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# Industrie 4.0:
# Potentials of Smart Factory Approaches for an Automotive Supplier

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# Kurzfassung


Seit den 1980er Jahren haben wir miterlebt wie die erste Welle der IT-Technologie zur Erreichung vollautomatisierter Anlagen in Fabriken integriert wurde, welche auch als Computer Integrated Manufacturing (CIM) bekannt ist.

Die Vision bestand darin, dass die Kosten- und Qualitätsprobleme zukünftig in Fabriken ohne menschliche Arbeitskraft auf Basis modernster Computer-Technologien gelöst werden können.
Jedoch hat sich in der Realität die Informatik und Informationstechnik in der Fertigungsindustrie anders entwickelt als man es sich vorgestellt hat. Wir sind heute noch immer weit davon entfernt diese Visionen umzusetzen. Vielleicht ist es auch nicht erforderlich diese Ziele zu erreichen, da sich die Vollautomatisierung als zu unflexible, fehleranfällig und zu kostspielig in der Wartung herausgestellt hat.

Zu Beginn der 90er Jahre wurde die „Lean Production" von Toyota zum ersten Mal der westlichen Industrie präsentiert. Seither wird die Vision der Zukunft mit dem Begriff „Lean" in Verbindung gebracht, nicht nur in Bezug auf Organisation, sondern auch in Bezug auf Planung und Technologie. Zusätzlich steigt die Kundennachfrage nach qualitativ hochwertigen Produkten zu günstigeren Konditionen und einer schnellen Lieferung. Der globale Konkurrenzdruck steigt dramatisch und der Wettbewerb im industriellen Fertigungssektor wird ständig härter. Durch die allgemeinen Verbesserungen und Optimierungen werden die Automatisierungssysteme in der Produktion nicht nur komplizierter und unflexibler, sondern sie führen auch in die entgegengesetzte Richtung, zur vorhin erwähnten „Lean Production".

Es ist an der Zeit für eine genauere Betrachtung, wie wir einen weiteren Quantensprung in unseren Fertigungstechnologien machen können, ohne in den Wechselzyklus von Verbesserung und Komplexität zu verfallen. Um diese Anforderungen zu erfüllen müssen die Fertigungsanlagen in immer kürzer werdenden Intervallen und Zeitfenstern ausgelegt und umgebaut werden. Daher muss die zukünftige Fabrik hoch adaptive, flexibel und rekonfigurierbar sein.

Die industriellen Automatisierungssysteme der Fertigungsanlagen bilden das zugehörige Schlüsselelement, welche hauptsächlich durch die Entwicklung der Informatik sowie Informations- und Kommunikationstechnologie, mit dem Ziel, mit geringem Aufwand die nahtlose Adaption zwischen Organisation und Technik zu erreichen, vorangetrieben werden.
Für die Industrieautomatisierung werden hier zwei Grundkonzepte zur Entwicklung solcher Steuerungs-Paradigmen herangezogen: Cyber-physische Systeme (CPS) und Service-orientierte Architekturen (SOA).

Cyber-physische Systeme (CPS) werden als ein neues Maß an Flexibilität, Interoperabilität und Anpassungsfähigkeit innerhalb von Automatisierungssystemen behandelt.

Service-orientierte Architekturen (SOA) werden als integrierter Ansatz beschrieben, welche zur Implementierung einer umfassenden vertikalen und horizontalen Integration von Softwarekomponenten geeignet sind.

Diese Konzepte und/oder Strategien bilden die Grundlage von Industrie 4.0.

Industrie 4.0 verfügt über enorme Potentiale.

In dieser Arbeit werden die Potentiale von Industrie 4.0 für einen Automobilzulieferer analysiert. In weiterer Folge wird der Fokus auf Maschinenstörungen in der Produktion, zur Steigerung der Gesamtanlageneffektivität bzw. „Overall Equipment Effectiveness“ (OEE), welches einer der Hauptziele von „Total Productive Maintenance“ (TPM) aus dem Blickwinkel von Industrie 4.0 darstellt, gelegt.

Zu diesem Zweck wird die Kapazitätsauslastung bzw. „Capacity Utilization” (CU), welche eine wichtige Leistungskennzahl bzw. „Key Performance Indicator” (KPI) des Unternehmens ist, vorgestellt.

Industrie 4.0 implementiert eine digitale horizontale Integration durch die Wertschöpfungsnetzwerke, „End-to-End“, vom Engineering über die gesamte Wehrschöpfungskette, sowie eine vertikale digitale Integration von vernetzten Fertigungssystemen.

In dieser Arbeit wird auch eine Industrie 4.0 Architektur vorgestellt, sowie die optimale Verbindung zwischen Materialfluss und Informationsfluss mithilfe einer Wertstromanalyse veranschaulicht. Es wird eine Lösung aus dem Blickwinkel von Industrie 4.0 vorgestellt und anhand einer Kapazitätsauslastungs-Grafik bzw. „Capacity Utilization” (CU) Grafik dargestellt. Durch die Eliminierung der überflüssigen Elemente aus den bestehenden Prozessen und durch den Einsatz der Lösungsvorschläge kann schlussendlich eine schlanke Fertigung erreicht werden.

*Stichwörter:* Industrie 4.0, potentials, CPPS, Industrial automation, VSM, CU.

# Abstract

Since the 1980's, the first wave of IT technologies has been witnessed to integrate into factories for achieving fully automated plants, which is known as computer integrated manufacturing (CIM). Its vision is in the desired factories with no workers for solving cost and quality problems on the basis of state-of-the-art computer technology. However, the progress and development of computer science and information technology in the manufacturing industry on reality are quite others as imagined. Today, we are still far away from this vision and maybe we will never need to achieve it because the full automation was proven as inflexible, error-prone and expensive to maintain.

At the beginning of the 90's, lean production from Toyota has firstly been explained to the western industry. Since then the vision of the future must become "lean" is formulated up, not only in organization, but also in planning and technology. Additionally, the customer is increasingly asking a high quality product at a lower price and quick delivery, and the global competition is dramatically becoming fiercer and fiercer in the manufacturing engineering sector. The general improvement and/or optimization are leading the automation system in the production not only more and more complicated and inflexible but also in the opposite direction of lean production mentioned. It is the time to take into account how to make a quantum leap in our manufacturing plants, but not a cycle between improvement and complexity. In order to fulfill these requirements manufacturing companies have to setup and configure their production plants in ever-shorter time intervals and time frames.

Therefore, the future factory must be highly adaptive, flexible and reconfigurable and so on. For those purpose, the key enabler is required. It is the industrial automation system of the future factory that is mainly driven by the development of computer science and information and communication technologies, and aims to accomplish the seamless adaptation between organization and technique with low effort.

The two concepts here are used to develop such a control paradigm for industrial automation: Cyber-Physical System (CPS) and Service-oriented Architecture (SOA). Cyber-Physical System (CPS) is treated as a new level of flexibility, interoperability, and adaptability within automation systems. Service-oriented Architecture (SOA) is depicted as one integrated approach that is able to implement a highly vertical and horizontal integration of the software components. Those concepts and/or strategies are noted as Industrie 4.0.

Industrie 4.0 holds huge potentials.

In this paper, the potentials of Industie 4.0 for an automotive supplier is analyzed, and further specially focus on the disturbances of machines in the production in order to increase Overall Equipment Effectiveness (OEE) that is the main objective of total productive maintenance (TPM) in the point view of Industrie 4.0. For this purpose, Capacity Utilization (CU), which is one of the Key Performance Indicators (KPIs) at company, is introduced.

Industrie 4.0 implements horizontal integration through value networks, end-to-end digital integration of engineering across the entire value chain, and vertical integration and networked manufacturing systems.

The paper shows also one Industrie 4.0 architecture and the best connection between material flow and information flow (value stream mapping). The solution is given in point view of Industrie 4.0 and is depicted by the graphic of Capacity Utilization (CU).

Finally, the lean manufacturing can be accomplished because all the wastes are eliminated in all the processes via adopting the given solution.

*Keywords:* Industrie 4.0, potentials, CPPS, Industrial automation, VSM, CU.

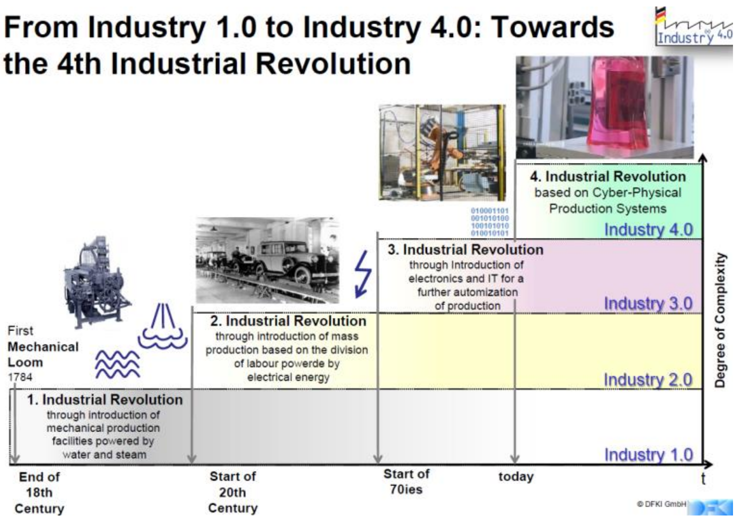
# Preface

Nowadays the manufacturing companies feel gradually trampled by the relentless march of technology. The rapid development of computer science and information and communication technology make the modern manufacturing companies facing grave challenges, such as the products need to be more individualized and be offered in more variants, they must be adjusted to the market requirements in shorter time, the product life cycles are shorter than ever before and the global competition ever stronger. To rise to the challenges and gallop ahead in the race to develop new technology manufacturers have been struggling to find ways to implement the flow or continuous production without stocks. Since the manufacturers have firstly known lean manufacturing derived mostly from the Toyota Production System (TPS) and identified as "lean" only in the 1990s, they have already started to think of how to achieve “lean” - not only in organization, but also in planning and technology. But the reality is cruel. The most manufacturing companies have not yet to achieve completely lean production in their factories. One of the popular words for improving production is optimization. The result is the increasing complexity in structures and control systems, which result in an inflexible monolithic production system. The more we do the research on improving our product structures and control management in our products, the more complexity and inflexibility come to production plant. But the future must become “lean! Lean means reducing complexity, avoiding waste technologies and information and strictly supporting the humans in their daily work.

Thus, from now on we must start to take into account how to make a quantum leap in our manufacturing plants, but not a cycle between improvement and complexity. We must develop technologies which could radically help us to speed up planning and setup, to adapt to rapid product changes during operation, to reduce the planning effort, and to radically implement continuous production beyond any consideration of inventory. Therefore, a new industrial control system providing a high interoperability and adaptability of networked automation devices is necessary.

Western civilization has already witnessed three industrial revolutions, now the fourth industrial revolution is on its way. Even it looks not really like general revolution because it changes slow and steady. Nevertheless, it is gathering more and more momentum and also can be described as disruptive leaps in industrial processes resulting in significantly higher productivity.

The term Industrie 4.0 was first used in 2011 at the Hanover Fair (Kagermann & Lukas, 2011). In October 2012 the Working Group on Industrie 4.0 chaired by Dr. Siegfried Dais (Shareholder of Robert Bosch Industrietreuhand KG) and Prof. Henning Kagermann (President, acatech), the working group drafts strategic recommendations for implementing measures to strengthen Germany as a high-tech industrial location (Kagermann et al., 2013). On 8 April 2013 at the Hanover Fair the final report of the Working Group Industrie 4.0 was presented (Kagermann et al., 2013). The term Industrie 4.0 refers to the fourth industrial revolution. The first three industrial revolutions came about as a result of mechanization, electricity and IT, see the Figure below (Wahlster, 2012, P. 3). More basic information is can be seen in chapter 1.1 in terms of definition, vision, and concepts of Industrie 4.0, and in chapter 2.1 in terms of architecture, status quo, and potentials of Industrie 4.0.




The four stages of the industrial revolution (Wahlster, 2012)

Its essential concepts include ubiquitous and/ or pervasive computing, and/ or ambient intelligence for the manufacturing industry use that can be achieved via the shape of Cyber-Physical Systems (CPS) that will establish global networks that incorporate their machinery, warehousing systems and production facilities, and the abstract software architecture Service-oriented Architecture (SOA) that has been proven as a promising approach enables a high degree of reusability, flexibility and interoperability through whole traditional automation hierarchy. Those three items focus on only slightly different aspects of future information technology. CPS and SOA are specified in chapter 3. In this paper, they are treated no difference. It has also to be differentiated from smaller concepts, such as the Internet of Things (IoT), Cyber-Physical Systems (CPS), Smart Factory, Smart Production, Smart Product, which is mainly explained in chapter 2.1.1. In addition, it also has to be clear between the definitions of all types of sensors, such as sensors, smart sensors, integrated smart sensors, integrated smart sensor systems and wireless sensor network.

Industrie 4.0 holds without a shadow of doubt huge potentials. Via the technology Industrie 4.0 it is possible to break down our industrial constraints today and get out the cycle between optimization and flexibility to implement completely continuous production without inventory, further to deliver the products just in time. From point view of production, it enables last-minute changes to production and even one-off items can be manufactured profitably, and also the special cases, such as down time in the production, could immediately be delivered to the relevant individuals like the suppliers for the necessary actions like reschedules, if necessary. In terms of the customer the individual customer requirements can be fully achieved. Those potentials immediately make the term "Industrie 4.0" famous because it sounds like it can help manufacturers to actualize lean or continuous production that they are longing for years. However, Industrie 4.0 is a complex strategy that embraces several partially overlapping areas, especially its high-abstractive adaptation between organization and technology that make it cover a mysterious veil in front of world.

With the technologies of Industrie 4.0, we are able to break down our industrial constraints today and get out the cycle between optimization and flexibility to implement completely continuous production. Industrie 4.0 will focus on the horizontal integration through the value networks, the vertical integration and networked manufacturing systems as well as end-to-end digital integration of engineering (from inbound of raw material to outbound of finished industrial goods inside a plant) across the entire value chain. Think about a service task in a huge manufacturing plant: A valve does not work properly leading to an overheat situation in the system. With Industrie 4.0, the resulting alarm can be directed to the service staff via the mobile phone system anywhere; their smartphones will guide the responsible one via GPS or equivalent indoor location systems very quickly to the place of malfunction. Their portable PC-systems will identify the broken valve e.g. by RFID-technology and download all necessary information about this valve and possible replacements instantly via wireless communication channels like WLAN. The service staff can make photos with their smartphones and send them to a spare part shop for better identification. And finally, after a successful repair the crew can check the successful system restart even while having a snack in the cafeteria using their powerful mobile devices. Of course, the necessary signal about this broken valve will also direct immediately to other relating people, e.g. production leader and planner, for help them to recognize what happened in production plant and take some action if necessary. By this example, it is easily to see we have formulated a networked automation pyramid in a production plant. This paper describes how a fluent information flow between different automation levels in one production plant can be achieved from process planning to executable control procedures and at last the field devices take action, see chapter 4.2.

Thinking of the production flow both on processes/planning and on their implementation in reality, which have never left the top management, always schedule in manufacturing Industries. They have also been struggling for finding ways to help their Industries ahead competitors by not only on ensuring the customer's requirements but also on far exceeding customer' expectations. They wish to radically gain the highest flexible and the most qualified production processes without the consideration of any stocks as well as the technological upgraded production equipment and products. In this case, the control procedures need to be adaptable and reusable, and the production facilities must be flexible enough to adapt various control procedures. It has been proven that the Industrie 4.0 is a industrial promising approach to keep the first-class position of the global manufacturing leader. Even though Industrie 4.0 is a strategic policy from German government, see chapter 2.1, the manufacturing Industries would also be a clear winner from this strategy.

Industrie 4.0 will deliver greater flexibility and robustness together with the highest quality standards in engineering, planning, manufacturing, and operational and logistics processes. It will lead to the emergence of dynamic, real-time optimized, and self-organizing value chains that can be optimized based on a variety of criteria such as cost, availability and resource consumption. This paper will bring the basic Industrie 4.0 concepts, such as what is Industrie 4.0 and why it comes, what and how the manufacturing industry can be benefited via Industrie 4.0, see chapter 2.1 and 3, what are the potentials of Industrie 4.0, see chapter 2.1.4, especially the potentials for an automobile supplier, here is Miba Sinter Austria GmbH (MSA), see chapter 4.3. This paper analyzes the potentials from Industrie 4.0 via a methodological approach, the Weighted Criteria; mainly concentrate on the potentials from Smart Factory which is the key part from Industrie 4.0 will be described in chapter 2.3.

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# List of Abbreviations

ADC: Analog to Digital Converter
B2B: Business-to-Business
BDE: Betriebsdatenerfassung
CPS: Cyber-Physical Systems
CPPS: Cyber-Physical Production Systems
CS: Computer Science
CU: Capacity Utilization
CAQ: Computer Aided Quality
EDI: Electronic Data Interchange
ICT: Information and Communication Technologies
ITU: International Telecommunications Union
IERC: European Research Cluster on the Internet of Things
JIT: Just-in-time
MST: Manufacturing Science and Technology
MUI: Mobile Universal Interaction
MMI: Mobile Machine Interface
MDE: Maschinedatenerfassung
OEE: Overall Equipment Effectiveness
PPC: Production Planning and Control
PLCs: Programmable Logic Controllers
PCAST: President's Council of Advisors on Science and Technology
PZE: Privatezeiterfassung
PPM: Parts Per Million
PU: Product Unit
QC: Control Circles
SOA: Service-oriented Architecture
SMEs: Small and Medium-sized Enterprises
SL: Stock Level
TPS: Toyota Production System
TEEP: Total Effective Equipment Performance
TPM: Total Productive Maintenance
TQC: Total Quality Control
USI: Universal Sensor Interface
VSM: Value-stream Mapping
WBK: Warenbegleitkarten
ZD group: Zero Defect Group

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# 1. Project Introduction

## 1.1 Industrie 4.0 in General

**Industrie 4.0** is a project in the high-tech strategy of the German government, which promotes the computerization of the manufacturing industry (Forschung-BMBF, 2014) for supporting the european manufactures to keep their first-class manufacturing leading position in the world and has been described in the realm of manufacturing as the fourth stage of industrialization.

The term Industrie 4.0 can be seen as a collective catalogue that is full with computer science, information and communication technologies and manufacturing science and technology. It is expected to achieve eventually a quantum leap in manufacturing plants, e.g. to set up and reconfigure their production plants in ever-shorter time intervals and time frames.

Industrie 4.0 is based on the availability of relevant data in real time through the interconnectedness of all instances related to the value creation process, and moreover on the ability of deriving an optimized value creation process from the available data (Sihn, 2014, P. 11). The "Real time" here refers to data processing that occurs synchronously with events in the real world, as opposed to data processing where a delay is involved (Kagermann et al., P. 26).

**The vision of Industrie 4.0** is with regard to the individualization (batch sizes of 1) at mass production prices will become a reality, the highly flexible manufacturing extremely achieves maximum productivity (up to +50%) via using minimum resources (up to -50%) and will also be compatible with an urban environment, dynamic design of business and engineering processes, work-life balance between personal's needs and company's requirements, older specialists with the smart assistance systems, which should be able to achieve eventually a quantum leap in manufacturing plants, and further could lead a success in the crucial competition (Kagermann et al., 2013, P. 5). The aim is to set up a new industrial control systems providing a high interoperability and adaptability of networked automation devices in the shop floor, and intercommunicating in all the automation levels for implementing lean production. It is expected that with Industrie 4.0, industrial constraints today can essentially be broken through and completely get out the cycle between optimization and flexibility to ultimately bring about continuous production.

**Industrie 4.0** consists of primary two concepts, smart factory and smart production. Smart factory, which will be led by the cyber-physical production systems (CPPS) for the manufacturing industry use, concentrates on the research of the smart production system and process, as well as the implementation of networked distributed production facilities. Smart Production deals with the production logistics management of whole plant, human-machine interface, and 3D printing as well as application of material manufacturing in industrial production process.

## 1.2 Project Aims

Miba Sinter Austria GmbH (MSA), which is one of the most important automotive suppliers, has regularly to deliver engine and gearbox components just in time to the customer. MSA like others industrial manufacturers has been driving their production to lean manufacturing.

Due of the high variety of components MSA like all other manufacturers primarily has batch production in their factory that is one of the manufacturing process, in which components or goods are produced in groups (batches) and not in a continuous stream.

The company has been making efforts on the continuous production and wishes implement the customer-tacted process without inventory. This is depicted in the type D of the Figure 1.1, and details are explained in chapter 2.2.3. Furthermore, The long process chain needs a through-put-time of six weeks in average: pressing, sintering, sizing, grinding, turning, rolling, packaging, quality control, external works and so on. At last, MSA has to deal with disturbances at any time; it is a challenge to fluently let the material flow through all the processes without any downtime of machines, quality issues and so on. For all the purposes, the concepts of Industrie 4.0 have caught many manufacturing companies' attention.

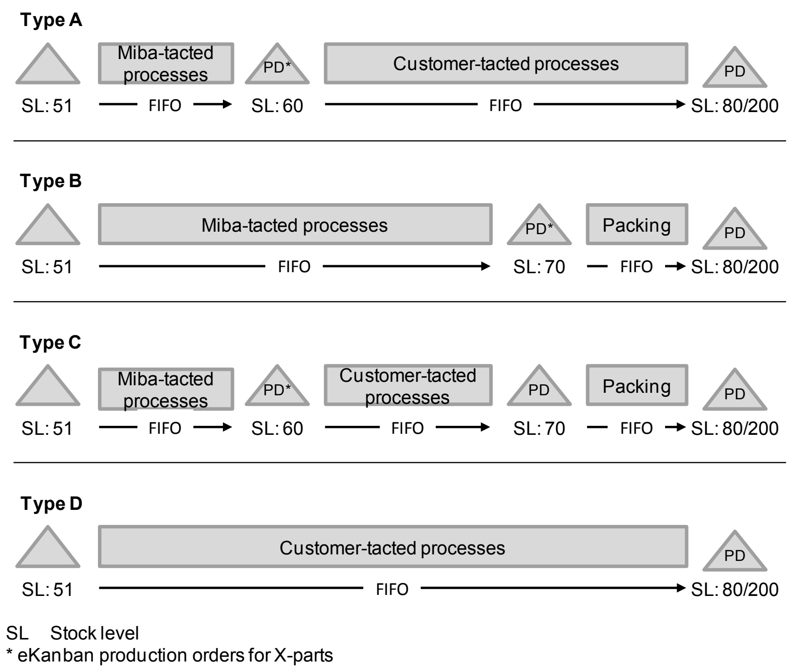



Figure 1.1 Value stream types at MSA (MSA)

Industrie 4.0 enables not only continuous resource productivity and efficiency gains to be delivered across the entire value networks but also last-minute changes to production and immediately deliver those special cases to the suppliers, for example. Additionally, smart factories could meet the individual customer requirements and mean that even one-off items can be manufactured profitably.

The aim of this paper is to find out the potentials of Industrie 4.0 for MSA and give the solutions in point view of Industrie 4.0 in terms of the connection between the material flow and information flow, the continuous production, the long through-put-time and large inventory etc. Optimization strategy for the issues mentioned should not be employed as well as the software programming is not required.

Industrie 4.0 holds huge potentials. In this paper, the potentials of Industie 4.0 for Miba Sinter Austria (MSA) is analyzed, and further specially focus on the disturbances of machines in the production in order to improve Overall Equipment Effectiveness (OEE) that is the main objective of total productive maintenance (TPM) in the point view of Industrie 4.0. For this purpose, Capacity Utilization (UI), which is one of the Key Performance Indicators (KPIs) at company, is introduced.

