.200,00)

Kelch GmbH · Werkstr. 30 · 71384 Weinstadt · Tel.: +49 (0) 71 51 / 2 05 22-0 · Fax: +49 (0) 71 51 / 2 05 22-11 · info@kelchgmbh.de · www.kelch.de
Geschäftsführer: Dipl.-Betriebswirt Frank Wildbrett · HRB 733 476 Stuttgart · Ust.-IdNr.: DE269897911 · St.-Nr.: 90493 / 40070
UniCredit Bank AG Stuttgart · SWIFT-Adresse: HYVEDEMM473 · IBAN: DE14 6002 0290 0015 9347 86
Volksbank Schwäbisch Gmünd · SWIFT-Adresse: GENO DES1VGD · IBAN: DE98 6139 0140 0112 4600 03

Attachment 11: Statement of retrofit costs for an AutoID system at the pre-setting machine Kelch Kalimat a (1/2), source: Kelch GmbH

KELCH

Seite 2/3

Angebots-Nr.: **AN16/003994**
Datum: 07.10.16

Pos.	Artikel-Nr. / Bezeichnung	Termin / Warenausgang	Menge/ME	Preis/ME EUR	Rab. %	Gesamt EUR
	24V-Netzteil+Software lesen/schreiben Größe: BIS-C-600,KslV3-5,SI/KA- C + E					
40	Option **1046877** IS-Lesekopf autom. Zustellung Kalimat A,USB		1 Stück	(2.100,00)	(20,00)	(1.680,00)
50	Option **1064511** TDS-Format Easy max. Softwareaufwand 2MT		1 Stück	(1.300,00)	(20,00)	(1.040,00)
60	**D-1002** Inbetriebnahme, erster Tag inkl. Reisekosten - Termin nach Vereinbarung - - Jeder weitere Tag 1.100,00 EUR . Lieferzeit: ca. 4-6 Wochen		1 Stück	1.280,00		1.280,00
				Total EUR		**21.730,00**

Lieferbedingung: EXW 71384 Weinstadt Germany

Lieferadresse:
BRP-Rotax
GmbH & Co. KG
Rotaxstraße 1
4623 Gunskirchen
Österreich

Rechnungsadresse:
BRP-Rotax
GmbH & Co. KG
Rotaxstraße 1
4623 Gunskirchen
Österreich

Zahlungsbedingungen: 30 Tage netto

Kelch GmbH · Werkstr. 30 · 71384 Weinstadt · Tel.: +49 (0) 71 51 / 2 05 22-0 · Fax: +49 (0) 71 51 / 2 05 22-11 · info@kelchgmbh.de · www.kelch.de
Geschäftsführer: Dipl.-Betriebswirt Frank Wildbrett · HRB 733 476 Stuttgart · Ust.-IdNr.: DE269897911 · St.-Nr.: 90493 / 40070
UniCredit Bank AG Stuttgart · SWIFT-Adresse: HYVEDEMM473 · IBAN: DE14 6002 0290 0015 9347 86
Volksbank Schwäbisch Gmünd · SWIFT-Adresse: GENO DES1VGD · IBAN: DE98 6139 0140 0112 4600 03

Attachment 12: Statement of retrofit costs for an AutoID system at the pre-setting machine Kelch Kalimat a (2/2), source: Kelch GmbH

Angebot 16.55.1888-1 für Kunde BRP-Powertrain GmbH & Co KG, AT-4623 Gunskirchen

G-BAUREIHE SERIE G550

Eine detaillierte Beschreibung der einzelnen Positionen finden Sie in der beiliegenden technischen Beschreibung.