Furthermore, one typical value stream mapping (VSM) has been mapped for an important component at Product Unit 4 (PU 4) that covers both internal and external work at company in order to bring the issues in the presence of people and give the solutions for describing how to formulate the best connection between material and information flow in both external and internal work via the technologies from Industrie 4.0.

Lastly, the latter analysis is on the disturbances of machines in order to focus on one thing that could be immediately be adopted by the company, and the solutions are naturally from Industrie 4.0. The analysis is partly about the important parameters (existing and additional) in which the maintenance personnel are interested, among which how many parameters are already tracked in the machines. Another reason I concentrates on the disturbances of the machines because they are the essential reason of others items that come from capacity utilization (CU). The solutions are specially facing to the maintenance personnel.

## 1.3 Methodological Approach

This paper is defined as four phases, as shown in the table 1.1. This masterwork lasts 20 weeks (five month) in total.

| | Phase I | Phase II | Phase III | Phase IV |
|---|---|---|---|---|
| **Name of Phases** | Understanding MIBA Vorchdorf | Modeling typical value and information streams | Find out critical information in MIBA | Documentation |
| | | | | |
| **Duration (Weeks)** | 2 | 6 | 10 | 2 |
| **Start planned (Week Nr.)** | 40 | 44 | 50 | 08 |
| **End planned (Week Nr.)** | 43 | 49 | 07 | 09 |
| **Tasks** | Introduction<br>Become acquainted with employee | Analysis status quo: internal (initial situation), external (possibly) | Goals defined, Specifications created | Biweekly written status report |
| | Training courses (responsibility, security, production process…) | Analysis on desired state and objectives through theoretical and in-house investigation | Modeling Information flow structure | |
| | Create phase plan | Relative terms: definition, analysis, rough conclusion | Optimization the module of information flow | Correction and Rough draft |
| | Activity Order & Writing job description | Modeling information streams and find out the connection between information and material flow | | |
| | Literature research | | | |
| | Analyze the status quo of smart factory discussion | | | |
| **Results** | Step 1:<br>1.1 Work Contract<br>1.2 The first presentation | Step 2:<br>2.1 Modeling information flow<br>2.2 Connecting information and material flow | Step 3:<br>3.1 Identifying critical information and ideas for optimization | Step 4:<br>4.1 Draft version of the master thesis<br>4.2 Final presentation<br>Submission of the thesis<br>4.3 Finalized master thesis |

Table 1.1 All phases of the whole paper

Figure 1.2 shows an overview of the process steps of the whole paper.

According to the project aims, firstly my task is to collect all the potentials on the basis of total concepts that Industrie 4.0 includes, value them by the comparison with the aim of this project and actual situation of the company (MSA), further analyze the high-valued ones that are defined as high potentials for Miba Sinter Austria (MSA) via the methodological approach – the weighted criteria, and lastly carry out the results of those high potentials of Industrie 4.0 for MSA and give the solutions in point view of Industrie 4.0.

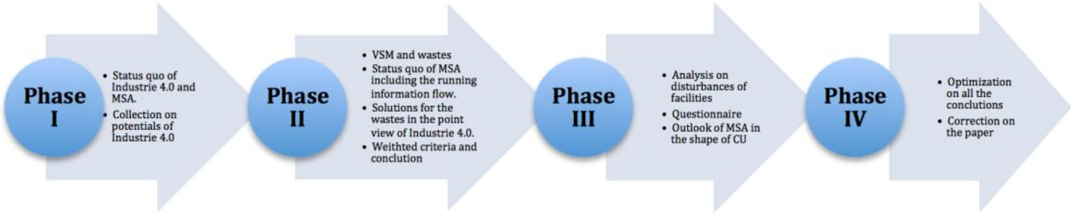



Figure 1.2 Process steps of the whole paper

My aim is to narrow down the high potentials of Industrie 4.0 to one for MSA and later it can be introduced to the company. However, the result of analysis shows that it is not possible to introduce one potential for industry use at company because the potentials of Industie 4.0 are linked together. There is no sense to take a single one or some out for use. Take an example of Radio frequency identification (RFID) for industry use, which is highly expected in the view of Industrie 4.0 due to the potentials of intelligence on the formulation of the automation network, must work with other technologies together. Then its advantages, such as intelligence, could be clearly recognized and further will be smoothly performed. MSA has one time employed RFID in the production; however, it was not adaptable for inventory and was later replaced by labeling system. So far, the top management at MSA does want to switch back to RFID from labeling system because the labeling system works well, cheap, and simple in comparison with RFID. Thus, Industrie 4.0 introduces RFID, which is because of its intelligence that is useful to link other technologies in future factory. Additionally, it is not possible to incorporate one or some such intelligent technologies into the production because there are no benefits in terms of return on investment (ROI).

Since this time I am thinking to know about the problems of machines in the production at MSA, further to focus on one problem, and lastly to carry out the solutions in point view of Industrie 4.0.

When I was in this phase, both my supervisor from UFO and the colleagues from MSA have supported me. My supervisor Wolfgang Marko has made big efforts on the weighted criteria. Markus Hoertenhuber from MSA has introduced the company to me and fully supported me to collect all the information that I need for my topic, Michael Goertz explained me the material logistics and gave also me lots of others help. Bernadette Loidl from Side Department, who is responsible for labeling system that is a universal transportation and traceability system for all production steps including powder, external operations and distribution, has supported me to understand the MES system in the production.

As they deepen their understanding of lean production and stabilize their processes, they need to identify the total value stream that creates the end product or service. Additionally, one of the aims of this paper is model a connection between information and material flow via technologies that Industrie 4.0 introduces. That is why a typical value stream mapping (VSM) is required. MSA has so far defined four types of value streams. This is depicted in the Figure 1.1. Each product can be allocated to a certain type of value stream, which can be distinguished by number of stock levels and the differentiation between Miba-tacted and customer-tacted processes. The VSM that I map, as shown in Appendix B, is type C because this one is most complicated one of all the value streams and also covers all the issues both internal and external work. The issues of external works can be from customers in terms of later frozen order date and delivery time etc., and from suppliers in terms of earlier frozen date and earlier informed if there is a problem in the production and so on. The internal issues mainly reflect on the production planning and control, such as the schedules cannot be implemented because they firstly delivered to the supervisors in shop floor, not possible yet directly to the various responsible workers with machines, the production plan needs at least one shift to be executed due to the setup tools, the changeable orders in the forecast or unpredictable small amount of orders mainly depend on safety stock, and also production lead time last too long in comparison with processing time and so on. To increase transparency and reduce the complexity MSA’s production is divided into four production units (PUs) on the organizational front. Products are allocated to one of these PU by criteria. The VSM that I map is for the production unit 4 (PU4) because the turnover from PU4 occupied approximately half turnover from total turnover at MSA. From the ABC - Analysis the component 1.3.445 is the second of the A products in the PU 4. Therefore, the VSM is particularly for the component 1.3.445, as shown in Appendix B.

After a summary of all the issues around production that VSM brings the suggestions and solutions come into existence in point views of Industrie 4.0. My solutions include what does Industrie 4.0 mean for MSA, which kinds of the benefits can company get from this strategy, why the company need to take action for it, how does it looks like at company if this concept is set up and which step could be the first step for introducing this concept to the company.

When I am mapping the VSM, my colleague Stefan Klaffenböck who is the production planner at PU4 and is responsible for the component 1.3.445 supports me to input all the parameters that a VSM needs.

Due to the supply chain management involves the actions of customers and suppliers I only here give the suggestions for the external work and mainly focus on the internal work and at least I think I should start with the production at home. The performance of the production is measured by Key Performance Indicators (KPIs) which are the Figures to weekly and/ or monthly analyze the performances of the Production Units (PU) in terms of quality, logistic, production and personal, is known as the production cockpit at MSA. KPIs are one of the four types of performance measures. They are the performance metrics that are applied to evaluate some factors that are important to the success of an organization, and lead to a series of potential improvements. Thus, KPIs, especially the Figure “production” from KPIs is a start point of my third phase in the paper. Furthermore, after I talked with the supply chain manager, Dietmar Hoheneder, I decide to focus on the Capacity Utilization (CU) that is one of the Figures from the item “production” of KPIs. He said he is interested in increasing Overall Equipment Effectiveness (OEE) and Total Effective Equipment Performance (TEEP) via eliminating the unplanned down time of machines and improving Total Productive Maintenance (TPM) activities. This is also the wish of top management at company. So far, it sounds like my task is clear to analyze the CU. All the mentioned items are specified in chapter 5.

CU is constructed to measure the productive runtimes of key machines at MSA. The details and relevant Figures are shown in chapter 5.1.4. There are five segments of bar in graphic of CU in terms of legal down tome, lost time due to logistic reasons, unplanned down time due to technical reasons, planned down time and productive runtime. The Productive runtime measures the time for all key machines, when they are producing parts. The legal down time is defined via the base and production calendar. The lost time measures the lack of order, material, tools, setters or operators. The down time represents the problems with machine, tool or part inclusive of changeover after repair. The planned down time is defined as the sample production, cleaning, TPM activities, planned changeover and set up and so on. The vision of my analysis in this phase is to drive the unplanned downtime due to technical reasons into productive runtime. The aim is to the fullest extent reduce unplanned repairing time of maintenance personnel. For this purpose, I firstly analyze the disturbances from BDE for six machines in the production, among which two are for compacting, two for sintering and two for sizing, in order to find out the technical reasons of unplanned down time. Six items are included in this analysis and defined by company. Furthermore, I take the results of the analysis on those machines and further talk with the maintenance personnel and lastly find out it is not possible to get reasons for the unplanned downtime because the data I am taking is from BDE and the maintenance personnel I am talking use the system SAP. There is no direct connection between the disturbances from BDE and from SAP that is used in maintenance department. So far, I have to clarify that there are two groups for handling the unplanned downtime at MSA: one is from production and is known as setter; another is from maintenance department and is known as maintenance personnel. The department (SAP) defines three areas to describe the problems but the BDE defines various items, such as lack of material, quality problem of components and technical problems and so on, for registration of the disturbances by setters. The only connection between two groups is the maintenance personnel take the actions on the unplanned maintenance only if the setters in the production need or they register. The collecting work for reasons from BDE in the production is difficult because there is no detailed documentation to explain why the machine is down. That is why latter my analysis basically depends on the maintenance personnel because they write short explanations for the problems in the SAP. Even they have this kind of description, it is also difficult to do filter the valued datum for one year (the period of analysis is from 01.10.2013 to 01.10.2014) and the explanation for one single problem could be different. Additionally, the maintenance personnel mix the planned and unplanned downtime together. I have made large efforts on separating the unplanned downtime from total. During the analysis, my colleges Barbara Katzengruber and Margot Zauner help me to collect the disturbance from BDE in the production; Kurt Werl, who is the leader of Plant Engineering (Maintenance Department), has organized different people to help me to collect the data from SAP.

The conclusions I carry out is a quantum leap for the MSA in point view of Industrie 4.0, which is depicted in the Figure of Capacity Utilization (CU) in terms of productive runtime and legal down time. Other segments of bars from CU disappear due to the introduction of technologies from Industrie 4.0.

In addition, the item “problem” and “disturbance”, the item “potential” and “technology” are treated no difference in this paper.

# 2. General Introduction

## 2.1 Introduction of Industrie 4.0

### 2.1.1 Industrie 4.0 Architecture

The basic idea of Industrie 4.0 is make everything smart. In a „smart, networked world“, the Internet of Things and Services will make its presence felt in all of the key areas. This transformation is leading to the emergence of smart grids in the field of energy supply, sustainable mobility strategies (Smart Mobility, Smart Logistics) and Smart Health in the realm of healthcare. Industrie 4.0 as part of smart networked world, as depicted in the Figure 2.1, within which the smart factory as a key component brings the Internet of Things and Services to the manufacturing environment, enables humans, machines and resources as a social network to communicate with each other, and its interfaces with smart logistics and smart grids will make it a key component of future smart infrastructures. The crucial challenges of Industrie 4.0 are to control and monitor field devices in a desired way, to process data in terms of actuality, integrity and propriety, and to seamlessly incorporate the physical world into virtual world (Sihn, 2014, P. 12).

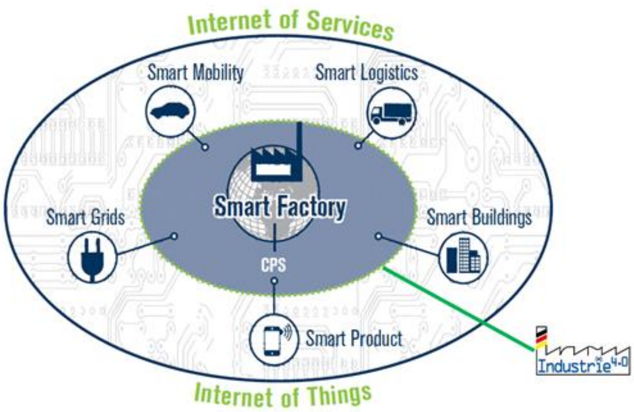



Figure 2.1 Industie 4.0 as part of the Internet of Thing & Service
(modified from Kagermann, 2013, P. 8)

**Smart Grid** is the blend of open and proprietary networks that enables the much larger network of measurements, controls, metering, and automation (Knapp & Samani, 2013, P. 1ff). It allows volatile energy sources to be incorporated by matching supply and demand in real time in a highly complex energy system, which make it be possible to connect manufacturing systems and business processes in factories and businesses in real time and across different companies – from ordering up to outbound logistics (Albach et al., 2015, P. 27f). Additionally, it is time to introduce the renewable energy sources such as wind and solar power into the grid as common electricity infrastructure in the manufacturing industry.

**Smart logistics** is that the supply chain will be networked with manufacturing facilities in real time so that production can respond instantaneously to supply variability via the Internet of Things (IoT), which is noted as the digitization of logistics. Smart Mobility is defined as an offer, "comfortable" and provides "energy efficient", "low emission", "safe", "cost-effective" mobility and is used by traffic participants intelligent (Brünglinghaus, 2013). Smart logistics and smart mobility enable efficient and reliable organization of transport between different locations (door-to-door transport) and throughout the entire life cycle of goods (production-transport-storage-consumption-disposal) (Albach et al., 2015, P. 30f). Lastly, the building under IoT is seen as smart building.

Industrie 4.0, which is focused on creating smart products, procedures and processes in the manufacturing area, mainly involves Smart Production and Smart Factory as shown in the Figure 2.2. With the help of the Internet of Things and Services, Smart Material will be transformed through the Smart Factory into Smart Products. In the Smart Factory, the desired industrial products will be produced under the environment of the ideal integration of the networked horizontal and vertical value chain. The networked horizontal and vertical value chain in this paper will be narrowed in one Smart Factory. It means, the networked vertical integration is the information flow in one manufacturing industry and the networked horizontal integration is the material flow in one production factory.

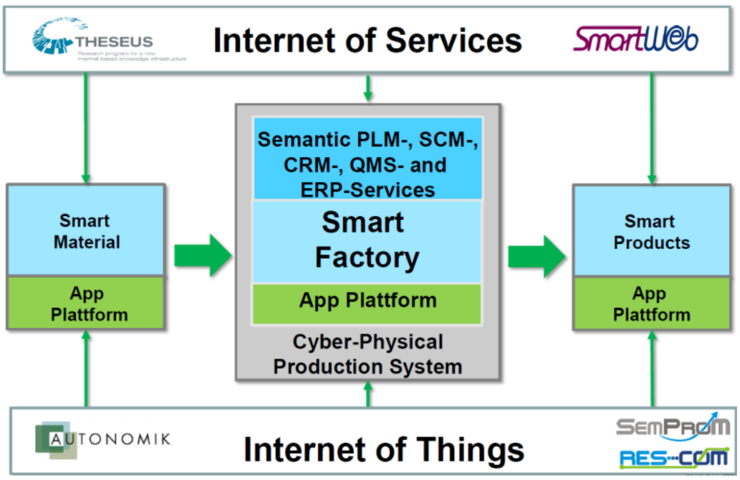



Figure 2.2 Industie 4.0 Architecture (Wahlster, 2012, P. 10)

**The Internet of Things and Services**, which is treated as a basis for the Smart Factory that Industrie 4.0 explains, makes it possible to create networks incorporating the entire manufacturing process that convert factory into a smart environment. The Internet is not only a network of computers, but it has evolved into a network of devices of all types and sizes, vehicles, smartphones, home appliances, toys, cameras, medical instruments and industrial systems, all connected, all communicating and sharing information all the time. The Internet of Things is a “global concept” and can benefit from the latest developments and functionalities commonly referred to as Web 2.0 (e.g. Facebook, Twitter etc.) through provision of new intuitive user-centered and individually configurable and self-adapting smart products and services, and further has to develop the powerful data-sharing models capable of Business-to-Business (B2B) requirements, such as data management and analysis. Considering the wide background and required technologies, from sensing device, communication subsystem, data aggregation and pre- processing to the object instantiation and finally service provision, generating an unambiguous definition of the “Internet of Things” is non-trivial (Vermesan & Friess, 2014, P. 15ff).

The Internet of Things (IoT) is defined by ITU and IERC

*“as a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual “things” have identities, physical attributes and virtual personalities, use intelligent interfaces and are seamlessly integrated into the information network.”* (Vermesan & Friess, 2014, P. 3)

However, it has some shortcomings and does not include all the information, such as mixed visions from ubiquitous/ pervasive computing, unclear tasks in comparison with Web 2.0 and it does not provide a reason why or how the IoT will be a self-sustainable and successful concept for the future. IoT partially overlaps all the fields of research in terms of ubiquitous/ pervasive computing, internet protocol, communication technology, embedded device, application, internet of people and intranet or extranet of things (Uckelmann et al., 2011 , P. 6ff). Numerous industrial analyses such as Acatech, Cisco, Ericsson, IDC, Forbes, have identified the evolution of the Internet of Things embedded in Smart Environments and Smart Platforms. The success of the Internet of Things will depend on the ecosystem development, is supported by an appropriate regulatory environment and a climate of trust, where issues like identification, trust, privacy, security, and semantic interoperability are pivotal (Vermesan & Friess, 2014, P. xiii).

In addition all above IoT, the term big data is referred to as data factories that is the wealth of data stored can then be mined using smart algorithms based on correlations and probability calculations. The cloud computing makes those affordable storage now available for the exponentially rising volume of data that is generated by smart objects and subjects (Albach et al., 2015, P. 26). It analyzes the required data from data factories and identifies the patterns, and further to generate the information that can be correlated in order to produce new knowledge. Using this knowledge the cloud computing provides the basis for developing innovative new services infrastructures that offer a compressive range of smart services for business webs with Service-oriented Architecture (SOA) that supports end-to-end cross-company business processes and flexible business networks, see the chapter 3.2.

**The App Framework** is the software platform that includes all the required manufacture-independent, modular software components that are in the form of field device apps, which is also known as industrial App Store.

The aim is to enable dynamic function deployment and extension by using apps on intelligent industrial field devices, which is used by developers and vendors for distribution and marketing, and is for users and CPS on site to purchase appropriate apps.

Thus, a much more user-friendly and useful interaction between the user and field device can be realized. Generally it needs develop a reference-architecture as a basis for incorporating into factory systems.

Additionally, apps are modular software components that are provided via standardized communication services in the network, such as App Store, for an effective, user-friendly interaction via uniform, mobile user interfaces like smartphone, tablet (Schmitt et al., 2014). Currently those apps are only mature in the consumer market (Verclas & Linnhoff-Popien, 2012, P. 185f). It is still a crucial challenge in the industrial area.

**Human-Machine Interface (HMI)** or the user interface is the space where interaction occurs between humans and machines in the industrial environment. HMI is seen as a trend that moves from specific stationary, further to cable-based mobile devices, and ultimately to universal mobile control devices. It is indispensable in the future factory due to its movability. In comparison with cables, HMI has no connection restricts; could save the operating costs on connection boxes (does not need); allows freedom of locality; is of expandable possibility for representation and interaction assure an unplanned increase of flexibility considering facility planning and operating.

Additionally, the training and introduction for various proprietary user interfaces from different devices (different vendors) are no longer needed.

The goal of HMI is for users to handle an increasing complexity of usability of field devices in terms of hundreds of control screens and displays including thousands of buttons from various vendors in industrial areas. Due to its movable nature setters and maintenance personnel will absolutely be benefited, see the chapter 5.

The basic idea, which is bases on transferring the modern information and communication technology (ICT), is so-called "smart" technologies into factory environments. It has been proven that ICT is one of the most important key factors for the future development in the area of production automation (Terwiesch & Ganz, 2009, P. 127-143).

The rising question is how to adapt those ICT to plant environment. One fundamental requirement for mobile devices is a correctly pre-configured communication interface (Flörchinger & Schmitt, 2011). The so-called technologies are the devices and applications from consumer electronics, such as smartphone, navigation systems, Bluetooth and WLAN, which are not common in production automation yet. Corresponding mobile industrial interaction devices have been developing and some exist today, such as Siemens SIMATIC Mobile Panel 277 IWLAN and uniqo UCP450 (Schmit et al., 2013), (Meixner et al., 2010). Lastly, HMI could achieve success only if the field devices have already embedded with communication possibilities respectively and industrial apps are available.

**Cyber-Physical Systems (CPS)** are systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the internet (Hellinger & Seeger, 2011), (Geisberger & Broy, 2012), (Report, 2013). The detail can be seen in chapter 3.1.

**Cyber-Physical Production Systems (CPPS)** (Monostori, 2014), relying on the newest and foreseeable further developments of computer science (CS), information and communication technologies (ICT), and manufacturing science and technology (MST) may lead to the fourth Industrial Revolution, frequently noted as Industrie 4.0 (Kagermann et al., 2013). CPPS partly break with the well-known traditional automation pyramid, as depicted in the Figure 2.3 (Bettenhausen & Kowalewski, 2013, P. 4), the critical control and field levels still exist in a traditional way. However, the upper levels have been changed.

Since they are basically providing non- physical functions and services, it is possible to migrate them into the cloud. The control level is divided into two parts (Givehchi & Jasperneite, 2013, P. 4). The first part is the physical control level that includes common PLCs close to the technical process to be able to provide the highest performance for critical control loops. The second part of the control level migrated to the cloud. It offers control functions directly to the lower levels from the cloud with a reduced performance.

**Smart Production** involves mainly the entire enterprise production logistics management, human-computer interaction and 3D technology in the industrial production process and so on. This subject will not be further researched in this paper.

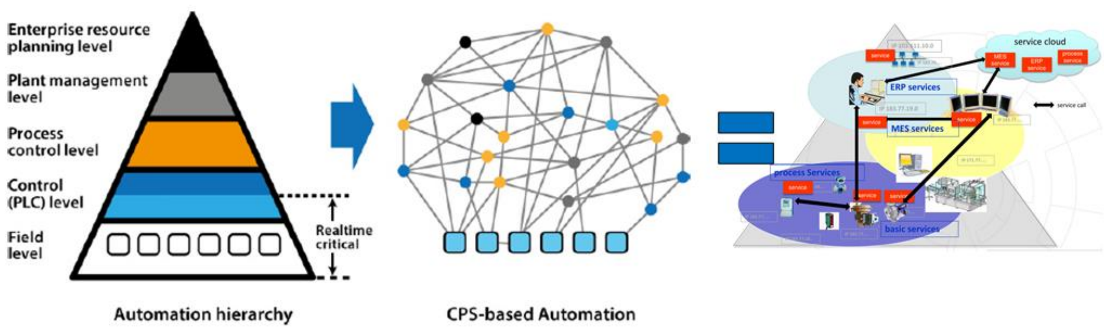



Figure 2.3 Decomposition of the automation hierarchy with distributed services
(modified from Bettenhausen & Kowalewski, 2013, P. 4)

**Smart Factory** means an intelligent socio-technical production system based on informed people, informed products and informed machines (Jasperneite, 2014, P. 8). It is the target system the upcoming revolution and represents the further development of lean production (Sendler, 2013, P. 50).