Technische Änderungen vorbehalten

			Einzelpreis €	Stück	Gesamtpreis €
		Paletten-Speicher-Systeme PSS			
44	G551-PSS001	Paletten-Speicher-System PSS-R5	149.900 €		
45	G551-PSS002	Paletten-Speicher-System PSS-R10	159.900 €		
46	G551-PSS003	Paletten-Speicher-System PSS-R13	164.900 €		
47	G000-KSS609	Ausblaspistole am Rüstplatz	450 €		
48	G551-WSS009	Werkstück-Spannsystem, Rüstplatz des Paletten-Speichersystems	13.100 €		
49	G551-PSS004	Paletten-Speicher-System PSS-L10	205.170 €		
		Steuerungsoptionen			
50	G000-CNC008	Maschinensteuerung HEIDENHAIN iTNC 530	3.050 €		
51	G000-CNC009	Voller Funktionsumfang smarT.NC, DXF-Import (HEIDENHAIN)	870 €		
52	G000-CNC015	Schwenkachsenkalibrierung GSC	2.540 €		
53	G000-CNC011	Kollisionsüberwachung DCM Collision (HEIDENHAIN)	1.100 €		
54	G000-CNC016	Maschinensteuerung SIEMENS SINUMERIK 840D sl	0 €	**1**	**0 €**
55	G000-CNC014	Programm zum Erstellen eines automatischen Spannablaufs	1.780 €	**1**	**1.780 €**
56	G000-CNC010	Interpolationsdrehen PLUS	5.830 €		
57	G000-CNC005	Energie-Effizienz-Paket EEP	990 €	**1**	**990 €**
58	G000-CNC006	Maschinensteuerung FANUC 30i-MODELL B	0 €		
59	G000-CNC001	3D–Kollisionsüberwachung 3DIF (FANUC)	1.380 €		
60	G000-CNC007	GROB-Prüfmittel zur Kinematikvermessung	2.070 €		
		Zubehör			
61	G000-WZM005	Werkzeugreinigungseinrichtung	1.900 €	**1**	**1.900 €**
62	G000-WZM006	Werkzeugcodierung, System BALLUFF	6.070 €		
63	G000-WZM007	Elektromechanische Werkzeuglängenprüfeinrichtung	3.840 €	**1**	**3.840 €**
64	G000-WZM008	Lasermesssystem LaserControl NT für Fräswerkzeuge	9.050 €		
65	G000-ZUB003	Vorbereitungen für die Verwendung des Messtasters M&H IRP25.50	3.180 €		
66	G000-ZUB004	Vorbereitungen für die Verwendung des Messtasters Heidenhain TS	3.180 €		
67	G000-ZUB005	Vorbereitungen für die Verwendung des Messtasters Renishaw OMP60	3.180 €		
68	G000-ZUB006	Vorbereitungen für die Verwendung des Messtasters Renishaw RMP600	3.920 €		
69	G000-ZUB007	Messtaster M&H IRP25.50 (einschließlich der Vorbereitungen)	5.130 €		
70	G000-ZUB008	Messtaster Heidenhain TS 640 (einschließlich der Vorbereitungen)	5.980 €		
71	G000-ZUB009	Messtaster Renishaw OMP60 (einschließlich der Vorbereitungen)	5.120 €	**1**	**5.120 €**
72	G000-ZUB010	Messtaster Renishaw RMP600 (einschließlich der Vorbereitungen)	7.940 €		
73	G000-KSS602	Druckluftzufuhr durch die Spindelmitte	2.310 €		
74	G000-KSS603	Äußere Druckluftzufuhr über einen flexibel einstellbaren Schlauch	1.770 €		
75	G000-KSS604	Erhöhter Druck auf den äußeren Kühlschmierstoffdüsen	1.840 €	**1**	**1.840 €**
76	G000-KSS610	Spülpistole am Arbeitsraum	450 €	**1**	**450 €**
77	G000-KSS608	Ausblaspistole am Arbeitsraum	450 €	**1**	**450 €**
78	G000-CNC003	Bedienhandgerät HT8	2.510 €	**1**	**2.510 €**
79	G000-CNC004	Elektronisches Handrad HR 520 (HEIDENHAIN)	2.480 €		
80	G000-CNC002	Bedienhandgerät HMO Panel (FANUC)	2.120 €		
81	G551-GMA013	Dezentrale Arbeitsraum-Absauganlage: 800 m³	4.850 €	**1**	**4.850 €**
82	G000-ZUB001	Maschinenzustandsleuchte	830 €		
83	G000-GMA010	Paket zum Erhöhen der Maschinengenauigkeit	8.400 €		
84	G000-KSS302	Kühlschmierstoff-Hochdruckanlage (5-38 bar, IKZ)	7.450 €		
85	G000-KSS303	Kühlschmierstoff-Hochdruckanlage (10-80 bar, IKZ)	11.650 €	**1**	**11.650 €**
86	G000-KSS601	Kühlaggregat für die Kühlschmierstoff-Hochdruckanlage	14.250 €	**1**	**14.250 €**
87	G000-KSS606	Ölskimmer zur Kühlschmierstoff-Pflege	1.480 €		
88	G000-KSS605	Kühlschmierstoff-Umwälzung an Wochenenden	1.630 €		
89	G000-KSS607	Spüleinrichtung für den Boden des Arbeitsraums	1.120 €		
90	G000-KSS612	Zusatz-Spüleinrichtung für die Aluminium-Volumenzerspanung	2.820 €		
91	G000-KSS502	Scharnierband-Späneförderer, Abwurfhöhe 1.100 mm	13.970 €		
92	G551-GMA007	Arbeitsraumtür, automatisch, für automatische Be-/Entladesysteme	4.400 €		
93	G551-GMA017	Arbeitsraumtür, automatisch, für manuelles Be-/Entladen	8.300 €		
94	G551-PWS005	Rüstplatztür, automatisch, für automatische Be-/Entladesysteme	2.520 €		
95	G551-PWS006	Rüstplatztür, automatisch, für manuelles Be-/Entladen	6.400 €	**1**	**6.400 €**