As a key feature of Industrie 4.0, smart factory will make the increasing complexity of manufacturing processes be manageable, increase the responsiveness and decision quality of employee, ensure that production can be simultaneously attractive and reduce lot sizes and energy consumption, and will be sustainable in an urban environment and profitable (Kagermann et al., 2013, P. 21), (EFFRA, 2013), (Majumdar & Szigeti, 2011).

Thus, human beings, machines and resources communicate with each other as naturally as in a social network in a smart factory. The big challenge here is to make the machines become intelligent, further to link to the higher level via the suitable communication technologies, such as radio technologies, human-machine interface and so on.

**Smart Products** know the details of how they were manufactured and how they are intended to be used. They actively support the manufacturing process, answering questions such as “when was I made?”, “which parameters should be used to process me?”, “where should I be delivered to?”, etc. Its interfaces with smart mobility, smart logistics and smart grids will make the smart factory a key component of tomorrow’s smart infrastructures. This will result in the transformation of conventional value chains and the emergence of new business models (Kagermann et al., 2013, P. 19).

Industrie 4.0 should therefore not be approached in isolation but should be seen as one of a number of key areas where action is needed. Consequently, Industrie 4.0 should be implemented in an interdisciplinary manner and in close cooperation with the other key areas.

Finally, one word about terminology: Note that the terms “manufacturing” and “production” are often used interchangeably in the literature, even though the term production typically signifies a broader range of activities than the term manufacturing does. Nevertheless, for this paper the two terms will be treated synonymously.

### 2.1.2 Status quo of Industrie 4.0

In 1991, Weiser described the vision of a future world under the name of “ubiquitous computing” that is also known as “disappearing computing” (Weiser, 1991). Since then, many devices in our daily life have become smart such as smart phones. Today, the resulting requirements for design, setup, and operation of our factories become crucial for success. In order to meet the challenges by making use of the smart technologies of our daily lives for manufacturing industry one project that has been found up by german government calls Industrie 4.0. Nerveless, for industrial use there are still many open questions to be answered (Kagermann et al., 2013, P. 39).

**(1) Standardization and open standards for a reference architecture**

Industrie 4.0 requires cooperation between companies in the machinery and plant manufacturing, automation engineering and software sectors, which need to agree a common basic terminology and build trust in the reference architecture. Although several established standards are already in use by the various technical disciplined, professional associations and working groups, a coordinated overview of these standards is currently lacking. That means, the existing standards e.g. in the field of automation (industrial communication, engineering, modeling, IT security, device integration, digital factories) need to be incorporated into a new global reference architecture. The reference architecture is referred as the complete technical description and implementation of these agreeable provisions. The role of the reference architecture is to pull together these divergent business models that come from different companies into one single, common approach. This will require the partners to agree on the basic structural principles, interfaces and data, see the chapter 2 in detail.

The standardization will be based on different paradigms because they are currently the norm in the machinery and plant manufacturing industry, e.g. open operating systems such as Linux, open development tools, open communication infrastructure such as the Internet protocol (TCP/IP) and e-mail protocol (SMTP).

**(2) Managing complex systems**

Products and their associated manufacturing systems are becoming more and more complex. This is a result of increasing functionality, product customization, dynamic delivery requirements, integration of different technical disciplines and organizations and the rapidly changing forms of cooperation between different companies. Those increasing individualization requirements, combined with the associated technical heterogeneity and complexity of products call for a system for managing this growing complexity (Schmitt et al., 2014).

Modeling can act as an enabler for building complex systems in the digital world. There are two kind of modeling: planning and explanatory models (Kagermann et al., 2013, P. 42). Planning Models provides a transparent information flow via a schematic as a example, which enables more efficient engineering by improving interdisciplinary cooperation and facilitating more consistent engineering data. A schematic used by an engineer could explain how he or she has implemented appropriate functions to meet the requirements placed on a system.

For this purpose, the model needs the engineer's knowledge. Explanatory models describe existing systems in order to acquire knowledge about the system through the model via using different analysis processes such as simulation. Currently the explanatory models are only useful for validation purposes during the development and design stages, not yet in the production stage to check whether or not the production is smoothly running, detect wear and tear without needing to halt production or predict component failure and other disruptions. Additionally, modeling is very common in big companies, but is still not standardized pervasive in SMEs due to the production volumes and cost-effective.

Industie 4.0 says all the partner companies should be unified in the reference architecture. Integrating SMEs into global value networks is also a challenge.

**(3) Delivering a comprehensive board infrastructure for industry**

A core character of Industrie 4.0 is the enhancement of existing communication networks to provide guaranteed latency times, reliability, quality of service and universally available bandwidth.

The vision of such a network of automation in manufacturing industry can be realized in form of a Cyber-physical Production System (CPPS), as specified in chapter 3.1. Currently, the CPPS is not available for the companies due to the simplicity, reliability, security, availability and affordability, many companies take just one or some information communication as research project at company. High operational reliability and data link availability are crucial for mechanical engineering and automation engineering applications. Guaranteed latency times and stable connections are key, since they have a direct impact on application performance.

**(4) Safety and security as critical factors for the success of Industrie 4.0**

Safety and security are two key aspects not only in the view of IT also with regard to manufacturing facilities and the products they make. The definitions of the two items are following (Kagermann et al., 2013, P. 47):

- ***Security/ IT security/ Cyber-security****: "The protection of data and services in (digital) systems against misuse, e.g. unauthorized access, modification or destruction. The goals of security measures are to increase confidentiality (the restriction of access to data and services to specific machines/human users), integrity (accuracy/completeness of data and correct operation of services) and availability (a means of measuring a system's ability to perform a function in a particular time). Depending on the technological system in question and the data and services that it incorporates, security provides the basis for information privacy, i.e. the protection of individuals against infringements of their personal data rights. It also enables know-how protection, i.e. protection of intellectual property rights".* (Kagermann, Wahlster, & Helbig, 2013, P. 47)
- ***Safety****: "The absence of unacceptable risks and threats to people and the environment resulting from operation of the system. "Safety" requires both operational safety and a high degree of reliability. Depending on the technological system in question, safety may also involve additional aspects such as prevention of mechanical or electrical hazards, radiation protection, prevention of hazards relating to steam or high pressure, etc. Operational safety refers to the aspects of safety that are dependent on the correct operation of the system or that are provided by the system itself. The elements required to deliver operational safety include low fault rates, high fault tolerance (i.e. the ability to keep operating correctly even when faults occur) and robustness (the ability to guarantee basic functionality in the event of a fault). Reliability refers to*

*the probability of a (technological) system operating correctly for a given period of time in a given environment".* (Kagermann, Wahlster, & Helbig, 2013, P. 47)

Both items influence each other; such as security awareness often plays a key role with regard to IT security issues.

In view of the fact that Industrie 4.0 will involve increased networking and cooperation between several different partners in a value chain, it will be necessary for partners to have a higher level of confidence in each other's competence (security & trust) and for them to provide hard evidence of their competence. Machinery and plant manufacturers are becoming increasingly aware of the value-added potential of software, resulting in a sharp rise in the number of software components found in manufacturing facilities and machinery.

However, the relevant IT threats in details are not listed. Industrial IT security has only started to be discussed in the automation industry since the public debate surrounding malware (malicious software) such as Stuxnet, Duqu or Flame (computer worms).

Moreover, software is also playing an increasingly important role in delivering and maintaining security and safety, but this is something that has not yet been properly taken on board by manufacturing processes – and where solutions are available they have yet to be implemented.

In general terms, Industrie 4.0 will require a much more proactive approach to safety and security than has hitherto been the case (especially with regard to security by design). At the moment, safety and security issues are often only raised reactively once the development process is over and specific safety or security problems have already occurred. However, this belated implementation of safety and security solutions is both costly and also often fails to deliver a permanent solution to the relevant problem.

Consequently, safety and security cannot simply be broken down into functional components but should instead be approached as a process. In order to achieve fast response times, it is also important to provide support through monitoring and comprehensive cross-sectorial information exchanges. There is insufficient monitoring of risk assessment indicators, particularly with regard to industrial IT security, and little if any information is exchanged about safety and security incidents. Action in these areas would help to stop the spread of viruses or indiscriminate cyber-attacks.

**(5) Work organization and work design in the digital industrial age**

Industrie 4.0 says that innovation efforts cannot be allowed to focus exclusively on overcoming the technological challenges but on smart organization of work and employees' skills and let employees play a key part in implementing and assimilating technological innovations. The quality of people's work will not be determined by the technology or by any technological constraints but rather by the scientists and managers who model and implement smart factories. The employees are empowered to act as decision-makers and controllers in smart factories where highly complex, dynamic and flexible systems are configured. Nevertheless, the demands of the new, virtual workplace also present a threat to the maintenance and safeguarding of human capital. The growing tension between the virtual world and the real could also result in workers experiencing a loss of control and a sense of alienation from their work as a result of the progressive dematerialization and virtualization of business and work processes. The declining workplaces are threating some employee groups, notably semi-skilled workers. All above would seriously hamper the successful implementation of the Industrie 4.0 initiative.

Therefore, it should be clear to the public that smart factory does provide an opportunity to create a new workplace culture. Nevertheless, it is not simply realized of its own accord. The reasons and the approaches should also be specified. Additionally, even though the modular concepts for machinery already exist, the automation and personnel tasks after structural modification are also necessary to be well clarified (Jasperneite, 2014, P. 19). As long as the issues above are solved and smart organization is available, Industrie 4.0 will be success.

**(6) Training and continuing professional development for Industrie 4.0**

New training and learning system are necessary for Industrie 4.0 success.

**(7) Regulatory framework**

In order to solve the complicity of the relevant regulatory issues two things are required: the formulation of criteria to ensure that the new technologies comply with the law and development of the regulatory framework in a way that facilitates innovation. The following are details that need to be taken into account (Kagermann et al., 2013, P. 59).

- Protecting corporate data

Current regulation of the protection of corporate data only addresses some aspects of these dangers and generally requires the data to be classified as business or trade secrets. It usually only applies to cases of illegal disclosure. As the Internet of Things becomes established in smart factory, both the volume and the level of detail of the corporate data generated will increase. The data protection we have today is far not enough, such as new instruments will be required to keep knowledge secret and new regulated business models are necessary for some valuable raw data.

- Liability

Some contractual clauses are necessary, which set out the requisite technical and organizational arrangements, any additional measures (e.g. the duty to provide notification of any security problems or breaches) and stipulates penalties in the event of non-compliance. In the view of Industrie 4.0, the issue of liability and responsibility becomes even more important – when autonomous systems are deployed in networks, a lack of structural transparency could make it almost impossible to explicitly determine who performed a particular action, resulting in uncertainty with regard to legal liability.

- Handling personal data

As the interaction between employees and CPS increased, so will the volume and level of detail of the personal data held for individual employees, for example, the employee’s location, their vital signs or the quality of their work and so on.

- Trade restrictions

In the view of Industrie 4.0 the encryption technologies are also both necessary and desired by customers in order to ensure the confidentiality and integrity of CPS communication. However, the situation is difficult in many emerging markets, such as China, the use, sale, importing and exporting of encryption products are only permitted under licenses.

**(8) Resource efficiency**

Three categories of resources: raw materials and others, human resources and financial resources. In general terms, Industrie 4.0 need to investigate and implement ways of reducing the resources consumed during industrial manufacturing processes as a whole and by the machinery and equipment used during production, particularly Industrie 4.0 should be able to smoothly shift human beings to other job position. The reduction of human resources is hitherto not a good solution.

Lastly, the terms “Smart Production”, “Smart Manufacturing” or “Smart Factory” are used in Europe, China and the US (SMLC) to refer specifically to digital networking of production to create smart manufacturing systems, whereas the equally fashionable term “Advanced Manufacturing” embraces a broader spectrum of modernization trends in the manufacturing environment (PCAST, 2010).

### 2.1.3 Potential of Industrie 4.0

There is no double that Industrie 4.0 holds huge potential (Kagermann et al., 2013, P. 16):

- The customer can be to full extent satisfied via meeting the individual customer requirements and just-in-time delivery.
- The complexity of products and associated technical heterogeneity can be managed via CPS-based ad hoc networking that enables dynamic configuration of production processes and machines in the production, which could further benefit the logistics. For example, when a machine needs to be reconfigured, the relevant departments and suppliers can be synchronized with this change without any delay. For this purpose, a multi-vendor “app framework” that enables dynamic function deployment and extension is required in order to transfer of established interaction technologies and metaphors.
- Optimized decision-making due to the end-to-end transparency in real time across all of a company’s sites in the sphere of production. At moment if this can be achieved in one plant, which deserves enough of manufacturer’s attention.

- Resource productivity and efficiency - minimum input for maximum output via CPS that allows manufacturing processes to be optimized on a case-by-case basis across the entire value network. Furthermore, Industrie 4.0 enables continuous production that is known as no waste.
- Creating value opportunities through new services via the cloud computing that could produce new knowledge to provide the basis for developing innovative new services infrastructures. Due to this the reconfiguration in the production can be done and the business-to-business (B2B) can be fully developed.
- Allowing more freedom for the people both in decision-making and workplace in terms of fewer of workers involved directly in production (fewer blue-collar workers) but indirectly jobs (more decision makers and experienced employees), the interactive and interdisciplinary working environment, shortened time for instruction and learning. The employee will find the best balance between their increasing needs and the company’s requirements.

Nevertheless, all above-mentioned potentials are broad and quite blurred to the implementation in the manufacturing industry. The concrete list of potentials of Industrie 4.0 is missing, through which it will be clear to see the possibility and benefits and so on if the company wants to introduce one and/ or some technologies or adopt the whole concept of Industrie 4.0 in the plant. The easiest way to carry such list out is to focus on the two concepts of Industrie 4.0: smart factory and smart production, and analyze the potentials from each.

Smart factory can be influenced by the following items: smart material, smart product, Internet Data & Service, Internet of Things (in industrial use, Internet of Factory will take turn), cyber-physical system, software tools, process model, plant layout, field device, hardware structure, service structure, backup system, ontology (library), industrial Apps.

Smart production will be achieved mainly according to four items: production logistics management of whole plant, human-machine interface, 3D printing as well as application of material manufacturing in industrial production process.

In summary, we should pay attention on human, technology, and organization.

## 2.2 Initial Situation at Miba Sinter Austria (MSA)

Miba Sinter Austria GmbH (MSA) regularly delivers the engine and gearbox components, which are made from special powder via special production processes, to the automotive manufactures.

MSA is a technological leader in PM applications. They work closely with the international automotive industry to meet the challenges of shorter development times, growing price pressure and new environmental guidelines. Their customers are offered tailored, cost-effective solutions. Like all the others, the manufacturing organization at MSA use equipment and machinery and employ labor to convert raw materials of relatively low value into industrial products of higher value with the objective of earning an adequate return on investment. Miba sintered components, are made from special powder, which are high-precision, high-strength parts produced using special process technology. They are used in car engines, transmissions, steering systems, brakes, exhaust systems and shock absorbers.

Due of the high variety of components MSA like all other manufacturers has currently batch production in their factory that is one of the manufacturing process, in which components or goods are produced in groups (batches) and not in a continuous stream. Those types of production can be recognized from the types of value streams within MSA. The company defines that each product can be allocated to a certain type of value stream, which can be distinguished by number of stock levels and the differentiation between Miba-tacted and customer-tacted processes. Miba-tacted process causes lots of stock at a highly cost €15 million. The company has been making efforts on the continuous production and wishes implement the customer-tacted process. For this purpose, many projects have been built up and many actions have been taken. Currently an experimental continuous production is running for one product at production unit 4.

Furthermore, The long process chain needs a through-put-time of six weeks in average: pressing, sintering, sizing, grinding, turning, rolling, packaging, quality control, external works and so on. At last, MSA has to deal with disturbances at any time; it is a challenge to fluently let the material flow through all the processes without any downtime of machines, quality issues and so on.

Miba Sinter Austria' powder suppliers are from Sweden, USA, Slovenia and Canada. There are two types of powders: fine powder could be directly used in production; another powder need to be blended in the house. MSA makes usually yearly, monthly and weekly forecast for powder ordering. Two weeks forecast schedules the next twelve weeks production need. The customers made also this kind of forecasts to the company. Daily powder order (milk run) is possible because of the consignment stock.

Miba Sinter Austria has three type of inventory: external inventory, internal inventory and consignment stock. The external inventory has approximately capacity 850t, which includes the blended fine powder and the powder blending that need to be blended in the house. The internal inventory must provide at least three days fine powder in production stock. The inventory will be officially checked once per year.

The software systems for powder order are EDI, PipeChain and SAP.

### 2.2.1 Overview of Production Units

Miba Sinter Austria's production is divided into 4 production units (PU) on the organizational front, which produce approximately 250 components. This is depicted in the Figure 2.4.

| Production Unit 1 | Production Unit 2 | Production Unit 3 | Production Unit 4 |
|---|---|---|---|
| **Part characteristic**<br>• All parts not assigned to PU 2, 3 or 4<br>• Many spare parts<br>• Net shape products (finished after sizing)<br>• Conventional compacting | **Part characteristic**<br>• Synchrohub<br>• No sizing but forming<br>• Multiple press technology<br>• SAK sintering<br>• Drilling (sintered parts)<br>• Milling<br>• Line production (compacting, sintering, sizing, sandblasting) | **Part characteristic**<br>• Rotor<br>• Green machining<br>• Grinding, turning<br>• Brushing, washing | **Part characteristic**<br>• Gears<br>• Multiple press technology 500t<br>• Rolling<br>• Special sizing process → no rolling necessary<br>• External operations for all parts<br>• Many process steps/high variation<br>• External honing |

Figure 2.4 Criteria for the allocation of products to each PU (MSA)

Each production unit has been allocated the produces components according the rules that are shown in the following Figure. The process chain needs a through-put-time of six weeks in average: pressing, sintering, sizing, grinding, turning, rolling, packaging, quality control, external works and so on. Production units are different from the allocated machines. It is also possible to distinguish the production units according to the produced components. Nevertheless, this way is not accurate because the most components are not fixed to a single production unit.

Each component has different production process.

Production unit 1: compacting, sintering, sizing, induction hardening and packaging, turning (supplier), quality control, and packaging.

Production unit 2: compacting, SAK sintering (normal sintering with a special technology for finer components), sandblasting, drilling, forming, quality control, and packaging.

Production unit 3: compacting, green machining, sintering, sizing, grinding, brushing, washing, quality control, and packaging.

Production unit 4: compacting, sintering, sizing and packaging, hardening (supplier), turning and honing (supplier), washing (supplier), quality control, and packaging.

Furthermore, the quality check is done after each discrete production process. Before compacting the scheduled component prototype will be done in the setup period, which tests whether or not the tools are accurate and the machines are ready for the production.

In addition, in the production process the compacting and sinter are continuously connected.

### 2.2.2 The Information Technology at MSA

An understanding on Information Technology (IT) that is running at MSA is required. No company will totally switch their production system that is based on IT, and applies a new one. The company usually incorporates the latest profitable technology into their running IT based production system. That is why it is necessary to tell whether it is possible to add the technologies that Industrie 4.0 introduces to MSA on the basis of the running IT technologies at there.

#### 2.2.2.1 The Relationship between SAP and SOA

The SAP SE (Systems, Applications & Products in Data Processing), is headquartered in Walldorf, Baden-Württemberg, which is the largest by revenue European (and non-US) software manufacturer and the world's fourth largest. Main focus is the development of software for the handling of all business processes of a company such as accounting, controlling, sales, purchasing, production, warehousing and human resources.

SAP Business Suite: ERP, CRM, SCM, SRM etc.
Enterprise Resource Planning (SAP ERP), the former R / 3 (in 1992), independently occurred recently in version 4.7, partly ERP Central Component is called. More details on technology, architecture, function modules and user interface. In addition, SAP R / 3 consist of modules: FI (Finance), CO (Controlling), MM (Materials Management), SD (Sales and Distribution), PP (Production Planning) and HCM (Human Capital Management).
Customer Relationship Management (SAP CRM) is an independent package that provides advanced functionality for customer care by means of a separate software architecture and runs on a separate server; with the ERP possibly shared data is synchronized via replication.
Supply Chain Management (SCM), Supplier Relationship Management (SAP SRM) and Product Lifecycle Management (SAP PLM) systems complement each other in a similar way to the base system across all Industries use functions.

In addition, SAP NetWeaver is a web-based and open integration and application platform that serves as a basis for service-oriented architecture (SOA).

SOA is integrated into the SAP ERP system and other products in 2003 by SAP SE, which is named as Enterprise Services Architecture (ESA) (Matthews & Campbell, 2006) that is described as "*an open architecture for adaptive business solutions*" and *"the blueprint for an architecture that enables innovation and standardization in a single environment"* (Fritz, 2004).

2.2.2.2 The running IT at MSA

SAP ERP Competence Center at Miba, which has been developing since 2004, supports nine production sites (Austria, Slovakia, USA). The version is currently ECC 6.0 (Ehp5). Database Server is Sybase DB or ASE (Adaptive Server Enterprise). The Operation System is SUSE Linux.

SAP Competence Center at Miba currently has ten modules: Material Management (MM), Sales & Distribution (SD), Logistics Execution (LE-SHP), Warehouse Management (LE-WM), Portfolio - and Project Management (PPM), Production Planning (PP), Human Resource (HR), Controlling (CO), Finance (FI), Enterprise Asset Management (EAM). But those modules are not completely implemented at every plant. Miba Sinter Austria in Vorchdorf implements all main modules. Moreover, Miba has not yet incorporated Enterprise SOA into their SAP ERP.

The material concepts of SAP Competence Center at Miba involve basic data, Manufacturing Resources Planning (MRP), general plant data/storage, accounting, plant stock, warehouse management (WM), purchasing, sales and distribution, work scheduling, quality management (QM), costing, classification. There are three organizational levels that have been defined for the material concepts at MSA: Data, valid for the whole group such as Material Number, Material Short Text, Product Hierarchy, Material Group; Data, valid for single plant such as Purchasing Data, Work Scheduling Data; Data, valid for single storage location such as Description Storage Location. Stock Level (SL) 50, 51, 60, 70, and 80 are explained in chapter 2.2.3, and the material types have been also defined as Z10, Z11, Z12, Z13, ZXX. Those numbers will be also found in storage and production concepts.

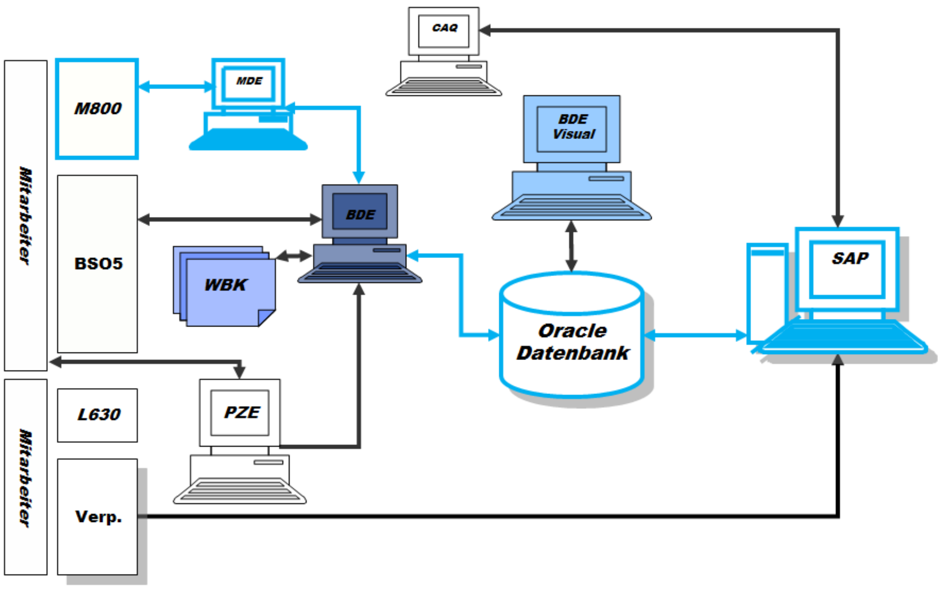



Figure 2.5 IT System at MSA (modified from MSA)

MSA employs the Oracle Datenbank (Sybase ASE) for the interface between Manufacturing Execution System (Cronetwork MES) in Vorchdorf and SAP, see the Figure 2.5. Cronetwork, which is the MES software from the company *Industrie Informatik*, is used at Miba Sinter Austria (MSA). Manufacturing Execution Systems (MES) provide an integrated toolset for the optimization of production processes. It integrates management, quality management, production planning and scheduling, IT and individual production employees in together in order to get an overall enterprise profit. Cronetwork as one of the MES softwares, which is the efficient toolset for production planning and control and for production optimization. Using an MES brings transparency to highly complex production tasks and supports you in the planning and control of orders all the way to the finished product. By collecting correct data that reflect reality and evaluating these data, you acquire a reliable basis for the control and optimization of your processes.

Cronetwork consists of modules: advanced planning and scheduling (APS), plant data collection (PDC), machine data collection (MDC), process data collection, transport and forklift management, time & attendance (T&A) and so on. Those modules are in german: Advanced Planning and Scheduling (APS), Betriebsdatenerfassung (BDE), Maschinendatenerfassung (MDE), Prozessdatenerfassung, Transportsteuerung, Personalzeiterfassung (PZE). In this paper the german name will be taken.

There are two types of operational data: organizational data that involves order and personal data and technical operating data that involves machine and process data. The order data shows production data such as times, numbers, weights, qualities, quantities and work progress, order status, confirmation of order-related job performance with respect to individual operations. The personal data is about labor cost and access control. The machine data includes every data related to machine like the run time, downtime, interruption, the quantity of parts produced, machine reports and disturbances, the intervention of operating workers, maintenance data (runtime, operation cycle), consumption of materials, energy and resources, and measurements of the temperature in warehouses or production, pollution limits and so on. Quality, process parameters and setting data belong to the process data. Those data communicate in BDE Visual and the integrated data can be a solid basis for targeted evaluations and analysis.

**Cronetwork Maschinedatenerfassung (MDE)** has the ability to connect any production machine, regardless of manufacturer or year via modern standardized connection technology and ensures precise and unambiguous real-time collection of machine status such as production, stoppage or disturbance. The status of the connected machine is automatically detected and a feedback is generated. Likewise piece counts, scrap quantities and disturbance reasons are recorded in this way. The machine status is always reachable at any time, no matter whether a machine or sensors on conveyor belts send automatic signals, or whether signals are sent via field bus modules or communication is handled at SCADA levels (control) at the machine via OPC (Kondor, 2015) or SQL interfaces. OPC is increasingly being used to interconnect Human Machine Interface (HMI). Automated feedbacks from Cronetwork MDE reduce the number of required manual inputs to a fraction. This saves personnel costs and largely prevents errors. The received data of utmost quality will be as the basis for subsequent evaluation and analysis such as OEE, OEE with disturbance at MSA. MDE at MSA currently also transfers status of piece quantity to BDE for checking whether or not the pieces have been produced in the production, e.g. the batch production is 150.000 pieces, 149.700 pieces are good and 300 are scrap, 600 minutes downtime, however, MDE generates only a signal: “yes, produced 149.700 pieces”. There is an overview in BDE about the type and duration of disturbance, which workers have to register each time, e.g. 250 - technical problem starts at 9:00 and ends at 10:00. Unfortunately the detailed reasons and solutions for the disturbances are invisible. No people will write the special skills they know. But the short description of the problems is given by the professional maintenance personnel in SAP.

Process data are generally collected with a view to quality assurance or documentation obligations. These are often sensor data such as pressure, temperature, moisture and energy consumption, and these are collected more often than plant data and saved with reference to their order (job/batch). Those data can also be collected by MDE server for accurate machine evaluation and perfect traceability beyond machine boundaries. But MDE server at MSA has not yet taken this ability. Cronetwork creates a homogeneous basis for simple connection to the machine level via standardized interfaces (e.g. OPC, Web services). Via pure archiving of the data, the data can be associated, aggregated and evaluated via statistical functions. Comfortable business intelligence (BI) tools allow you to access the data anytime.

At MSA the production data e.g. production run time, shutdown time, setup time, Sunday and holiday production etc., is managed in this way. Take an example of the disturbance, a clear disturbance overview of machines (machine name, disturbance type shown in Appendix C and duration time etc.) is given in business intelligence (exactly in Production Info Plus). The data can be also directly exported in Excel for archiving.

**Betriebsdatenerfassung (BDE)** is a collective term for the collection of actual data about states and processes in plants. Figure 2.5 shows the BDE interface. Therefore, the current status of the production is always in sight and this data can be integrated into plant information management systems, manufacturing execution system (MES) or SCADA systems.

At Miba this data is integrated into cronetwork MES (cronetwork and BDE Visual are defined the same in the company). Data collection is carried out centrally over monitor workstations at central production planning and control (PPC) systems, e.g. over monitor workstations at decentrally BDE systems or control centers, through data collection terminals or via direct Maschinedatenerfassung (MDE). The identification of the "BDE-object" often, e.g. of an operation, for which a BDE message is to be registered with barcode support. The BDE is hierarchical. It consists of BDE-machine, BDE-range terminals, BDE-group computers which are connected by BDE interfaces to a host computer.

**BDE** at MSA has two concepts (as shown in the Figure 2.6):

- **transport (WBK)**
- and **disturbrances** (see the Appendix C).

**Disturbrances** is specified in chater 5.

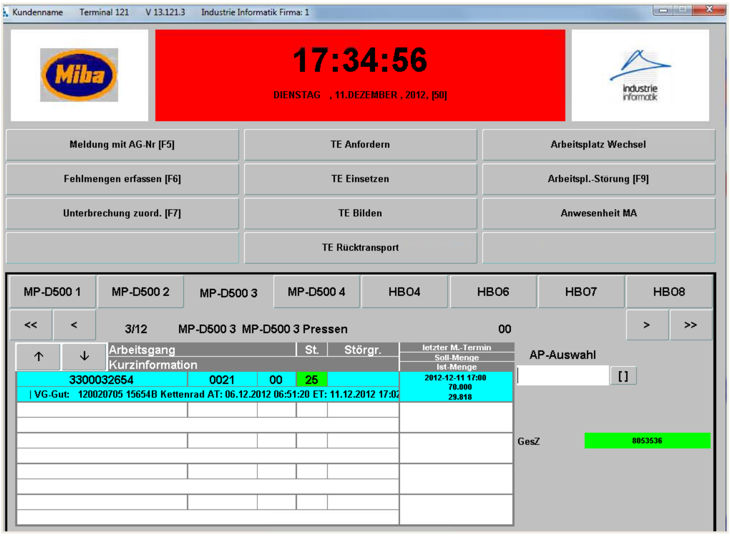



Figure 2.6 BDE-Terminal with new functions (MSA)

At MSA Warenbegleitkarten (WBK), which is the identification cards of the pallets, has taken this responsibility. The goal of WBK-System is to integrate transportation and traceability system for all production steps (powder compress to shipping), distribution and external works. It includes the registration and control of transport unit, edition of the transport tasks for forklift terminals via specific software, stock information on pitch level, new optimized labels and automatic printing of accompanying documents. Systematic FIFO presets and controls, traceability system on transport unit level (pallet level) etc., see the Figure 2.7. **Transport** and **Forklift management** are supported by Cronetwork

The characters of the WBK- System are following:

- Each pallet is uniquely identified by order number (Auftragsnumber), production steps number (AG Number), FIFO number.
- The pallet sequence will be preset and controlled.
- After each production step, a new label card is generated for each pallet.
- FIFO Numbers start after every production step with “1”.
- Automatically generation of transportation tasks with the labelling print.
- Forklift driver can deposit location of every transport unit.
- Barred products cannot get in use for production.

- Status “unlocked” (separated parts) is relayed.
- Unit traceability.
- For small reworking operations - set unit in lock mode.
- Permanent connection of external operators to the system in the near future.

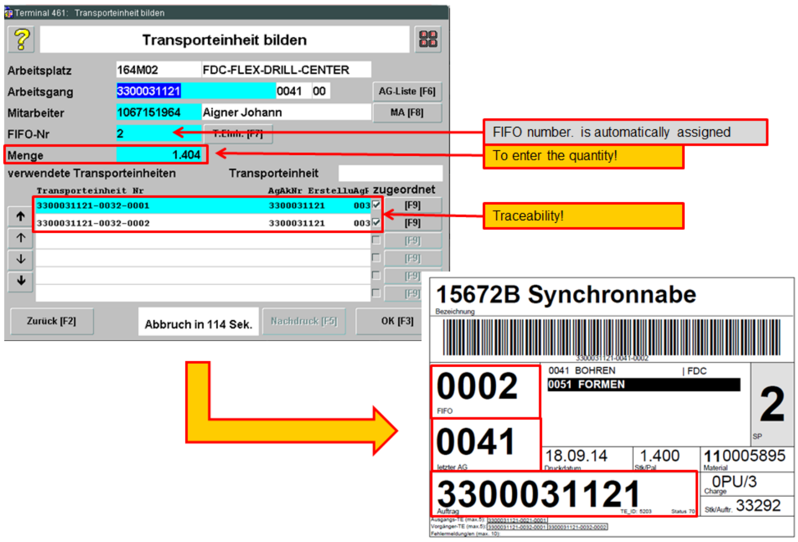



Figure 2.7 The creation of the transport unit – label print (MSA)

In serial production, labeling each pallet and the storage of corresponding relevant production data is required for complete documentation and traceability. For this purpose, the production order can be divided into any number of elements, often containers or boxes, here is pallets. Each of those pallets is assigned an accompanying map (WBK). This data set can record the required information such as raw material batches date, time, shift operator auditors, FIFO and so on. Each packing unit receives a label with a unique number. With this number, the data can be read immediately on the tracing. Therefore, the data stored in the Warenbegleitkarten (WBK) is given unmistakable in the final packaging of the packaging unit. The related workers will recognize the pallets for production orders via barcode in the WBK-System.

### 2.2.3 Value Streams Mapping (VSM)

The **value stream** is driven by customer demand, and it is necessary to keep maximizing added value across the chain in mind (Willmott & McCarthy, 2001, P. 193). It is an effective method to recognize the wastes in the production. For eliminating wastes and maximizing added values, other methods, such as total productive maintenance (TPM), is shown in chapter 5.

A value stream is all the actions (both value-added and non-value-added) currently required to bring a product through the main flows essential to every product: (1) the production flow from raw material (upstream) into the arms of the customer (downstream), and (2) the design flow from concept to launch. This paper focuses on the production flow from customer demand back through raw material, which is the flow we usually relate to lean manufacturing (Rother & Shook, 1999, p. 1ff).

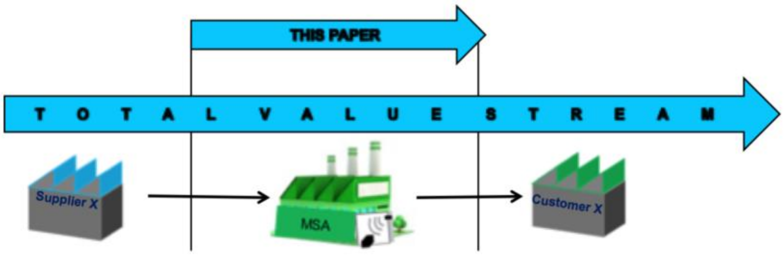



Figure 2.8 The “door-to-door” production flow (modified from Rother & Shook, 1999, P. 1)

Taking a value stream perspective means working on the big picture and focusing on building a map of the entire chain, not just individual process and optimizing the parts.

This paper covers the “door-to-door” production flow inside a plant, including shipment to the plant’s customer and delivery of supplied parts and material, see the Figure 2.8.

**Value-stream mapping (VSM)** is a special type of flow chart that uses symbols known as "the language of Lean" to depict and improve the flow of inventory and information. It is a planning tool and aim to optimize results of eliminating waste. At Toyota, it is known as "material and information flow mapping".

The term “value” is what the customer is buying and is defined by the customer. It is a capability provided to a customer of the highest quality, at the right time and an appropriate price,

VSM is a pencil and paper tool that helps you to see and understand the flow of material and information as a product makes its way through the value stream. Follow a product’s production path from customer to supplier, and carefully draw a visual representation (see the VSM in chapter 2.2.3) of every process by just waking a walk though whole material and information flow.

A typical VSM should answer those questions: where does it come it? How does it move? How long does it stay at any one stage? It should easily be recognized which steps are the value-adding and non-value-adding (Zylstra, 2005). The basic pattern of all value-stream maps is that the material flow is shown from left to right across the lower portion of the map and the information flow will be drawn from right to left across the upper portion of the map.

In addition, mapping is not the destination but we use this technique to see and focus on flow with a vision of an ideal, or at least improved, state.

Within the production flow, the movement of material through the factory is the flow that usually comes to mind. But there is another flow - of information - that tells each process what to make or do next. Material and information flow are two sides of the same coin. Both have to be mapped in the value stream mapping. In lean manufacturing the information flow is treated with as much important as the material flow. At Toyota, the intercommunication of supplier, company and customer are defined as information flow; the production flow of a product is material flow.

Miba Sinter Austria (MSA) has been driving their production to lean manufacturing. The value stream mapping (VSM) is one of the most important principles in the company.

At MSA, each product can be allocated to a certain type of value stream, which can be distinguished by number of stock levels (SL) and the differentiation between Miba-tacted and Customer-tacted processes.

Miba-tacted processes mean that company defines the produced amount of components. The production produces pieces according to the customer orders, which is referred as Customer-tacted processes.

The safety stock (SL) covers unexpected situations and avoids running out of stock. On the one hand SL has to continuously be adapted on the basis of experiences in the past or on basis of risks in the future. On the other hand it is necessary to work on the reasons, which cause the need of safety stock, to reduce safety stock systematically. The following two possibilities for defining the level of safety exist:

- Safety stock level is defined by customer request and the SLA (normally finished parts)
- Safety stock level is defined as X% of annual consumption

Due to the continuous change of consumption the safety stock has to be adapted on a regular basis. To cope with that situation the coverage profile in SAP is used.

SL50, 51, 60, 70, and 80 represent the storage of the raw material, semi-finished powder mixture, semi-finished components, finished components (produced parts without packaging), and finished components after packaging respectively. When the value stream involves Customer-tacted processes, the SL60 will be defined.

Figure 1.1 depicts the types of value streams, which are defined within MSA. These value streams define the number of stock levels, disposition strategies as well as the control process within the production. The disposition strategies will be fine turned on the basis of the ABC/XYZ-analysis. This item and control process will not be discussed in the paper because they involve many other parameters and have no direct connection with the arguments of this paper.

The definition of the value stream is based on the following five rules, which are also mirrored by Figure 2.9:

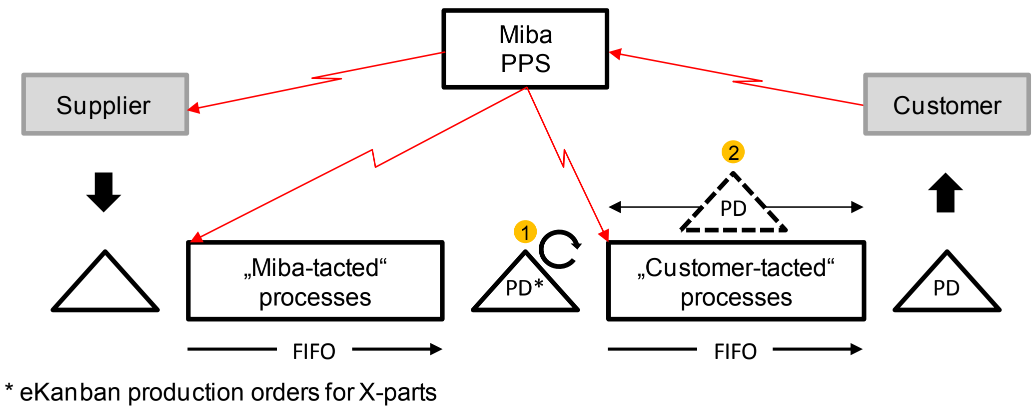



Figure 2.9 Framework for the definition of value streams (MSA)

**Rule 1:** Separation “Miba-tacted” processes from “Costumer-tacted” processes by using a stock level 1.

**Rule 2:** Usage of an additional stock level if certain technical restrictions and SLA requirements cannot be fulfilled by the stock level out of rule 1 2.

**Rule 3:** Decoupling of external operations by using a stock level before external operation.

**Rule 4:** Consumption-based control of “Miba-tacted” processes, demand-based control of “Customer-tacted” processes.

**Rule 5:** Order-based FIFO between processes.

Additional definitions for allocation of each product, such as service parts or prototypes as well as low volume parts (< 50.000 parts per year), to a certain type of value stream:

- Low volume parts (<50.000 parts per year): Type B
- Service parts: Type B
- Prototypes: Type D

Value streams of products, which do not comply with these requirements, have to be redefined.

Lastly, Overall turnover Miba Sinter Austria 2013/14 (01.10.2013 – 01.10.2014) is € 137.893.131, 00.

Turnover from PU4 in this period is € 57.000.763, 00 with the produced pieces 12.569.478 (30% of yearly pieces at MSA).

It means PU4 occupied approximately half turnover from total turnover. The ABC-Analysis shows that the component 1.3.445 is one of the A products in the PU 4.

Therefore, this paper maps the value stream for the component 1.3.445 in the PU4.

### 2.2.4 Value Stream Mapping of Production Unit 4

Before the description of the value stream mapping of PU 4, some lean measurements are necessary to be defined: Cycle Time (C/T), Value-Creating Time (VCT), Lead Time (L/T).

Cycle Time (C/T) measures how often a part or product actually is completed by a process, as timed by observation. Also, the time it takes an operator to go through all of their work elements before repeating them.

Value-Creating Time (VCT) or the processing time measures the time of those work elements that actually transform the product in a way that the customer is willing to pay for. The VSM as shown in Appendix B shows the total processing time involved in making one piece is 30.3 seconds.

Lead Time (L/T) measures the time of one piece to move all the way through a process or a value stream, from start to finish. Envision timing a marked part as it moves from beginning to end. The VSM as shown in Appendix B shows the total production lead time is 46 days. In addition, for mapping with multiple upstream flows the longest time path will be used to compute total lead time.

The start point of value stream is the customer; see the VSM as shown in Appendix B.

The customers forecast yearly, monthly, weekly. Two weeks forecast schedules the next twelve weeks production need. The frozen time is weekly although the customers want to freeze their orders as later as possible.

Based on those forecasts, production planners make weekly and daily production schedule. Weekly schedule will look for next ten weeks production plan. Then the schedule will be transferred to the supervisors or coaches in the shop floor, further to the relating responsible workers. At last, the workers setup machines according the schedule. After one shift, the machines will be ready for the production use. The through-put-time on average lasts six weeks from setup to shipment.

The material flow begins from the fine powder in production stock or milk run from consignment stock, after compacting and sintering (continuous process) the two third of pieces will be transported to production stock and one third of pieces will be transferred to the next workstation via palette truck for sizing, after packaging the pieces are ready for shipping to the first supplier for hardening, after it the pieces will be shipped back to in-house for quality check, removing the important information from this supplier and then packaging the pieces for next supplier, after turning and honing from the second supplier the pieces will be back to company to recycle the steps that is described in the first supplier until the third supplier ships the pieces back to the company after the washing, the final quality check and packaging are done, the pieces can be ready for shipping to the customers.

Furthermore, the company forecasts monthly, weekly and daily powder order based on the production schedule and SAP datum.

**With this value stream mapping, there are some issues can be seen:**

(1) Customers expect to freeze orders as later as possible, but the company would like to accept the frozen order as early as possible. The same situation exists also between the company and their suppliers. The frozen orders can be done earlier to our supplier only if the customer orders could be frozen earlier, but even so the suppliers will be informed later because of the transferred time and some other disturbances.

(2) The schedules will be delivered firstly to the supervisors in shop floor, not possible yet directly to the various responsible workers with machines, which delay the schedule and production. In contrast, the information will be also delayed to the planner or/ and other relating people when the schedules cannot be executed in the production due to the disturbances.

(3) Whether or not the fulfillment timely of schedules depends on personal check and daily machine reports from BDE Visual (Cronetwork). There is no current status of production visible (no overview). Disturbances need time to be recognized and make a solution or repaired.
Overall, the existing information technologies are not smart enough.
It means the information is not seamlessly intercommunicating within the automation pyramid: from field devices (sensor/actuators) and programmable logic controllers (PLC) through the process management and manufacturing execution systems (MES) to the enterprise level (ERP) software.

(4) The production plan needs at least one shift to be executed due to the setup tools and the throughput time needs on average at least 6 weeks due to batch production and other various reasons. The changeable orders in the forecast or unpredictable small amount of orders mainly depend on safety stock.

(5) The material movements that are pushed by the company, not pulled by the customer. “Push” means that a process produces parts regardless of the actual needs of the downstream customer process and “pushes” it ahead. Each process is able to set batch sizes and to produce at a pace, which makes sense from its perspective, instead of the value-streams perspective. This type of “batch and push” processing makes it almost impossible to establish the smooth flow of work from one process to the next that is a hallmark of lean production.

(6) Inventory mainly due of batch production. It means the inventory exists forever as long as the batch production takes the place of the lean production. The batch production will always play the key role as long as the production system is not highly flexible and reconfigurable, as long as the industrial control systems cannot provide a high interoperability and adaptability of networked automation devices.

(7) Production lead time last too long in comparison with processing time, primarily because the external supply chain need approximately 35 days. Most of times the pieces are waiting in the stock and on the way due to the quality check and movement of supplier' information that are done at home. The efficient way is not in use in the external supply chain.

(8) Labeling system works well at MSA, but not for future because of its limitations, such as it needs line of sight, can only be read and not changeable once it has been printed onto a label, data is not able to be encrypted, limits on the amount of stored information and so on.

(9) Delivery on pieces could not completely be just-in-time (JIT), which could not satisfy the customers. There are lots of reasons to influence delivery, such as disturbances as shown in Appendix B. An example is that the unpredicted change of one schedule could not immediately inform internal relating people and external suppliers. The efficiently action will delay due to the information delay.

All the issues, which are mentioned above are quite normal to the industrial manufacturers, exist more or less in all the big companies all over the world. Industrie 4.0 tries to make a quantum step via providing the solutions for those common issues.

The solutions will be given in chapter 4 in the view of Industrie 4.0.

# 3. A modern paradigm for industrial Automation

The automation pyramid that is shown in the Figure 2.3 has been treated as typical industrial control architecture. It comprises various layers that represent different automation levels. The drawback of this traditional structure in automation is the overall lack of integration capacity and a high complexity. Additionally, the control programs are hardware-dependent and complex since the programming takes place on signal level (PLC). Nevertheless, today's control architectures don't meet the requirements concerning horizontal and vertical integration and an advanced software design and implementation. To cope with these demands new concepts for industrial automation are required in order to a layer-spanning connection of different automation devices special middleware is needed which is tailored to the respective application (Zühlke & Ollinger, 2012).