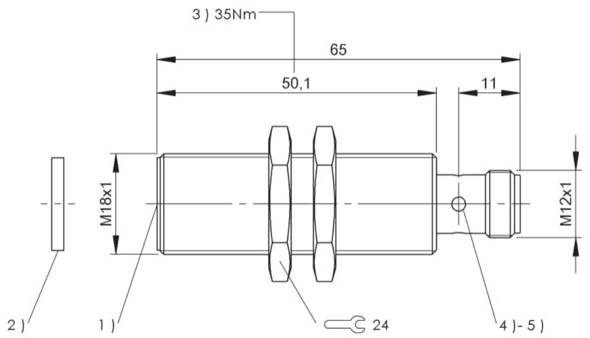
2 / 6

Attachment 13: Additional costs for an AutoID system at the manufacturing machine Grob G550, source: Alfleth Engineering AG

Schreib-/Lesekopf

BIS VM-332-401-S4
Bestellcode: BIS015P

BALLUFF
sensors worldwide



1) aktive Fläche 2) Datenträger 3) Anzugsmoment 4) LED (CP) 5) LED (Power)

- **rund**
- **bündig**

CE

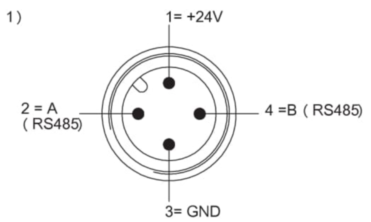
Allgemeine Merkmale	
Zulassungen / Konformität	CE
Schutzart nach IEC 60529	IP67
Funktionsanzeige	Power (AN), LED grün CP (Code present), LED gelb Operating, LED gelb blinkend
MTTF (40°C)	212 a
Elektrische Merkmale	
EN300330-1	Power Class 5
EN301489-1/-3	Klasse B
EN61000-4-2/3/4/5/6	Schärfegrad 2A/2A/4A/-/2A
Lesekopfanschluss	4-pol. Stecker
Mechanische Merkmale	
Antennenform	rund
Anwendungsgewicht	60.00 g
Dauerschockbeanspruchung	EN 60068 Teil 2-29
Durchmesser d1	M18x1
Einbauart in Stahl	bündig
Freier Fall	EN 60068 Teil 2-32

Lagertemperatur	-20 °C ... +85 °C
Länge	65 mm
Umgebungstemperatur Ta max.	70 °C
Umgebungstemperatur Ta min.	0 °C
Werkstoff Gehäuse	CuZn, Weißbronze Beschichtung
Werkstoff Gehäuse Zusatz	Muttern CuZn mit Weißbronze

Bemerkungen
Nur in Verbindung mit BIS VM-6xxx
Bei Erstausstattung: Zubehör siehe www.balluff.com
Zur Montage beigefügte Muttern und Befestigungsklammern verwenden.
Werte wenn nicht anders angegeben unter Nennbedingungen.

Weitergehende Informationen zu MTTF bzw. B10d siehe MTTF / B10d Zertifikat

Die Angabe des MTTF- / B10d-Wertes stellt keine verbindlichen Beschaffenheits- und/ oder Lebensdauerzusagen dar; es handelt sich lediglich um Erfahrungswerte ohne bindenden Charakter. Durch diese Wertangaben wird auch nicht die Verjährungsfrist von Mängelansprüchen verlängert oder sonst in irgend einer Form beeinflusst.



1) Ansicht in Steckrichtung

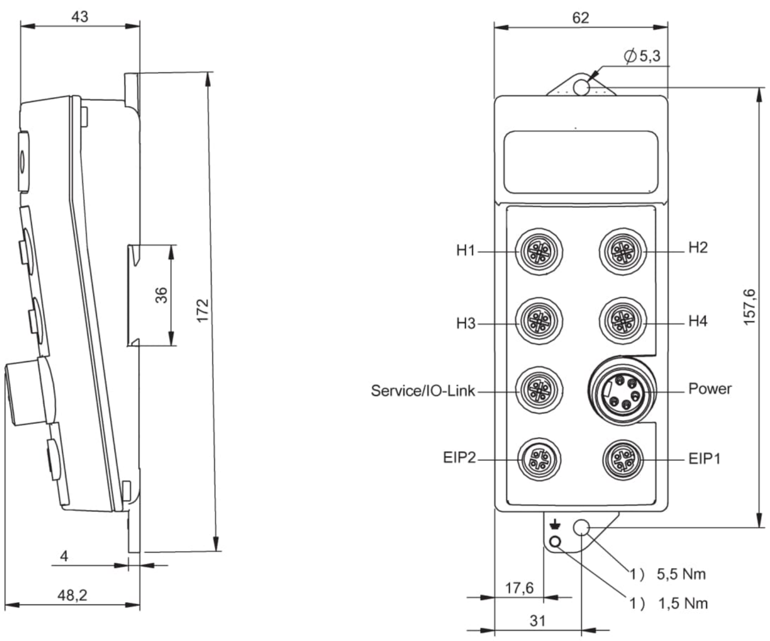
Internet	www.balluff.com	Begriffsbestimmungen siehe Hauptkatalog	BIS015P_244461_14/06/16	1(3)
Balluff Germany	+49 (0) 7158 173-0, 173-370	Änderungen vorbehalten		
Balluff USA	1-800-543-8390			
Balluff China	+86 (0) 21-50 644131			

Attachment 14: Datasheet of the Balluff reading and writing head, source: Balluff GmbH

Auswerteeinheit

BIS V-6106-034-C002
Bestellcode: BIS012F

BALLUFF
sensors worldwide



1) Anzugsmoment

■ **Ethernet**

Allgemeine Merkmale	
Zulassungen / Konformität	CE
Schutzart nach IEC 60529	IP65 (mit Steckern)
Funktionsanzeige	Link/ Activity, LED grün Ready, LED grün Network Status, LED grün/rot Module Status, LED grün/rot
Elektrische Merkmale	
Anschluss EIP1	EtherNet/IP-Teilnehmer: Einbaubuchse 4pol. D-codiert
Anschluss EIP2	EtherNet/IP-Teilnehmer: Einbaubuchse 4pol. D-codiert
Anschluss Service/IO-Link	Einbaubuchse 5 pol. A-kodiert
Betriebsspannung Vs	24 V DC LPS Class 2
Geräteschnittstelle	EtherNet/IP
IO-Link	max. 500 mA
Restwelligkeit	≤ 10 %
Stromaufnahme (bei 24 V DC)	≤ 2 A