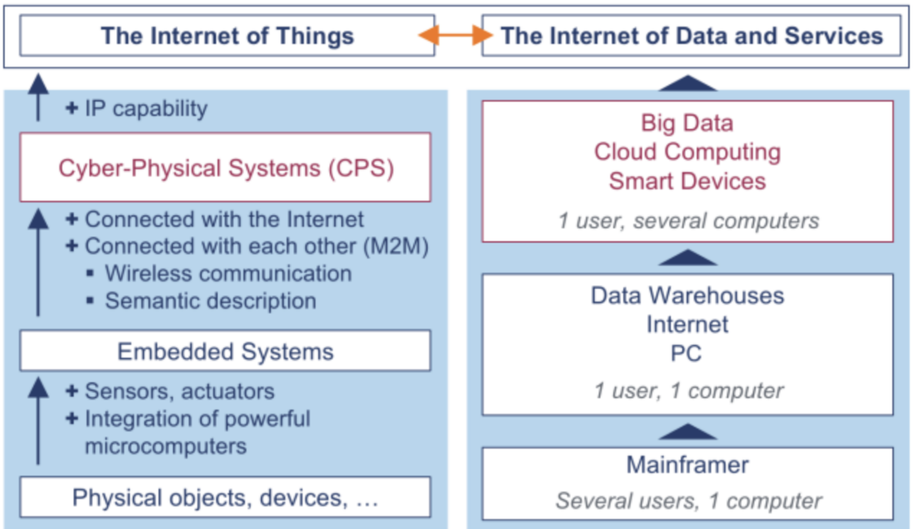



Figure 3.1 Two convergent technology developments as drivers of innovation

(modified from Kagermann, 2014, P. 8)

In the 1980's, the first wave of IT technologies is integrated into the factories, which is called computer integrated manufacturing (CIM). The vision was to set the totally automated planted up for solving cost and quality problems. Since the beginning of 90's the lean production is introduced in the western industry, this vision has been faded out due to its complexity in planning and operations and immaturity in technology as well as no role for human being. Actually no factory achieves lean production yet. Lean means reducing complexity and avoiding waste, but our factory is becoming more and more complex whilst suffering from large inventory and downtime due to the disturbances. Nowadays, the development of computer science and information and communication technologies has become the biggest driver for the industrial automation system of the production plant. It is expected to integrate computer science and CIM into manufacturing science and technology (MST) to the maximum extent, which could make a quantum leap for the automation systems and ultimately formulate a modern paradigm up for industrial automation.

The following two concepts are desired to develop such a new control paradigm for industrial automation: Cyber-Physical Systems (CPS) and Service-oriented Architecture (SOA). For seamlessly incorporating those concepts into the traditional automation system, it is necessary to clarify various different affordable technologies, as depicted in the Figure 3.1 (Albach et al., 2015, P. 25), in order to create synergies that in turn lead to qualitatively different opportunities and impacts that ultimately come to be as the $4^{th}$ Industrial Revolution, frequently noted as Industrie 4.0. The Internet of Data and Services can be seen in chapter 2.1.2. This chapter emphasizes on the sensors, embedded systems and CPS from this Figure.

## 3.1 Cyber-Physical Systems (CPS)

Industrie 4.0 addresses the convergence of modern computer science and information and communications technologies with traditional manufacturing science and technologies to so-called "Cyber-Physical-Production Systems (CPPS).

Definition between Cyber-Physical Systems (CPS) and Cyber-Physical Production Systems (CPPS):

- Cyber-Physical Systems (CPS) are systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the internet.
- Cyber-Physical Production Systems (CPPS), relying on the newest and foreseeable further developments of computer science (CS), information and communication technologies (ICT), and manufacturing science and technology (MST) may lead to the fourth Industrial Revolution, frequently noted as Industrie 4.0.

### 3.1.1 Sensors in General

In recent years, the topic on the sensors is becoming more and more popular, which is mainly because not only the information processing has been largely developed in the electronics industry, but also the availability of inexpensive microprocessors influences tremendous on the design of embedded products equipping with computing and communication. I introduce sensors here is because they are the base of embedded systems, further the base of CPS. Additionally, they are also one of the crucial elements to let physical objects, such as machines, be intelligent. This is describing in chapter 5.

Sensors can be classified in many ways. Nevertheless, according to the structure of this paper only one type will be specified. Additionally, this paper is mainly for industry use and thus the normal sensors here are referred as industrial sensors.

Finally, according to the evolution of sensors, sensors will be classified into four items: industrial sensors, smart sensors, integrated smart sensors, (Meijer, 2008, P. 3ff) and wireless sensor network.

#### 3.1.1.1 Basics of Sensors

*"A sensor is a device that converts a physical phenomenon into an electrical signal, and thus tends to be characterized as electronic device"* (Kenny, 2005, P. 1ff).

Signals are classified into six domains in terms of energy: electrical, mechanical, magnetic radiant, thermal, and chemical (Yurish & Gomes, 2004, P. 15).

A sensor is one type of a transducer whose aim is to sense things in the environment. The difference should be clarified. In terms of the types of energy a sensor converts any one type of energy into electrical signal, and but a transducer is able to transform one form of energy into another form of energy, such as magnetic, (Fraden, 2010, P. 3ff). A classic example for a transducer is the loudspeaker that converts an electric signal to sound. Thus, sensors and transducers are the energy converter.

Sensors can be seen as a special interface between measurands or sensing elements in the form of raw data/ bytes, and electrical devices or computing elements that is responsible for data processing and analyzing. Later those processed electrical signals from sensors will be received and converted into a series of actions (kinetic energy of movement) by actuators that are the actuation elements. In general, sensors usually work with actuators together to build up a sensing-processing-actuation loop.

There are several essential sensor characteristics are following (Kenny, 2005, P. 2ff):

(1) **Transfer Function** uses usually a graph that depicts the relationship between input and output signal.
(2) **Sensitivity** see also chapter 5.3.1.
(3) **Span or Dynamic Range** is the defined range of effective input signals of a sensor.
(4) **Accuracy or uncertainty** is the tolerance of the output signals between defined and actual values.
(5) **Hysteresis** is the tolerance of the input signals in terms of measured quantity.
(6) **Bandwidth** is the frequency range between upper (response time) and lower (decay time along the time) cutoff frequencies.
(7) **Linearity** describes the maximum deviation the item "transfer function" over the item "Span or Dynamic Range" on the basis of a straight line (ideal).

(8) **Noise** is produced by sensors.
(9) **Resolution** is defined as the minimum detectable signal fluctuation and can be specified in units of physical signal/root (Hz).

To sum up, it is important to understand the designed functions of sensors, which could make you take less efforts when you are about to choose a sensor for the use. Some characters are also described in chapter 5.3.

#### 3.1.1.2 Definition of Smart Sensors

Today the demands on the sensor are increasing in terms of performance, size, and cost with the rapid development of the standard process for **Very-large-scale integration (VLSI)**, **silicon micromachining and fabrication**.

**Very-large-scale integration (VLSI)** is one of the categories of the integrated circuits (ICs) that are based on the number of transistors or semiconductor devices or active devices per chip. It is regarded as VLSI when one chip is integrated more than 100,000 of transistors. Moreover, there exists also small scale integration (SSI) with less than 100 transistors, medium scale integration (MSI) with the number of transistors between 100 and 10000, large scale integration (LSI) with the amount of transistors between 1000 and 100,000, and ultra large scale integration (ULSI) with over one million of integrated transistors per chip (Godse & Bakshi, 2009, P. 4-1ff).

**Silicon micromachining technology**, which mainly stems from silicon microfabrication, in particular, from integrated circuit (IC), inherits the primary characteristics of IC, such as small size and large quantity. In the field of microelectromechanical (MEM), silicon micromachining is known as the bulk micromachining with a single-crystalline silicon substrate (Irwin, 1997, P. 1468).

An advanced type of sensors is called for meeting those increasing demands, which is referred as a smart sensor.

*"Smart sensor (or intelligent sensor) is one chip, without external components, including the sensing, interfacing, signal processing and intelligence (self-testing, self-identification, self-validation or self-adaptation) functions"* (Huijsing, Riedijk, & Horn, 1994, P. 1ff).

A smart sensor is the combination of four elements in one housing (Meijer, 2008, P. 9):

- a sensor,
- an analog interface circuit,
- an analog to digital converter (ADC)
- and a bus interface

Figure 3.2 depicts three kinds of combination of smart sensors. The type III achieves the highest integration. The type I has the lowest integration level.

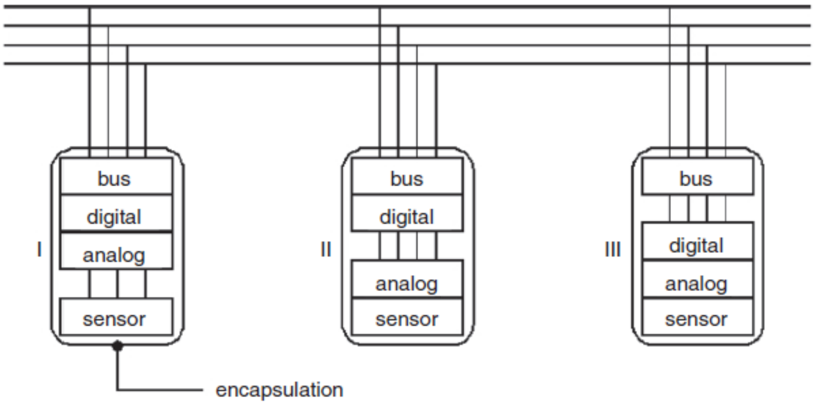



Figure 3.2 Hybrid smart sensors (Meijer, 2008, P. 9)

#### 3.1.1.3 Definition of Integrated Smart Sensors

Another advanced type of sensors is called the integrated smart sensor in order to meet the increasing demands on sensors in terms of the highest performance, the smallest size, and the lowest cost as mentioned before.

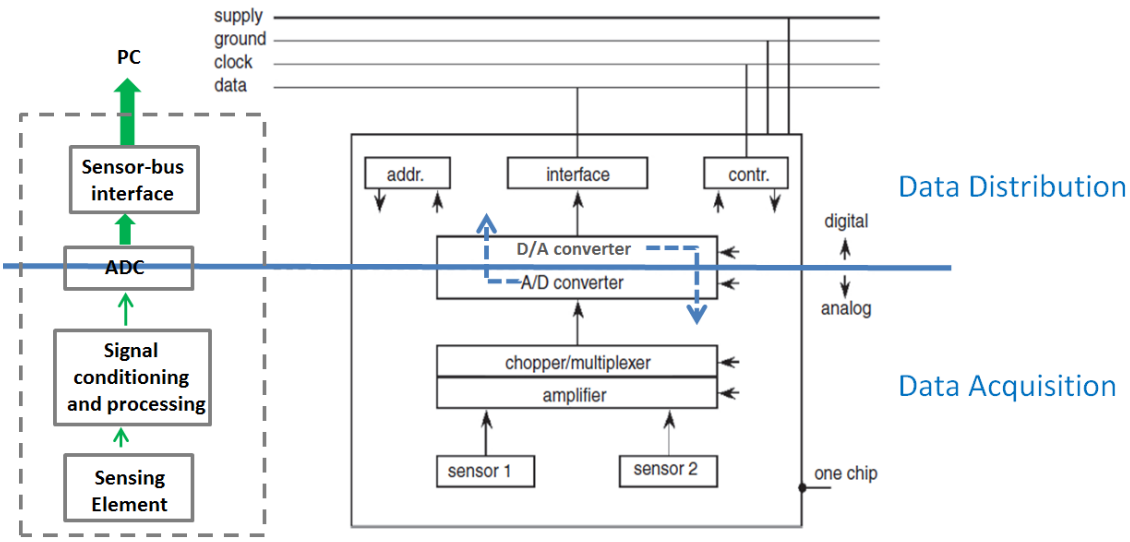



Figure 3.3 Functions of an integrated smart sensor

(modified from Meijer, 2008, P. 9; Yurish & Gomes, 2004, P. 5)

The integrated smart sensor per node should integrate all the necessary functions of sensors, through the microelectronics in terms of amplifiers, a chopper and multiplexers, an AD converter, buffers, to bus interface, addresses, and control and power management together in one chip (Yurish & Gomes, 2004, P. 9), (Meijer, 2008, P. 9). This is depicted in Figure 3.3.

From the figure it could clearly recognize that the sensors have been integrated on one chip. In this chip a central controller or microprocessor or a master node normally, which is heart of the integrated smart sensors, processes the raw data and also control the actuators, such as Actuator-Sensor Interface (ASi), Controller Area Network (CAN) etc. it is also seen that this integrated concept can be also noted as two levels: data acquisition, and data distribution (Wolffenbuttel, 1996, P. 4ff).

*“Data Acquisition (DAQ) is collecting and measuring electrical signals from sensors and/or transducers and inputting them to a computer for processing”* (National Instruments, 2000).

Date distribution could be done among the system nodes by the Data Distribution Appliance (DDA) that acts as a server node (National Instruments, 2001).

The integrated smart sensor is generally referred to as the integrated silicon smart sensor according to the material of sensor. This kind of integrated smart sensor will not corrupted by non-idealities of the basic sensing element. Furthermore, it is of the functions of the self-calibration and self-test. Lastly, the output signal is done via a standard serial bus protocol (Wolffenbuttel, 1996, P. 12f).

Additionally, it will be better to consider the same material of sensor and microelectronic for the material compatibility, for example, silicon sensor and silicon microelectronic, when the integration happens.

To sum up, the integrated smart sensor still have long way to go not only because of the technology - the fully integrating all sensors for different functions in one chip, but also because of the cost.

#### 3.1.1.4 Definition of Wireless Sensor Network

So far, the sensors sense and send raw data, only if the data exceeds a given threshold, to the base-station or a sink node that acts as a gateway providing the actuators with an actuation signal after analyzing and processing the raw bytes, which will be accomplished in one chip.

However, the vision of future is not only to integrated from all the functions (sensors) to bus interface, but also to integrate the wireless power source and wireless communication in one chip. The Figure 3.4 has shown this concept.

The mechanical sensing devices in the integrated smart sensor systems are equipped with wireless radio modules when they deployed in a field network, which is commonly known as a wireless sensor network.

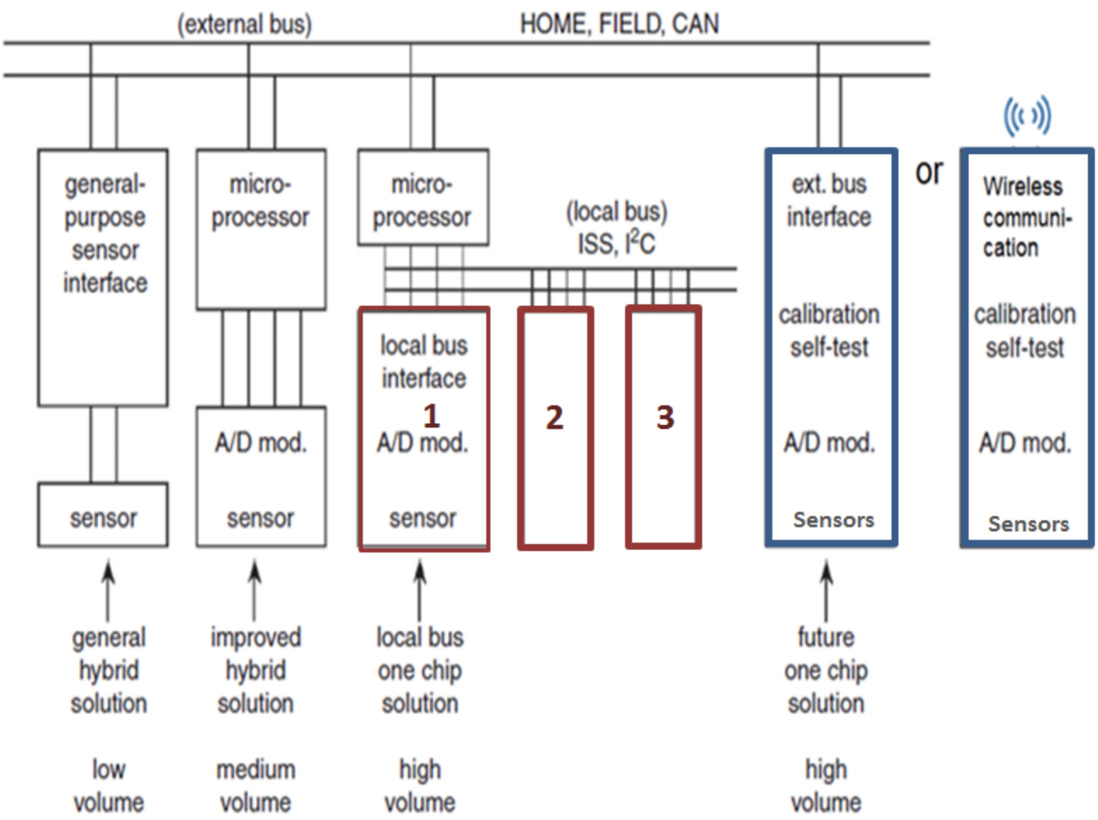



Figure 3.4 The evolution of smart sensor system

(modified from Meijer, 2008, P. 12)

Figure 3.4 depicts the progress of integrated smart sensor systems from low volume to high volume, in which high volume includes two solutions on the basis of bus or wireless interfaces of the output or processed signals.

### 3.1.2 Embedded Systems

Until the late eighties, information processing was associated with large mainframe computers and huge tape drives. During the nineties, this shifted towards information processing being associated with personal computers, PCs. The trend towards miniaturization continues and the majority of information processing devices will be small portable computers integrated into larger products. Their presence in these larger products, such as telecommunication equipment will be less obvious than for the PC. The most profound technologies are those that weave themselves into the fabric of everyday life until they are indistinguishable from it. Hence, the new trend has also been called the disappearing computer. However, with this new trend, the computer will actually not disappear, it will be everywhere. This new type of information technology applications has also been called ubiquitous computing (Weiser, 1991), pervasive computing (Hansmann et al., 2001, P. 24), and ambient intelligence (Marzano & Aarts, 2003). These three terms focus on only slightly different aspects of future information technology. Mark Weiser expressed ubiquitous computing of the following sentence: "*in the 21st century the technology revolution will move into the everyday, the small and the invisible*", whereas pervasive computing focuses a somewhat more on practical aspects and the exploitation of already available technology. For ambient intelligence, there is some emphasis on communication technology in future homes and smart buildings. Embedded systems are one of the origins of these three areas.

Marwedel defines that *"embedded systems are information processing systems that are embedded into a larger product and that normally not directly visible to the user* (Marwedel, 2006, P. xiii). Another definition is from Steve Heath in his book embedded systems design: *"an embedded system is a microprocessor-based system that is built to control a function or range of functions and is not designed to be programmed by the end user in the same way that a PC is"* (Heath, 2003, P. 2).

The embedded system exists at the different degree in the mentioned smart sensors, integrated smart sensors, integrated smart sensor systems and wireless sensor network.

The characteristics of embedded systems are following (Marwedel, 2006, P. 1ff):

- Frequently connected to the physical environment through sensors collecting information about that environment and actuators controlling that environment.
- Dependability in terms of reliability, maintainability, safety, and security.
- Efficiency in terms of energy (mainly battery), code-size (the compatibility between storage space and size), run-time efficiency (the minimum utilization of resources for maximum required functionality), weight and cost.
- Embedded systems are dedicated towards a certain application. For running additional programs it is not acceptable because of dependability etc.
- A dedicated user-interface (do not use keyboards, mice and large computer monitors for their user-interface), see in the disappearing computer.
- They must meet real-time constraints. In the context of real-time systems, arguments about the average performance or delay cannot be accepted. For example, Internet protocols typically rely on resending messages in case the original messages have been lost.
- Hybrid systems including analog and digital parts. Analog parts use continuous signal values in continuous time, whereas digital parts use discrete signal values in discrete time.

- The reactive systems. "*A reactive system is one that is in continual interaction with its environment and executes at a pace determined by that environment* (Rouillard, et al., 1995, P. 2)".
- Embedded systems are under-represented in teaching and in public discussions.

The result of the connection of embedded systems with global networks is a wealth of far-reaching solutions and applications for all areas of our everyday life.

### 3.1.3 Basics of CPS

#### 3.1.3.1 Why is CPS?

Cyber-Physical Systems find use in industrial automation, especially at the sensor-actuator level where sensors and actuators interact with the physical equipment, because the rising demands on production systems concerning flexibility and configurability call for the new industrial control systems providing a high interoperability and adaptability of networked automation devices.

CPS has been proven to meet those demands and could further achieve a new control architecture that is called the automation network. This is depicted in the Figure 2.3. With this network devices are able to intercommunicate and have some computational power, which results in a strong horizontal and vertical integration within automation systems.

#### 3.1.3.2 What is CPS?

CPS is based on the embedded systems.

For the embedded systems, the link to physics and physical systems is rather important. This link is emphasized in the following citation (Lee E. , 2006, P. 3):

*"Embedded software is software integrated with physical processes. The technical problem is managing time and concurrency in computational systems".*

The strong link to physics has recently been stressed even more by the introduction of the term "Cyber-physical Systems" (CPS or "Cy-phy" systems for short). Cy-phy systems can be defined as follows (Lee E. , 2007):

*"Cyber-Physical Systems (CPS) are integrations of computation and physical processes".*

It means that the physical process affect computation and vice versa.

Cyber-Physical Systems (CPS) are systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the internet (Monostori, 2014). It is not really clear which industrial communication the CPS must to take. However, Cyber physical systems will not only be operating in a controlled environment, and must also be robust to unexpected conditions and adaptable to subsystem failures (Lee E. , 2007, P. 3ff).

A CPS comprises a network of physically distributed embedded sensors and actuators are equipped with computing and communication capacities (Tabuada, 2011). They constitute integrations of computation with physical processes by monitoring and controlling the physical process by embedded computers (Lee E. , 2008).

The goal of the Cyber-Physical Systems (CPS) is to enable things to be connected anytime, anyplace, with anything and anyone ideally using any path/network and any service. The Internet of Things (IoT) has the same goal as CPS but IoT is a "global concept" that describes the global things from the world (Vermesan & Friess, 2013, P. 15).

#### 3.1.3.3 The Enablers of CPS

Today, many different network types have been promoted on a shop floor with cables on internet, such as *"control area network (CAN), process fieldbus (Profibus), Modbus, and so on. Nevertheless, how to select a suitable network standard for a particular application is a critical issue"* (Lee et al., 2007).

Additionally, for accessing networks and services without cables, wireless communications is a fast-growing technology to provide the flexibility and mobility (Willig, 2003). The wireless communication guarantees new freedoms in plant layout and reduces the planning effort in that cabling is no longer required. In combination with the modular construction it allows the facility to operate according to the "plug-in work" principle due to its nature of flexibility and mobility. This principle describes that the field devices can be connected without any configuration effort and the operator will be able to control all functions according to his qualification appropriately. Every element takes on a clear, well-defined function within the process chain. Because no physical connections exist between the components other than the power supply, it is relatively simple to replace or add individual components for a modification or extension of the production processes. The components recognize their function and position themselves within the process chain and integrate automatically into the control systems for plant management. The configuration of the information flow becomes ever simpler because the components identify their tasks from the manufacturing situation and attune themselves to the surrounding components:

In one word, the wireless communication is able to quickly process emergency and errors can be easily tracked.

The wireless technologies as the enablers that are the bases to build up a successful CPS, which are currently only common in the consumer market and it is rare for industry use. They transfer the information via radio in a short-range around 10-100 meters (Lee et al., 2007). Radio waves are a form of electrical energy.

Those wireless technologies are usually held by four protocol standards: the Bluetooth over IEEE 802.15.1, UWB over IEEE 802.15.3 a, ZigBee over IEEE 802.15.4, and Wi-Fi over IEEE 802.11 a/b/g.

Bluetooth started in 1994 and the first version of its specification came out in 1999. The name came from the surname of a Danish king. It is the earliest alternative to the cables and aim for facilitating the communication between mobile devices (Bray & Sturman, 2001, P. 1ff).

Ultra-Wideband (UWB) is a wireless radio technology that stems from UWB radar world for secure military communications and radar via electromagnetic waveforms that are characterized by an instantaneous fractional energy bandwidth (more than 0.20-0.25) (Benedetto & Giancola, 2004, P. 1ff). UWB requires lower power to transfer a large number of digital data over a wide spectrum of frequency bands in a small range (EC-Council, 2010).

ZigBee is a technical standard that defines a set of high-level communication protocols used to create low-data-rate-short-range personal area network (PAN) (ZigBee Alliance, 2008). ZigBee is seen as a future effective energy-saving technology and enables devices (ZigBee-enabled devices) replace their batteries after several years later due to its specific "*sleep mode*" (Farahani, 2008, P. 1ff). Additionally, ZigBee supports star, tree, and mesh topologies (EC-Council, 2010, P. 3), among which all nodes in mesh topology cooperate each other in the distribution of data. This is depicted in the Figure 2.3 and 5.13.

Wi-Fi is a wireless standard or protocol used for wireless communication from Wi-Fi Alliance who is aim for promoting interoperability of devices based on 802.11 (Davis, 2004, P. 8ff).

Each of them offers different advantages and also disadvantages. A comparative list of wireless protocols is attached in Appendix E. Figure 3.5 depicts that ZigBee consumes the least energy.

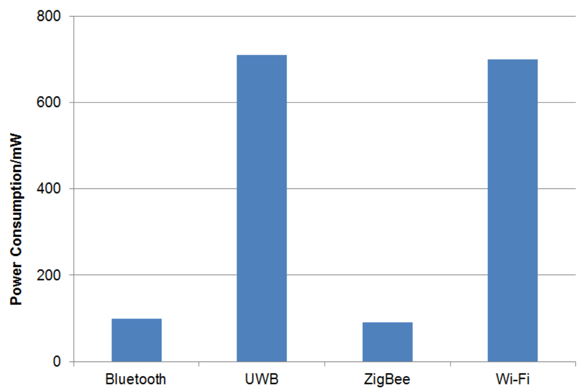



Figure 3.5 The Comparison of the normalized energy consumption for each protocol

(Pothuganti & Chitneni, 2014)

Most modern smart devices have Bluetooth and Wi-Fi built-in and therefore no additional hardware is required for these two wireless protocols. This fact rules out ZigBee, which would need a special, device specific hardware or a Bluetooth or Wi-Fi to ZigBee converter. Such a converter would increase the complexity and latency of the connection and probably introduce some compatibility issues. Although Bluetooth is slower and has a smaller number of cell nodes compared to Wi-Fi, Bluetooth has been chosen as the appropriate protocol for wireless measurements (Tašner et al., 2013).

In addition, Radio frequency identification (RFID) is specially used for traceability. It is maturing for industry use. RFID has been expected a lot for the formulating the automation network due to its maturing market in the realm of industrial area, and its potentials of intelligence. When a highly integrated, low-power and low-cost processor extending with a memory and a wireless communications interface is developed and affixed to each component, the “intelligence” of a central system is moved into every product. Products know their histories and their routers, and thereby not only greatly simplify the logistic chain but also form the basis for product life cycle data memories. When this technology is the master in the mass market, the next step will be couple sensors and actuators on the chip to build up an autonomous actuator-sensor network.

Those radio technologies, which are treated as an extended link from the sensor-actuator level to the other higher levels, have been involved in building the CPS up. It is difficult to give a conclusion regarding which one is superior since the suitability of network protocols is influenced by practical applications and technical factors, such as the network reliability, roaming capability, recovery mechanism, chipset price, and installation cost and so on. Industrie 4.0 tries to combine all the advantages of those network technologies under the consideration by cost and function-driven strategies as specified in chapter 4.3.

### 3.1.4 Definition of Internet of Things (IoT)

One definition has recently been formulated in the Strategic Research Agenda of the Cluster of European Research Projects on the Internet of Things (Vermesan, et al., 2011, P. 10): *“Internet of Things (IoT) is an integrated part of Future Internet including existing and evolving Internet and network developments and could be conceptually defined as a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual “things” have identities, physical attributes, and virtual personalities, use intelligent interfaces, and are seamlessly integrated into the information network”.*

As mentioned in chapter 2.1. IoT is a global concept based on the success of CPS. This paper will focus on CPS – a relevant local networking.

## 3.2 Service-oriented Architecture (SOA)

Cyber-Physical Systems (CPS) improves productivity across shop floors by reducing configuration time and provides an automated way to control different facets of the shop floor (EFFRA, 2013, P. 51).

It is proven that the modern automation system can be achieved via directly linking the components/ smallest element in the lowest level of automation pyramid that is noted as component-based method that is of high efficiency in handling complexity and reconcilability to an information flow.

For realizing such an automation network, the question arises how the communication is realized with high interoperability and how the tasks can be organized in a transparent, hardware independent, and flexible way. To avoid the problems due to the signal-based communication we have to move to more abstract descriptions of control processes. Then hardware and software can be linked at a later stage so that processes within the complete life cycle from planning to design, operation, and maintenance can be realized more dynamically and with lower effort. Furthermore, abstract component and task models can improve the interoperability between communication partners so that the basis for high horizontal and vertical integration is provided (Zühlke, 2010).

Therefore, Service-oriented Architecture (SOA) is called for providing the control procedures with the manageability, adaptability, and reusability (Theorin et al., 2013, P. 213).

Today, the process diagrams of the planning phase are firstly mapped in the process logic controller (PLC), by which the production process can be done. Nevertheless, PLC programs are often hardware-dependent, complicated, and monolithic and thus error-prone and difficult to adapt or reuse (Zühlke & Ollinger, 2012). SOA is seen as a well-documented design procedure that could be adopted during the initial engineering and manufacturing phase, in particular reconfiguration of field devices for the production order.

Additionally, the SOA approached applied within Automation is referred to as SOA-AT (Karnouskos et al., 2010), which can be combined with the Model-Driven Development and Engineering (MDD and MDE) in order to apply rather more abstract SOA principles for industrial use. MDE for SOA-AT describes how a fluent information flow can be achieved from process planning to executable control procedures by using service-orientation and modeling (Ollinger et al., 2013). Its goal is to design service-oriented control applications on the basis of the requirements of the product, system, and business planning (Ollinger et al., 2013).

The potential of applying SOA within the automation domain has already been recognized in several research projects like the SIRENA (Jammes et al., 2005), SOCARDES (Souza et al., 2008), and other publications (Mersch et al., 2010).

### 3.2.1 Definition of Service-oriented Architecture (SOA)

The SOA describes generally a system architecture that represents software functions as encapsulated services in an open and implementation independent way (Melzer, 2008). In the context of automation, a service is defined as an encapsulated automation function that is available via open and well-defined interfaces (Ollinger, Wehrmeister, Pereira, & Zühlke, 2013). The services serve as building blocks for the generation of new functionality (Erl, 2005, P. 23) via a unit of solution logic that can legitimately be called “service-oriented” (Erl, 2007, P. 57).

The goal of SOA is to design control procedures as cooperating building blocks that are easy to reuse or rearrange (Ollinger et al., 2013). Because of those advantages of SOA it could be possible to seamlessly integrate vertical and horizontal level together that constitute the traditional automation pyramid.

In summary all above, the paradigm of industrial automation can be designed and implemented in a distributed environment in terms of dynamic collaborations of distributed automation devices due to the highly degree of reusability, flexibility, and interoperability of software components in the Service-oriented Architecture (SOA), via which the information flow (vertical integration) can seamlessly be connected to the material flow (horizontal integration). In this paper, the horizontal and vertical integration is narrowed down to one plant.

### 3.2.2 Service Levels and Types

For introducing SOA in a special application domain it is necessary to clarify the reference data within an organizational structure that is required by data transformations and rule evaluations, which is defined as reference structure (Brown, 2008, P. 39).

There are two types of services: basic service, composed service.

General speaking, SOA basically has three layers: process description, service orchestration, and services. The process description describes abstract how the process should be executed. The service orchestration is responsible for mapping of abstract process and real services to an executable process. The principle is to control and monitor services (actors and/ or sensors) via the process logic that is generated by the service orchestration where the relevant data from process description and services is integrated and processed. The Figure below (Ollinger et al., 2013) shows how the services interact with each other.

The product planning and plant engineering are treated as process description. They provide the physical structure of the production system, such as material flow, component structure and so on to the control services that integrate this information with the current production tasks from lower level and further generate suitable process logic to control and monitor the basic and composed services.

The lower layer from this Figure, which includes basic and composed services, executes a set of process logic from service orchestration in order to achieve the desired behavior or the expected reconfiguration. The upper layer is classified into product services that handle various product types by specifying the sequence of production steps, and control services that define the process logic.

The supporting services are defined as other control program (Güttel et al., 2008).

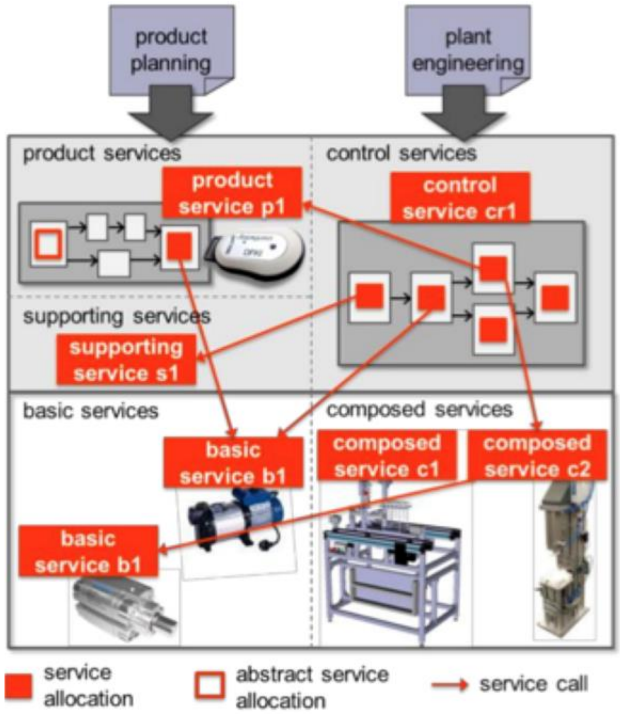



Figure 3.6 Interaction between the service types

(Ollinger, Zühlke, Theorin, & Johnsson, 2013)

The Figure 3.6 illustrates an example about the defined service types and how they interact. The composed service “c2” uses the basic service “b1”. Within the control service “cr1” a supporting service “s1” and the product service “p1” are called.

In summary, the degree of reconfiguration and adaptation depends on the coarseness of field devices in the shop floor. The implementation of the basic and composed services on the embedded systems is the most complicated part.

## 3.3 Software Tools

Figure 3.7 shows a modeling language representation for service-oriented control procedures. It can be seen as two levels: higher levels, and device level in the shape of the traditional automation pyramid. Due to highly abstraction in the automation systems of future factory that SOA offers, the higher levels is defined as abstract level and the device level is the concrete level.

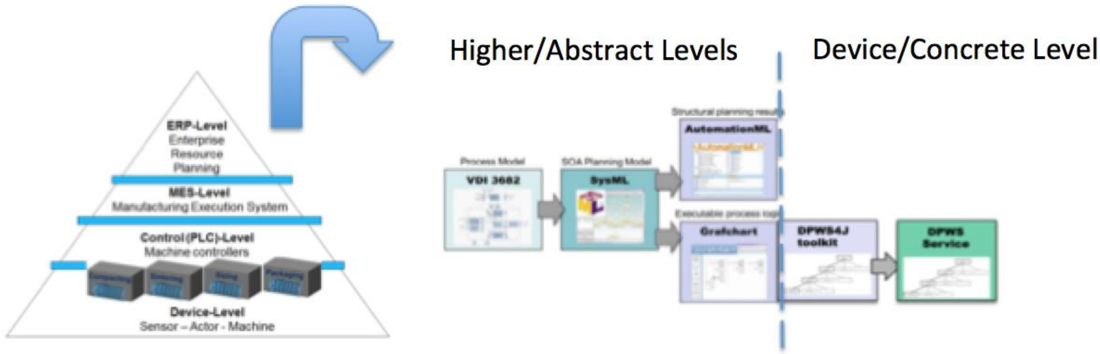



Figure 3.7 A modeling language representation for Service-oriented Control Procedures and its Implementation with SysML and Grafchart

(modified from Ollinger & Zühlke, 2013)

SysML is chosen because it is a wide-spread modeling language for systems engineering (OMG, 2012). The process logic/ the designed control architecture is generated in SysML, which is independent how the services and service orchestrations are implemented.

It is proven that Grafchart is a dutiable process modeling language for the development and execution of service orchestrations in combination with the Devices Profile for Web Services (DPWS) service technology (Theorin, Ollinger, & Johnsson, 2013, P. 213-228). Graphical programming languages (Graph Chart), which are well-known in automation industry due to its simplicity and visual overview of the applications in comparison with textual languages, is a graphical programming language based on Grafcet or Sequential Function Charts (SFC), one of the IEC 1131-3 PLC standard languages (Johnsson, 1999, P. 35), and uses the same graphical syntax with steps and transitions (Johnsson, 1999, P. 68).

The research shows that the biggest field of application of SOA currently is enterprise software and most definitions and practices deal with business processes (Krafzig, Banke, & Slama, 2004, P. 39), (Bieberstein, 2005, P. 30). However, automation and business applications differ in many ways, particularly in executing process logic and monitoring field devices. Thus, the Devices Profile for Web Services (DPWS) is chosen as service technology in the field device because it is able to define a profile specifically targeted for SOA in the lowest level using existing WS-* specifications (Jammes et al., 2005) (Zeeb et al., 2007). The following Figure depicts the existing languages, standards, and tools for Service-oriented Control Procedures and its Implementation with SysML and Grafchart. The concretization levels between the abstract and the concrete design can clearly be depicted by means of the object-oriented principles of UML/SysML (Ollinger & Zühlke, 2013). An the Automation Markup Language (AutomationML) model is a engineering data base fulling with the tranformation of the structural planning results in terms of behaviour, sequencing etc., the services in terms of geometry, kinematics etc., and the hardware structure, such as plants, cells, components, attributes, interfaces, relations and references (AutomationML, 2011).

## 3.4 Summary

For bringing about a modern paradigm for industrial automation, we must seamlessly integrate the technologies (CPS) and organization (SOA) together. The coarseness of field devices is proportional to the time of set up, flexibility and adaptation of the automation systems, and reconfiguration of production plants.

As already mentioned, CPS could benefit industry because it enable the whole dynamic automation systems in the shop floor and further directly linked to the higher levers for intercommunication. Whether CPS can be success or not depends on how smart of sensors in the embedded system and radio communication technologies in terms of maturity and reliability and security and so on.

SOA as a basic software architecture in Industrie 4.0 needs develop specific standards, technologies, and models and so on for industrial automation use because it mainly is using in business domain.

# 4. Industrie 4.0 at MSA

This chapter gives the solutions for the issues from VSM that is mapped in chapter 2.2.4. The potentials of Industrie 4.0 that is listed in chapter 2.1.4 are analyzed and concluded here.

## 4.1 Solutions in the view of Industrie 4.0

As mentioned already, the manufacturer is consistently integrating information and communication technology (ICT) into its traditional high-tech strategies so that he can become the leading supplier of smart manufacturing technologies for maintaining or achieving his global market position. Since 2013 the integration between ICT and manufacturing technology becomes also the essential step to bring about the shift from industrial production to Industrie 4.0, or from batch production to completely continuous production. Above item could be one of the most attractive reasons to catch the aggressive manufacturing Industries' attention like Miba Sinter Austria (MSA). Industie 4.0 is becoming familiar in the company, because MSA has been looking for the solutions for the issues that are listed in chapter 2.2.4 and the publicity of german government about Industrie 4.0. Furthermore, the important customers in automobile industies of the company are researching or are interested in Industrie 4.0, which will be a threat for the company in the future when some technologies from Industrie 4.0 are successfully adopted in the customer's factories. If the company is looking forward to a long and successful development in this unstable global market, new terms or technologies like Industrie 4.0 have to be always recognized and analyzed.

For those purposes, the following features of Industrie 4.0 should firstly be recognized (Kagermann et al., 2013, P. 20):

• Horizontal integration through value networks
• End-to-end digital integration of engineering across the entire value chain
• Vertical integration and networked manufacturing systems

In the manufacturing environment, vertical networking, end-to-end engineering and horizontal integration across the entire value network of increasingly smart products and systems is set to usher in the fourth stage of industrialisation – "Industrie 4.0".

The entire value chain framework, which will take the definition from Porter (Porter, 1985, P. 87), is defined from inbound logistics, production, outbound logistics, marketing & sales, to service.

*"In the fields of production and automation engineering and IT, horizontal integration refers to the integration of the various IT systems used in the different stages of the manufacturing and business planning processes that involve an exchange of materials, energy and information both within a company (entire value chain) and between several different companies (value*

*networks). The goal of this integration is to deliver an end-to-end solution."* (Kagermann et al., 2013, P. 20)

It means whether within a single company or between companies, various IT systems that are integrated together will involve an exchange of materials, energy and information in whole value chain framework from the point view of Industrie 4.0, as depicted in Figure 4.1. MSA could benefit from the earlier frozen customer orders, which will let the production orders have enough time to be scheduled and executed in the production. The powder and external suppliers will be happy to be informed earlier if there exists a change in the production orders.

The production lead time - 35 days in external supply chain, will be reduced because the pieces will be delivered via a effective way, e.g. in this case the pieces will be directly delivered to supplier Y and further only if the supplier Y is nearby supplier X as shown in the Figure 4.2. For this purpose, the quality check need to be done in the supplier X' house but not at MSA (currently every quality check is in house). The important information have naturally to be encrypted before the delivery to the next supplier, which could be done now, for example, by RFID. The suppliers and customers will see the information that we are aloud. The data information can only be read by authorized user via various IP dresses. This could be one of the most essential reasons why the labeling system is not introduced by Industrie 4.0 due to its insecurity.

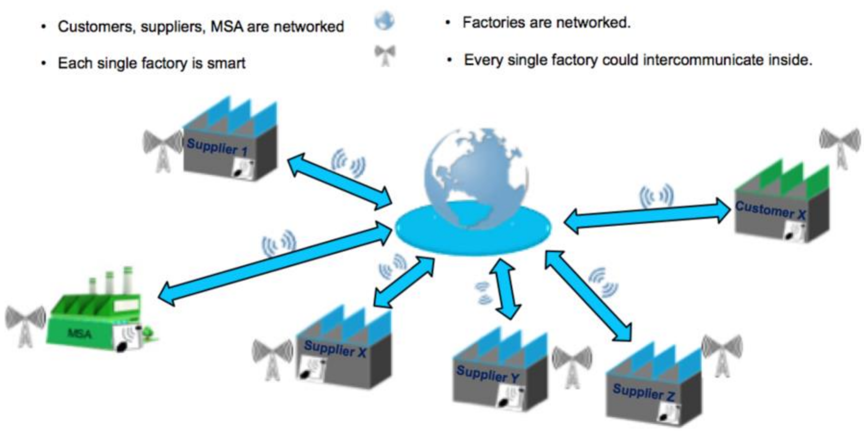



Figure 4.1 Supply chain management of component 1.3.445

Moreover, via the network the external suppliers will be immediately informed as long as the material requirement planning has been finished and production order is about to be released at MSA. If there exists no secret they could also get signals at the phase of sales order or even at period of inquiry/ quotation. When MSA receives a urgent or a changeable order the external suppliers are able to get this information just at the same time as MSA from customer. They could make actions earlier when it is necessary, e.g. the urgent situation at MSA will be informed immediately to supplier X, Y, Z and so on; the supplier Z has enough time to arrange his tasks according to the new schedule. Of course, the same information will be defined by different end-users, e.g. the same information from a MSA' customer will be encrypted, which let the supplier only get the information they should normally know. When there is a change, such as big disturbances in the production at MSA, the external suppliers are going to get the related information "delay".

Figure 4.2 illustrates one of the most effective ways to handle the external works in Industrie 4.0. RFID technology here can be seen as a pioneer. A highly integrated, low-power and low-cost processor is extended with a memory and a wireless communications interface and affixed to each component in a mass market. In effect, the "intelligence" of a central system is moved into every product. Products know their histories and their routes, and thereby not only greatly simplify the logistic chain but also form the basis for product life cycle data memories. This technology is mastering and could be manufactured for just a few cents (differentiate the type of tag and reader), the next step will be to couple sensors and actuators on the chip and turn it into an autonomous actuator-sensor network. In the example pictured in the Figure, only the objects being produced are being tagged. Tagging could be extended to production machinery and tools, thus allowing even tighter control of the production process and improving inventory control. Even personnel could be tagged. Given the obvious concerns regarding privacy and loss of control, however, any potential benefits need to be carefully gauged against the considerable drawbacks.

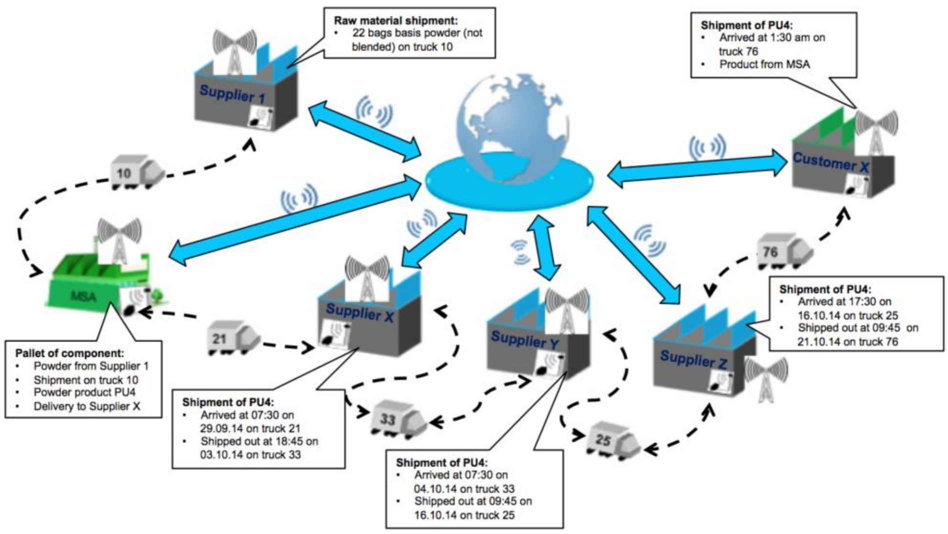



Figure 4.2 An example of supply chain management of component 1.3.445

In the fields of production and automation engineering and IT, the vertical integration refers to the integration of the various IT systems at the different hierarchical levels as descripted in the Figure 4.3 (e.g. the actuator and sensor, control, production management, manufacturing and execution and corporate planning levels) in order to deliver an end-to-end solution. The different hierarchical levels are also the automation pyramid that is shown at point "b" in chapter 2.2.4. Everything, down to the smallest piece of equipment, will have a certain degree of built-in intelligence. The challenge is today that the plant IT structures are mostly strictly centralized (thick servers, thin clients). A powerful network infrastructure is required to route the task data between the devices in real-time and are furthermore to device-dependent. For this purpose, a sensing system in the production, especially in the machine must be built. Then an autonomous actuator-sensor network should be set up. The technology like RFID, which is introduced in Industrie 4.0, could couple sensors and actuators on the chip and turn it into this kind of network, e.g. RFID technologies are deployed among the pallets and machines and so on in the production, which serve as an extended link at the sensor/ actuator level. Using those radio technologies make it possible to employ new, mobile and flexible systems for the operation, maintenance, and diagnostics of the production facility. On the higher levels of communication the already proven network technologies like UWB, ZigBee or WLAN (Appendix D) will take over offering high communication capacities at low installation cost. So we are moving towards the Internet of Things where every single piece has an IP address and can communicate. But with today's standards we will reach the technical limits soon. The IP address space must be enlarged to cope with the enormous growth of the required network addresses (Garfinkel, 2004). A permanent WLAN connection has been implemented for the decentralized control systems of the machines in the shop floor to the higher level control center.