Mechanische Merkmale	
Anschluss Power	Vs 24 VDC: Einbaustecker 5 pol. 7/8"
Anwendungsgewicht	750.00 g
Breite 1	50.00 mm
Dauerschockbeanspruchung	EN 60068 Teil 2-29
EN55016-2-3	EN61000-6-4
Freier Fall	EN 60068 Teil 2-32
Höhe	62.00 mm
Lesekopfanschlüsse	H1,H2,H3,H4 4xEinbaubuchse 5 pol. Für alle VM-3/VL-3… mit Stecker 4pol.
Länge	170 mm
Umgebungstemperatur Ta max.	60 °C
Umgebungstemperatur Ta min.	0 °C
Werkstoff Gehäuse	GD-Zn

Zusatztext
Bei der Installation sind die technischen Normen und Vorschriften

der entsprechenden Länder zu beachten.
Werte wenn nicht anders angegeben unter Nennbedingungen.

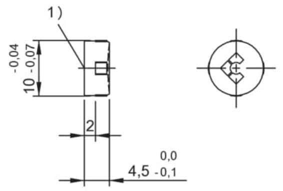
Internet	www.balluff.com	Begriffsbestimmungen siehe Hauptkatalog	BIS012F_233570_22/09/15	1(3)
Balluff Germany	+49 (0) 7158 173-0, 173-370	Änderungen vorbehalten		
Balluff USA	1-800-543-8390			
Balluff China	+86 (0) 21-50 644131			

Attachment 15: Datasheet of the Balluff processing unit, source: Balluff GmbH

Datenträger

BIS M-122-02/A
Bestellcode: BIS004A

BALLUFF
sensors worldwide



1) aktive Fläche

- **Datenträger**
- **2000 Byte**

CE

Allgemeine Merkmale	
Zulassungen / Konformität	CE
Schutzart nach IEC 60529	IP67
Elektrische Merkmale	
Datenerhaltungszeit / Jahre	≥ 10 bei 55 °C
EN55022	Gr.1,Kl.B
EN61000-4-2/3/4/5/6	Schärfegrad 4A/3A/-/-/-
Lesezeit	User ID für 8 Byte: 0,02s für 16 Byte: 0,030s
Lesezyklen	unbegrenzt
Programmierzeit	für 16 Byte: 0,060s
Programmierzyklen	≥ 10.000.000.000
Speicherkap. lesen/schreiben	2000 Byte
Speicherkapazität nur lesen	8 Byte
Speicherorganisation	250x8 Byte
Mechanische Merkmale	
Antennenform	rund

Anwendungsgewicht	1.50 g
Dauerschockbeanspruchung	EN 60068 Teil 2-29
Durchmesser d1	Ø10 mm
Einbauart in Stahl	bündig
Freier Fall	EN 60068 Teil 2-32
Höhe	4.50 mm
Lagertemperatur	-25 °C ... +85 °C
Umgebungstemperatur Ta max.	70 °C
Umgebungstemperatur Ta min.	-25 °C
Werkstoff Gehäuse	PA12
Werkstoff Gehäuse Zusatz	PU Verguss

Zusatztext
Zeitangabe inklusive Datenprüfung.
Einsatzbedingungen siehe entsprechender Schreib-/Lesekopf.
Nur in Verbindung mit dem dafür geeigneten Schreib-/Lesekopf.
Werte wenn nicht anders angegeben unter Nennbedingungen.
Schlagbeanspruchung ist nicht zulässig.

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Begriffsbestimmungen siehe Hauptkatalog BIS004A_155416_20/07/15 1(1)
Änderungen vorbehalten

Attachment 16: Datasheet of the Balluff Bis M RFID tag, source: Balluff GmbH