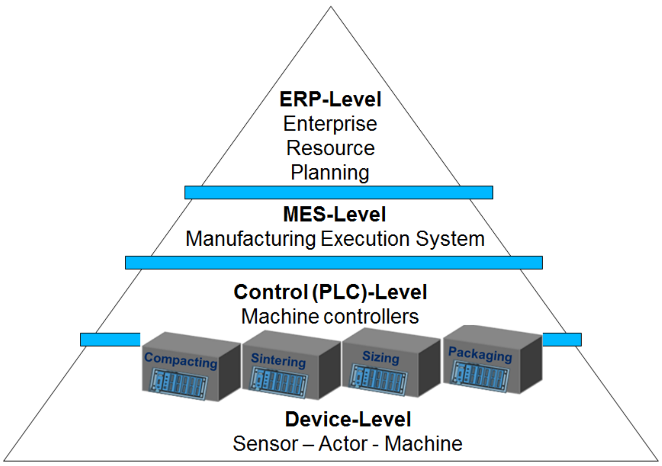



Figure 4.3 The pyramid of automation

At MSA there exists the sensing system, but unfortunately it is not completely and an extended communication linkage is not possible. The Powder Presses (the compacting machine) are less sensing. The oven and sizing machine are equipped with lots of sensors. The sensor data generates an alarm/ error descriptions to setter or maintenance personnel for checking or repairing. The alarm gives only a range of errors, which causes the checking time of the maintenance personnel occupies large portion of total down time. The collected data is usually for archiving. The production schedules will be checked by daily machine report in BDE Visual. Mobile phone is the main tool for informing the problem.

Currently Java software is used, which runs on the mobile phones of several different bands, it is possible to monitor and configure a multitude of field devices in the factories.

In the fields of production and automation engineering and IT, the end-to-end digital integration refers to the integration of the appropriate IT systems in the entire value chain, from product development to manufacturing system engineering, production and service. A holistic systems engineering approach is required that spans the different technical disciplines.

The more solutions for the internal work via other technologies will be shown in chapter 5.

## 4.2 Ideal Model for the connection between information flow and material flow at MSA

The company in the future will be portrayed as in the Figure 4.4. The compacting, sintering, sizing and packaging constitute the material flow. Others elements without customers and suppliers are defined as information flow.

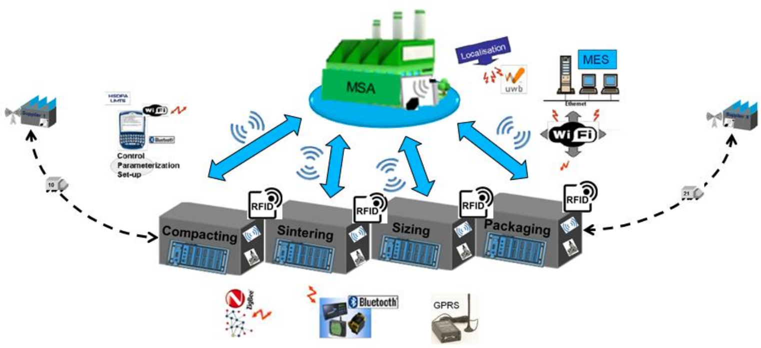



Figure 4.4 Smart Factory - CPPS at MSA

The industie 4.0 introduces two concepts for achieving the modern paradigm of automation industry:

**(1) Cyber-Physical Systems (CPS)**

**(2) Service-oriented Architecture (SOA)**

**CPS** based on the embedded systems of the sensor-actuator level will directly link to the higher level for intercommunication in the future. Every single device will be allocated an Internet Protocol (IP) that could be highly redundant and then reliable. The basic "intelligence" starts with the sensors in the field devices, such as compacting, sintering, sizing and packaging.

Those sensors are the sensors equipped with computation and communication. The more coarseness of field devices will offer the more re-configurability and flexibility. The network technologies for the higher levels of communication like UWB, Bluetooth, ZigBee or WLAN. The decentralized Process Control (traceability) will be done via RFID because its intelligent potential in terms of memory and encryption and so on. In such future factory, every service can be arbitrarily modifiable and expandable; devices from different vendors will be connected and are able to intercommunicate each other. For this purpose, a mobile universal interaction (MUI) device is required, such as Smartphone, SmartMote, Seamless Navigation Application, and Augmented Reality (Schmitt et al., 2013), which enable of communicating with various field devices and machine modules and programmable logic controllers (PLC) from different vendors via either wireless or cable communication standards according to the needs. HUI is expected to take the responsibility in terms of parameterization, control, monitoring, diagnosis and maintenance. Especially for the maintenance personnel it could help them to find fault location. Failure Indication is done via General packet radio service (GPRS).

**SOA** as a software architecture is introduced by Industrie 4.0 to handle the complexity of the automation pyramid. Figure 2.3 (right side) is depicted as networked automation services of the automation hierarchy with distributed services.

## 4.3 Potentials of Industrie 4.0 at MSA

Industrie 4.0 holds huge potentials and also is a complex strategy that embraces several partially overlapping areas, especially its high-abstractive adaptation between organization and technology. The following shown potentials have already been screened out on the basis of the actual situation of MSA, are defined as high potentials for the company.

### 4.3.1 The Criteria of Assessment

The criteria of assessment of Industrie 4.0 potentials at MSA depends on the existing production process and system, the implementation of networked distributed production facilities in site, the existing production logistic management and SAP system.

Figure 4.5 depicts the whole potentials of Industrie 4.0 on the basis of Industrie 4.0 architecture as shown in Figure 2.2. In order to select the high potentials for Miba Sinter Austria (MSA) out, the early assessment is based on the aim of this project, and actual situation of MSA, such as the existing IT. Those high-valued items from Figure 4.5 that are defined as high potentials for MSA, which will further be analyzed via the methodological approach – the weighted criteria.

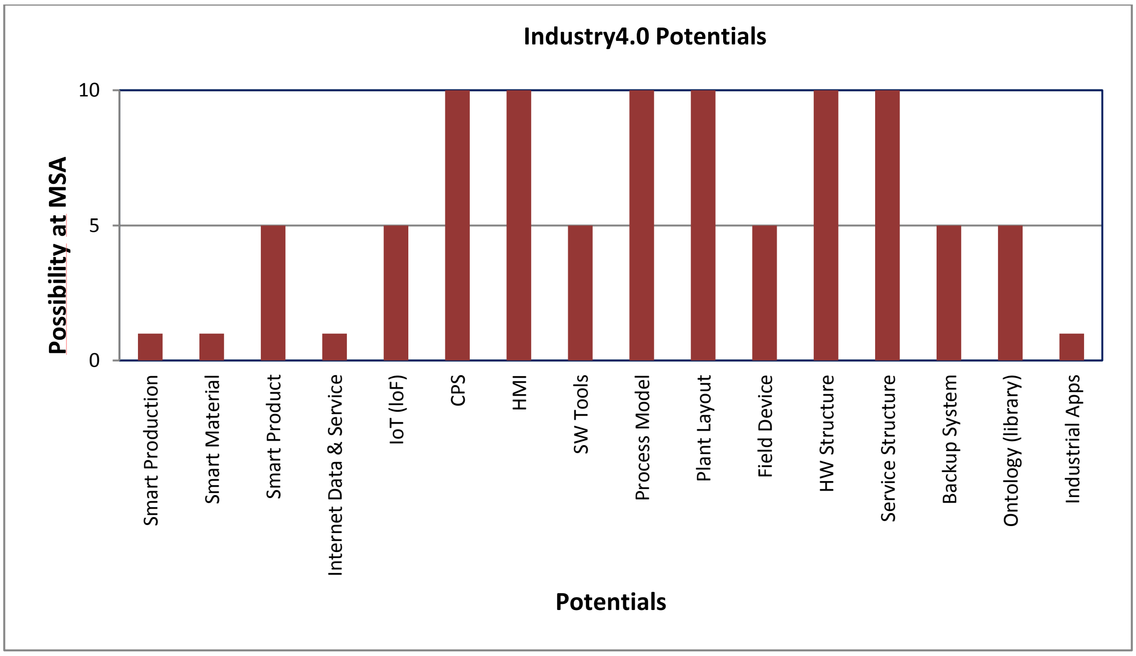



Figure 4.5 Industrie 4.0 Potentials

The horizontal and vertical axes of the Figure 4.5 represent potentials and value in the eyes of the MSA respectively. The value from low to high is defined as 0, 5, 10. The high values (10) are the high potentials that will be further analyzed.

Smart Production and Smart Material involve the behaviors/actions of suppliers and/or customers, which is out of decision of MSA and actually not be considered in this analysis.

Internet of things (IoT), smart material, and smart product are already mentioned in chapter 2.1.2. Internet of factories (IoF) is especially for the factory use. As mentioned in the previous chapters, IoT is a global concept. This assessment is at the center of MSA, which is a local concept. In others word, this paper will mainly give the suggestion what MSA can do or organize. Global networked sites (Miba Sinter Factories in whole world) will not be ready if the local site (MSA) has no desire on this concept (Industrie 4.0). In contrast, even if the local site is interesting in industrie 4.0, it does not mean that the global sites enable work on it. Nevertheless, one thing is for sure that it could be successful in global sites when the local site has this proposal. Additionally, the supply chain management around MSA could improve due to Industrie 4.0 because MSA is generally the propellent for their suppliers. However, MSA affects the supplier's activities but not decisions. To sum up, MSA can make a proposal on Industrie 4.0 that only affects global sites and suppliers. Thus, that is why IoF here with a middle value. This reason is also suitable for CPS.

Ontology (library) can be treated as a digital library or database. It is possible for the company now to build such digital library. The rising question is whether is really usefully for the future or not because it offers all the information that CPS and SOA need. Nevertheless, the both concepts are not available and will not immediately be set up at site. That is why they are given a medium value. The same way can be used by backup system.

Human-Machine Interface (HMI) or Mobile Universal Device (MUI) has future and is selected out as a high potential here because it as one of the smart technologies will turn our factory in intelligent environments. It could eliminate the complexity of device interfaces of various vendors via a prototypical mobile panel for universal access to filed devices, plant modules and programmable logic controllers in industrial production environments. The compacting machine Dorst 250 at MSA enable the remote control but this function is not used yet. Additionally, such HMI has been already developed and exist in the market, for example, UCP450. Nevertheless, they are in the development phase in the view of product life cycle. That is why they are given a high value.

As mentioned in chapter 2.1.2, the apps in the consumer market are becoming more and more mature. However, for the industry use they have still long way to go. The progress of the development depends on the needs of field devices. As long as the field devices are characterized with intelligence, the relevant app concepts will be quick developed.

The software architecture SOA has lots of potentials. To simplify the analysis, the whole potentials of SOA are defined into three items according to its structure: process description, service orchestration, and services. The process description including process model and plant layout are selected out as two potentials because of its physical nature. Process Model is referred as the process description of the required production process. Plant Layout is the results from earlier planning phases that are particularly the product design and the rough planning of the production plant. The both items are given with high value here because they exist already at MSA. Services are decentralized in terms of field devices, hardware structure and service structure. Field devices describe whether the decomposition of the machines into the elementary mechatronic services and production modules or cells or not. The hardware structure defines the field devices and how they are structure to higher units, like modules or production cells. The structure of the control software for the hardware is the service structure. The last two items are with high values (10) because they exist at MSA. The value of field devices is in the middle, which depends on the possibility in the production at company.

### 4.3.2 Weighted Criteria

The original idea of this project is to select one high potential of Industrie 4.0 for MSA.

In chapter 4.3.2, the whole potentials of Industrie 4.0 have been mainly screened into several items (high potentials): CPS, HMI, process model, plant layout, HW structure, and service structure. The intercommunication between devices in the device level and devices with higher level is in the form of CPS. This intercommunication is mainly abstract via SOA in terms of process model, plant layout, HW structure, service structure. In order to get the highest potential via evaluating the selected high potentials in terms of a number of decision criteria, the methodological approach – the weighted criteria, as one of decision – making tool is chosen.

Weighted criteria is a useful tool in making complex decisions, especially in cased where there are many alternatives and many criteria of varying importance to be considered (DESIGNWIKI, 2013).

Table 4.1 shows an example of weighted criteria.

| | | **A1** | | **A2** | |
|---|---|---|---|---|---|
| C1 | 2 | 2 | 2*2=4 | 2 | 2*2=4 |
| C2 | 5 | 1 | 5*1=5 | 3 | 5*3=15 |
| | | | 9 | | 19 |

Table 4.1 Weighted criteria

The criteria, which are used on the scoring model, are assigned a weight depending on its importance to the company/project from 1 to 5. More important criteria should carry a higher weight than less important criteria. In the Table 4.1, the criteria are C1 and C2. Furthermore, C2 is more important than C1. The alternatives are rated on a scale from 1 to 5, for example, with the higher number being the more desirable outcome to the company and the lower number having the opposite effect. This rating is then multiplied by the weight of the criteria factor and summed to other weighted criteria scores for a total weighted score. In the end, alternative 1 has a value 9 and alternative 2 has a value 19 in total. Finally, alternative 2 is the best choice.

According to the importance at MSA, the criterion of assessment is defined as compatibility, software standard, grounds, return of investment (ROI), possibility, and exemplar. The existing IT system at MSA, such as MDE, BDE, SAP, together with the production process and planning and product logistic management at company will be as basis to evaluate those defined items.

The criteria, which have been given by the extent of the importance for the company, are divided into four items from 0.5 to 2.0: not necessary, balanced, good to have, very important. This is depicted in the Table 4.2. The definition of each criterion can be seen in the Table 4.3.

| Criteria | Rating | Definition |
|---|---|---|
| Compability | 1.5 | Good to have |
| Software standard | 1.5 | Good to have |
| Grounds | 2.0 | Balanced |
| ROI | 2.0 | Very important |
| Possibility | 2.0 | Very important |
| Installability | 1.0 | Balanced |
| Exemplar | 1.0 | Balanced |

Table 4.2 The ratings of the criterion

| Criteria | Definition | Score Value |
|---|---|---|
| Compability | The compatible extent with the existing technology at MSA | Perfect, good, not good |
| Software standards | The range of extensive use. | developed, partly developed, developing |
| Grounds | The pressure for employing the technology | high, medium, low |
| ROI | The extent of benefits to company resulting from the investment | high, medium, low |
| Possibility | The extent of technological availability for the company | high, medium, low |
| Installability | The ability for amounting/ adopting the technology | easy, uncomplicated, complicated |
| Exemplar | The technology life cycle | the decline phase, the maturity phase, the ascent phase, R&D |

Table 4.3 The definations of the criterion

The alternatives are the high potentials (the possibility Nr. is 10 at Industrie 4.0 potentials from chapter 4.3.1) are defined from high value 4 to low value1 see the Table 4.3.

| Score Value | Definition | | | | |
|---|---|---|---|---|---|
| 4 | the decline phase | developed | very high | perfect | easy |
| 3 | the maturity phase | partly developing | high | good | uncomplicated |
| 2 | the ascent phase | - | medium | - | - |
| 1 | R&D | developing | low | not good | complicated |

Table 4.4 The definitions of values

Total weighted scores are shown in the Appendix I. The reasons for the given scores of the alternatives (high potentials) are listed in following:

The item “compatibility or adaptability” evaluates the compatible extent with the technologies of the existing systems such as the Maschine Daten Erfassung (MDE), the Betriebsdatenerfassung (BDE), SAP etc. at MSA. This item will check whether or not the smart technologies from Industrie 4.0 are compatible with those existing systems, especially with the IT systems. The score values are defined by perfect, good and not good.

The item “software standard” has been developing for smart technologies such as IEEE 802.15.4 standard for ZigBee and RFID has so far hundreds of different software standards, which evaluates the range of extensive use. The score values for this item are developed, partly developed, developing.

The item “grounds” evaluates the pressure that forces the company to make effort on Industrie 4.0. The evaluated pressure could be from customers who are researching or have already employed some technologies from Industrie 4.0, which drive the company to introduce the same technological platform if they do not want to lose in the competition. It also could be from company-self who are searching some solutions for the existing issues that Industrie 4.0 could solve them perfectly. Take a example of the technology RFID, could transfer further the information from shop floor to top floor or other relating systems, scan automatically in a valid field, track for ensure accurate and real- time reporting about production status as well as production steps, improved traceability and so on, which are much smarter than the labeling system that is using at MSA.
The interesting is the company has switched some years ago from RFID into the labeling system because of ROI. But if the company's customers want to build a universal system (Industrie 4.0) on the basis of RFID, the company probably has to switch back to this technology. By adopting the universal interface device (UID), users have NOT to learn many different user interfaces and interaction devices from different vendors and operator will come to machine according to the signal that he gets. By adopting the Positioning System – Sensors, it will be easily to track the whereabouts of products and raw materials and also could improve maintenance. ZigBee is famous of low power consumption, transmission distances to 10–100 meters and its star and mesh network which is one of the main concept of Industrie 4.0. The score values for are high, medium, low.

The item “ROI” evaluates the extent of benefits that the company could get after investment. Take the example of RFID, tags have read/ write memory capacity as much as 2KB data, which could improve the value stream by reducing the production, lead time from external logistic but they are cheaper than before in the market because of the volume production. It is said that the technology positioning system – sensors are our "eyes” and "ears" to help us to make "on-the-fly" decisions and are the basing of Internet as well as they are small and inexpensive. The score values are the same as the last item. ZigBee (a low-cost, low-power, low data rate wireless mesh network standard) is able to minimize disruptions to building occupants and impact to physical structure during retrofits, to simplify design while increasing flexibility, to place sensors where they can provide optimal control and energy management, to install new or upgrade/expand legacy systems seamlessly and cost-effectively. The score values are the same as the last item.1.

The item “possibility” evaluates the technological availability for the company. This item is going to check how difficult it is if the company wish to introduce some smart technologies into their existing system. In other words, it is possible to introduce the smart technologies into the company without big change. The score values are the same as the last item.

The item “installability” evaluates the installable or adaptable extent of the technologies from Industrie 4.0. For example, is it possible that some sensors can be mounted into the machine for sending some signals to some smart devices in order to solve some issues, the data from the Maschine Daten Erfassung (MDE) could be directly adapted by smart devices via programming or some abstract connections. The score values are easy, uncomplicated, complicated.

The item “exemplar” evaluates the technology life cycle. Hong Kong Electroplating Company Speeds Up Production With RFID; VOLVO, is using APOGEE Wireless with ZigBee technology from SIEMENS, which has proven on 30% energy savings in 400,000 square foot plant .The score values are the decline phase, the maturity phase, the ascent phase, R&D.

### 4.3.3 Conclusion

After the analysis and calculation via the methodology-weighted criteria, the result is out of original expectation but logic.

There is no big difference between the potentials because Industrie 4.0 has sorted out advantages of technologies before they use them.

# 5. The critical Potential at MSA

In order to achieve the lean production, Japanese have developed lots of other items, such as, control circles (QC), total quality control (TQC), zero defect group (ZD group), total productive maintenance (TPM), and just-in-time (JIT). Those items, which are also famous at MSA, are incorporated into the production for improving overall performance of factory and facilities in the manufacturing organization.

MSA measures the behaviors/performances of production via a set of measures that is noted as KPIs. Due to the analysis of this paper is mainly focusing on the facilities in the production, the following measuring items of performances of facilities, which are capacity utilization (CU) that is constructed to measure the productive runtimes of key machines at MSA, Overall Equipment Effectiveness (OEE)/Total Effective Equipment Performance (TEEP) that quantify stand or fall a manufacturing unit relative to its designed capacity, during the scheduled, Total Productive Maintenance (TPM) that stands for total effectiveness, total maintenance, and total participation, are necessary to be specified.

In the production, the loss of capacity due to breakdowns is recognized as a major cause for poor performance of the facility. The stoppage due to logistics is treated as loss time at MSA.

In this paper, the term maintenance is synonymous with repair.

## 5.1 The measuring Tools on Performance of Facility

### 5.1.1 Total productive Maintenance (TPM)

#### 5.1.1.1 Why TPM?

TPM offers a very large reduction in the number of unexpected equipment failures, in the direct costs of maintenance, in quality costs – both internal failure costs due to defective products and defects in production processes and external failure costs in the form of a significant reduction in customer complaints and adjustment claim, in work-in-process inventory, and a significant increase in labor productivity in terms of the value added per worker.

TPM stands for total effectiveness, total maintenance, and total participation (Bikash, 1998, P. 45f).

(1) Total effectiveness aims at the pursuit of economic efficiency and improvement of productivity and profitability.

(2) Total maintenance includes not only periodic or routine or preventive maintenance (PM) activities but also condition-based maintenance of plant and machinery, of building in of reliability and maintainability features, and of plant modifications and other activities aimed at maintenance preventive and designing-out-of-maintenance. The basis of condition-based

maintenance is the observation, measurement and analysis of the prognostic parameters that could be carried out while a facility is running or it has to be shut down for the purposed actions. Its benefit is that the identification of the condition of the equipment by monitoring of certain parameter(s) gives an early signal of an impending failure that not only enables timely preventive action but also facilitates maintenance planning, which results in reduced maintenance costs, in greater safety and availability and in improving lifecycle of facilities. However, the signal gives only a rough range of fault location, which will be discussed in detail in the following.

Because the thousands of sophisticated devices and machines in the production result in a high probability of failure, and further in increasing maintenance costs including both direct repair costs and lost production due to breakdowns, the designing-out-of-maintenance is on turn.

The designing-out-of-maintenance aims to reduce the need for maintenance for improving the performances of new facilities in terms of availability, reliability, maintainability, safety (Nakajima, 1989, P. 26, 287). Additionally, it also aims to improve the work procedures and maintenance management systems in terms of spare parts planning, scheduling of inspections & replacement, overhaul planning, and development of procedures for repair and servicing, and to improve factory and facility modifications in terms of reducing repair time/downtime and incidence of failures. The usual way is to analyze the past maintenance data via the suitable technology, further identify important failure modes that are the observable behaviors of items when they fail and failure situations, and finally carry out the solutions for taking the best actions in the direction of eliminating those failures. If the failures cannot be eliminated, fault trees are required in terms of failure modes (consequences) and failure mechanisms (causes).

(3) Total participation can be achieved through a motivated workforce, job enlargement of production operators, maintenance skills training of maintenance tradesmen and small group activity in every department and shop and at every level of the organization.

#### 5.1.1.2 Definition of TPM

Firstly, the difference must be specified among total productive maintenance (TPM), productive maintenance (PM), preventive maintenance (PM1), maintenance prevention (MP), and maintenance.

Maintenance is classified into connective maintenance in terms of breakdown maintenance and planned maintenance, and preventive maintenance (PM1) in terms of periodic preventive maintenance and predictive preventive maintenance/condition-based maintenance (Bikash, 1998, P. 29f).

Breakdown maintenance refers to a maintenance activity that is necessitated by a breakdown. There are two kinds of maintenance: planned maintenance and unplanned maintenance that is brought about by an unforeseen breakdown or damage is normally so-called emergency repair from Glossary of maintenance management terms in terotechnology (B.S. 3811:1984).

PM can be seen as the joint of the preventive maintenance (PM1) and the maintenance prevention (MP) (Bikash, 1998, P. 1ff).
PM1 was first introduced in Japan from USA in order to improve equipment availability via clarifying responsibility of workers, which can be traced back to 1951. PM1 tries to maximize the utilization of the production equipment for producing the desired quality of products efficiently. MP aims at freeing the maintenance personnel from routine maintenance tasks and taking up the essential tasks of maintenance planning based on equipment performance, plant and equipment modifications for improved reliability and maintainability specifications for new equipment and designing-out-of-maintenance.

However, Total Productive Maintenance (TPM) means more than any item as mentioned above. One of the identifying characters of TMP from the listed items above is the stress that place on the elimination of "sig big losses" that are described as the breakdowns of production facility, defects and defective components, set up, adjustment of facility, idling and minor stoppages, and the speed losses (low productivity and yield losses) (Bikash, 1998, P. 45f).

TPM is an original Japanese management protocol developed to alleviate production losses caused by machine breakdowns (Willmott & McCarthy, 2001, P. 1f). The Japanese Institute of Plant Engineers (JIPE) gives the formal definition of TPM in 1971 (Bikash, 1998, P. 1f). TPM is aimed at maximizing equipment effectiveness (OEE), establishes a total system of PM covering the entire life-cycle of the equipment in both all departments, such as equipment planning department, equipment usage department, maintenance department and so on, and all employees participate from top management down to shop-floor workers. TPM also promotes PM through motivation management, like small group autonomous activities.

Thus, TPM is a macro-concept that involves all the activities inclusive of human and machine for maximizing equipment effectiveness.

### 5.1.2 OEE/ TEEP and Business Calendar

As mentioned one of the main objectives of TPM is to maximize OEE and vice versa. The maximized OEE stands for the most effective of TPM activities.

Overall Equipment Effectiveness (OEE) and Total Effective Equipment Performance (TEEP) are two closely related metrics that measure the overall facilities and assets productivity on the basis of actual availability and performance efficiency of facilities and product quality in a defined timeframe for manufacturing operations. The item "overall" means to maximize the utilization of the facilities and assets to produce the best in quality and the most on quantity products within the specified timeframe operations (Gulati & Smith, 2009, P. 182ff). The objective of OEE/TEEP is to directly recognize the gap of productivity of facilities between the actual and ideal value.

OEE quantifies how well a manufacturing unit performs relative to its designed capacity, during the periods when it is scheduled to run.

OEE separates the performance of a manufacturing unit into three measurable elements: Availability, Performance, and Quality. Each element is directed to an aspect of the process that is able to be targeted, which aims for improvement. It is not possible that the facilities and assets run at 100% OEE. Different manufacturers set various benchmark on OEE based on the production. Nevertheless, 85% is not uncommon (Gulati & Smith, 2009, p. 182).

OEE can be calculated by the following formula:

OEE = Availability x Performance x Quality

Each factor has two associated losses making six in total. The losses on availability are in terms of breakdowns and product changeover quality, and on performance are in terms of running at reduced speed and minor stops, and on quality are related to startup rejects and running rejects. To identify then to prioritize and eliminate the causes of the losses in order to increase the overall equipment effectiveness of plant equipment, which is also the main objective of total productive maintenance (TPM). TPM focuses on improving the quality of the equipment by preventing equipment break-down and standardizing the equipment. Due to its result of less variance and then naturally better quality it will be usually seen as a way to help achieving the goal of total quality management (TQM).

MSA calculates OEE and OEE with disturbance by the summed productive run time such as S74 and down time due to disturbance. The value of OEE and OEE with disturbance will be respectively compared with the old value of them.

Example for the machine O100 Pressen:

A given productive runtime_64 is 318.164,73 minutes; the available capacity (S64) is 406.080,00 minutes; down time due to logistic is 54.455,12 minutes. The old value of OEE is 80%.

Therefore,

OEE = productive runtime_64/ S64 = 78%

OEE with disturbance = (productive runtime_64 + down time due to logistic)/ S64 = 92%

The result is minus 2% difference on OEE and plus 12% on OEE with disturbance due to logistic. The normal way is to find out what happened this year and why the machine capacity is down and try to make the improvement.

Normally, the most industrial manufacturers suffer from the large portion of lost time and unplanned downtime, which directly affect their productive runtime. At MSA, the disturbances will be added to the production runtime when they yearly calculate the Overall Equipment Effectiveness (OEE). It makes sense to do so because if they only take the number of productive runtime the difference between OEE and OEE standard (could be old OEE some years ago) is 99% minus. In other words, if we could somehow deal with the lost time and/or unplanned downtime, the Overall Equipment Effectiveness (OEE) will increase. The vision of the cyber physical systems is able to solve this issue. The cyber physical systems has been formulated not for operating in a planned environment, but robustly for the unexpected conditions and being adaptable to subsystem failures.

TEEP measures OEE effectiveness against calendar hours, this is to say, 24 hours per day, 52 weeks or 365 days per year.

TEEP = the maximal productive time = 365days x 24hours x 60minuter = 525.600,00 minutes

Currently MSA has four shifts in the production, in which one shift is always free. With it the business calendar, that is to say, the working days calendar for the production will be defined.
There are three legends in the business calendar:

- 5 days per week with 3 shifts, S53 for short.
- 6 days per week with 4 shifts, S64 for short.
- 7 days per week with 4 shifts, S74 for short.

In the year of 2014/2015 (01.02.2014~01.02.2015), S53, S64, S74 respectively means 233, 282 and 332 working days. The calculations are as follow:

233 working days = 365 calendar days – 52 Saturdays – 52 Sundays – 11 national holidays – 5 SNA – 12 plant holidays

282 working days = 365 calendar days – 52 Sundays – 12 national holidays – 5 SNA – 14 plant holidays

332 working days = 365 calendar days – 52 Sundays – 12 national holidays – 5 SNA – 16 plant holidays

In other words,

S64 = TEEP – 52 Sundays – 12 national holidays – 5 SNA – 14 plant holidays = 282 working days

S74 = TEEP – 52 Sundays – 12 national holidays – 5 SNA – 16 plant holidays = 332 working days

It has to be clear that the increase of OEE of facilities does not mean that the wastes are fully eliminated if the customer services are not improved. Additionally, OEE is a controversial management tool as shown in Appendix D. The top management at MSA manually calculates OEE with disturbance (yearly).

### 5.1.3 Key Performance Indicators

There are four types of performance measures, see the figure 5.1 (Parmenter, 2010, P. 1):

- Key result indicators (KRIs) tell you how you have done in a perspective or critical success factor within a defined timeframe, such as monthly or quarterly cycles.
- Result indicators (RIs) tell you what you have done, which are more for financial use.
- Performance indicators (PIs) tell teams what to do to align themselves with strategy of organization
- KPIs tell you what to do to increase performance dramatically, which are reviewed on a daily or weekly cycles.

KRIs is measures that often have been mistaken for KPIs. Actually KRIs spans a longer period of time than KPIs. This is depicted in Figure 5.1

*"KRIs involve in customer satisfaction, net profit before tax, profitability of customers, employee satisfaction, and return on capital employed."* (Parmenter, 2010, P. 2)

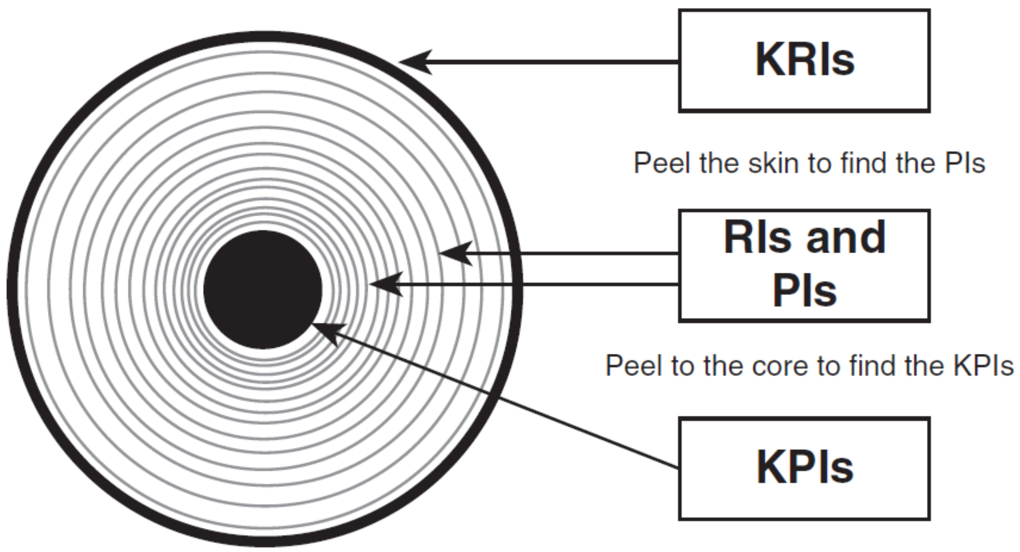



Figure 5.1 Performance measures (Parmenter, 2010, P. 2)

Between KRIs and the true KPIs there are RIs and PIs.

The RIs measures the financial performance, such as daily or weekly sales.

*"Result indicators that lie beneath KRIs could include: net profit on key product lines, sales made yesterday, customer complaints from key customers, hospital bed utilization in week."* (Parmenter, 2010, P. 4)

"*Performance indicators (RIs) could include: percentage increase in sales with top 10% of customers, number of employees' suggestions implemented in last 30 days, customer complaints from key customers, sales calls organized for the next week, two weeks, late deliveries to key customers."* (Parmenter, 2010, P. 3)

KPIs are the performance metrics that are applied to evaluate some factors that are important to the success of an organization. They lead to a series of potential improvements. The item success is the repeated, periodic achievement of operational goals, such as zero defects, full capacity of facility. The definition is following:

*"KPIs represent a set of measures focusing on those aspects of organizational performance that are the most critical for the current and future success of the organization."* (Parmenter, 2010, P. 4)

KPIs vary between companies, even organizations, depending on their priorities or performance criteria; that is, what is important to the organization. That is why it is also referred to as "key success indicators (KSI)".

At MSA, KPIs evaluate

- **quality** in terms of internal scrap [%], scrap value [kEUR], customer claims [#], customer scrap [ppm],
- **logistics** in terms of orderbook backlog [kEUR,%], special transport cost [kEUR], stock in production [days] and total stock value [kEUR],
- **production** in terms of production value [kEUR], productivity achievement [% actual versus target minutes], capacity utilization [%],
- **personal** in terms of lost time accidents [#], personal utilization [%] for blue collar, continuous improvement projects [#] are the KPIs.

Because capacity utilization from the KPI - Production measures the performance of facilities, this paper later focuses only on this indicator.

### 5.1.4 KPIs - Capacity Utilization (CU)

Capacity and capacity utilization (CU) are naturally the short-run concepts. The short-run means that the stock of capital is fixed (no increase or decrease) and the state of technology is determined.

Thus, the potential output may differ from a steady-state, long-run concept concepts (Morrison, 1985). It is clear that the both items are defined under conditions of a fixed stock of capital and the determined state of technology. The former is the notion from economics, and the latter is technologically derived physical notion. In general, CU rate is the ratio of actual output to the potential output that is different in those two notions.

The both notions of capacity utilization are described as the following:

(1) **Engineering**

In the realm of engineering, the capacity output or a potential output is referred as a maximal physical capacity output of a production facility. CU is the (weighted) average of the ratios between the actual output of facilities that is actually produced with the existing facilities, to the maximum output that could be produced with them (Johanson, 1968).

(2) **Economics**

In the realm of engineering, the capacity output or a potential output is defined as an optimum output. CU measures have traditionally been constructed as indexes of output for a firm, industry, or economy, as compared to potential output.

Capacity output, *Y**, is characterized by the steady-state level of production given the existing level of stocks and exogenous prices of inputs and determined as the tangency point between the short- and long-run average cost curves. In short, The *Y** implied by economic analysis of fixity is the "best" output level given available fixed inputs or "capacity" in terms of capital, the services of labor, energy, material, the state of technology, and others (Morrison, 1992, P. 55). This can be expressed in a function:

Y=f (capital, the services of labor, energy, material, the state of technology, others)

The CU ratio, which is defined as a capacity utilization index, is then constructed as the ratio between this and the realized level of output *Y*; CU = (YIY*) (Morrison, 1992, P. 163).

High capacity utilization rate can also lead to new investments in factory equipment and plant expansion so that companies can increase output in the future (Baumohl, 2007, P. 146). In contrast, the low rate will motivate the industrial manufacturers for improvements.

To sum up, the definitions of CU from both realms have mentioned the actual and potential output. The difference between both outputs is known as the output gap or the space for improvement.

The mentioned CU in this paper stays in the realm of engineering; this is, the notions in related with costs will not be considered, and but the formula:

CU = (YIY*)

will be applied for the expression of CU.

Capacity utilization is constructed to measure the productive runtimes of key machines at MSA. The full capacity output *Y** is defined to be calculated according to the base calendar. It is the same as TEEP in terms of quantity. The production function can be wrote in Y= f (production runtime). The inputs have, such as planned down time etc., been listed in Figure 5.2. The segments of bar in graphic is defined as follow:

- Productive runtime, which is displayed in green, is calculated by actual number of pieces*standard time. Its basis is production tracking sheet that track all the key machines, has to be filled out by operator, and must be monitored by all management levels, see the Figure 5.2. The colors of segments in those Figures are corresponding to each other. In addition, this sheet could also track the rough reasons of downtime.

- Planned down time, which is displayed in yellow, is calculated via sample production, Total Productive Maintenance (incl. cleaning), planned changeover/ set up.
- Down time, which is displayed in orange, is calculated via unplanned stops due to machines, parts quality or tool problem.
- Lost time, which is displayed in red, is calculated via unplanned stops due to the lack of order, material, absent employees (setter, machine operators etc.).
- Scheduled down time, which is displayed in gray/pink, is calculated by calendar days and shows the difference between the base (= maximum productive time) and business calendar that is defined by the company, and the sum of the listed times above.

There is a line in the graphic, which means the scheduled down time, to show what time will not be used for productive work.

All the segments in the graphic of capacity utilization are assumed as full capacity (100%).

The maximal productive time = 365days x 24hours x 60minuter = 525,600 minutes

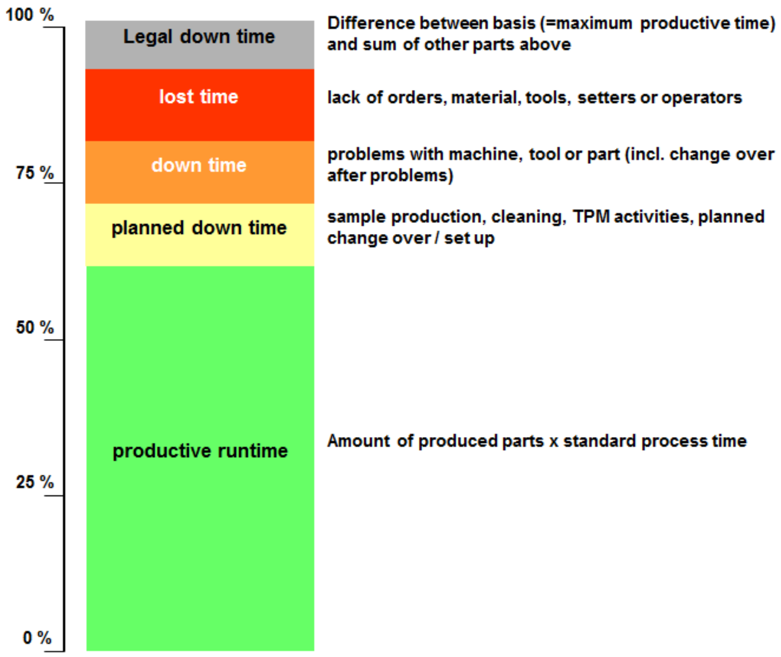



Figure 5.2 Capacity utilization of key machines (MSA)

In the capacity utilization, the most essential segment is item “lost time”, however, this paper tries to analyze the machines and then the down time due to the machine, tool or part will be the best choice, which is drawn in orange in the Figure 5.2.

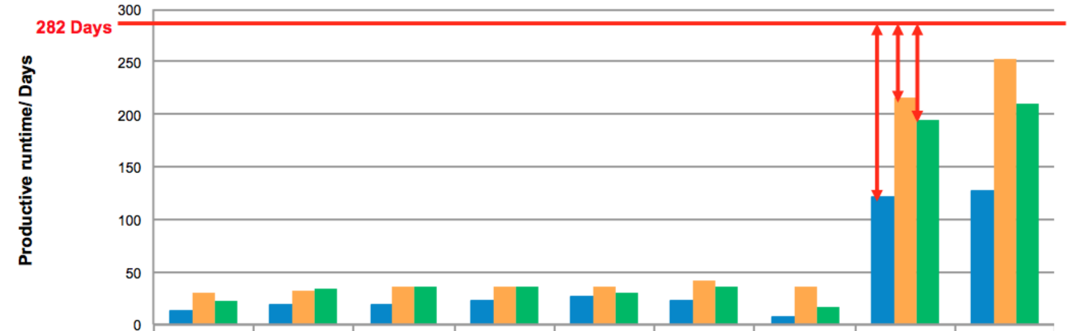
## 5.2 Analysis of technical Disturbances and Conclusion

The period of analysis on disturbance is from 01.10.2013 to 01.10.2014.

It will be treated no difference between the item “disturbance” and “problem” in this paper. The Powder Press is a compacting machine that compacts the powder into semi-component, such as O100 Pressen, MP-D250 IV Pressen (D250 in short).

### 5.2.1 Productive Runtime

The Productive runtime measures the time for all key machines, when they are producing parts.




| | Mon. | Tue. | Wes. | Thu. | Fri. | Sat. | Sun. | S64 | S74 |
|---|---|---|---|---|---|---|---|---|---|
| MP-D250 IV Pressen | 12,7 | 17,8 | 18,3 | 23,3 | 27,0 | 22,1 | 6,7 | 121,2 | 127,9 |
| BSO 8 Sintern | 31,0 | 32,8 | 36,0 | 36,2 | 36,9 | 42,7 | 36,6 | 215,6 | 252,1 |
| L400 IV Kalibrieren | 23,3 | 34,4 | 35,6 | 35,6 | 30,0 | 35,7 | 16,4 | 194,6 | 211,0 |

Figure 5.3 The yearly production runtime in the production

In the Figure 5.3, the horizontal axis shows three analyzed machines that are MP-D250 IV Pressen, BSO 8 Sintern and L400 IV Kalibrieren. The vertical axis portrays the productive runtime in the time unit days. The productive runtime on Monday means the amount of the total Mondays in the analyzed year. The bars from other days are ibid. As mentioned in chapter 5.1.2, the production calendar at MSA the items S53, S64, S74 respectively means 233, 282 and 332 working days.

The aim of this analysis is to find out the capacity utilization of machines in terms of productive runtime, and further the gap between production calendar and actual productive runtime of machines in the production.

The conclusion is that the oven (BSO 8 Sintern) performs better in comparison with other two machines, however, it had still 67 days in total 282 days (S64) in a stopping status. Those losing days are the target of further analysis in terms of causes and solutions.

### 5.2.2 Disturbances in the Production

The analysis focuses on six machines, among which two are for compacting, two for sintering and two for sizing. The analyzed Powder Presses (the compacting machines) are O100 Pressen and MP-D250 IV Pressen in the production at MSA. Currently O100 Pressen, which is proximately 15 years old, is equipped in the production unit 4 only for producing one component. MP-D250 IV Pressen is shown in chapter 5.2.2. The analyzed Sintern are SAK 2 Sintern that is equipped in the production unit 4 on 01.02.2006, and BSO 8 Sintern is shown in chapter 5.2.2. The analyzed sizing machines are CA100/K2 Kalibrieren that is equipped in the production unit 4 on 01.04.2012, and L400 IV Kalibrieren is shown in chapter 5.2.2.

In the production, the machine is described as workstation. O100 Pressen, SAK 2 Sintern, and CA100/K2 Kalibrieren correspond to the workstation 131M18, 132M20, 133M07 respectively. The workstation 131M19, 132M25 and 113M05 represents MP-D250 IV Pressen, BSO 8 Sintern and L400 IV Kalibrieren. Those workstations are used as the input parameter about machines in the production. When I collect the data about disturbances on Cronetwork, the input indexes are only the workstations.

The disturbances show in a series numeric form, such as 233, 240, concrete details as attached in the Appendix C. Those numbers are growing. Several years ago there are only few numbers as defined for disturbances. Furthermore, this increase could also be seen as a reflection that the complexity is growing in the production at MSA.

Currently there are two setters for each production unit, among which one is mechanical & hydraulic setter, and another is electrical setter.
Each production unit has four production lines.
Each line normally includes one compacting, sintering, sizing machine.
The compacting machine has six dies. Lacking of setter is always one of the most essential disturbances in the production.

When a disturbance, which is shown in the Appendix C, comes out in the production, the relevant setter is responsible to solve this problem and register disturbance index (e.g. 250, 280) into BDE.

On BDE, there exists a clear overview about which workstation is down with which production order, duration and reasons of downtime. The concrete descriptions of disturbances are not defined, not to mention the solutions of disturbances.

A little bit more such details are given in the tracking sheet in the production, for example, the technical problems, as shown in orange in the Figure 5.4, could be subdivided into hydraulic or electrical or mechanical problem.

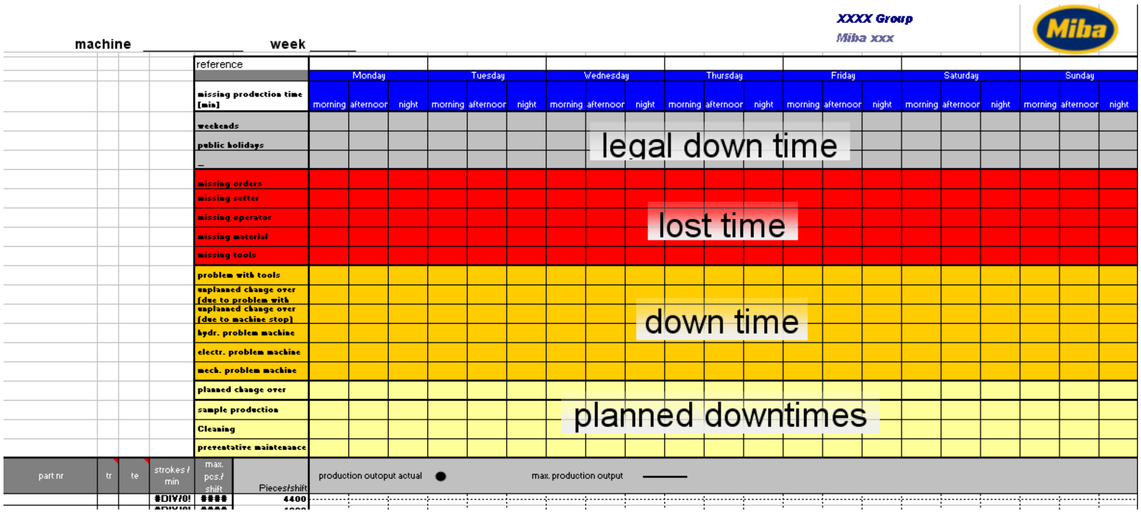
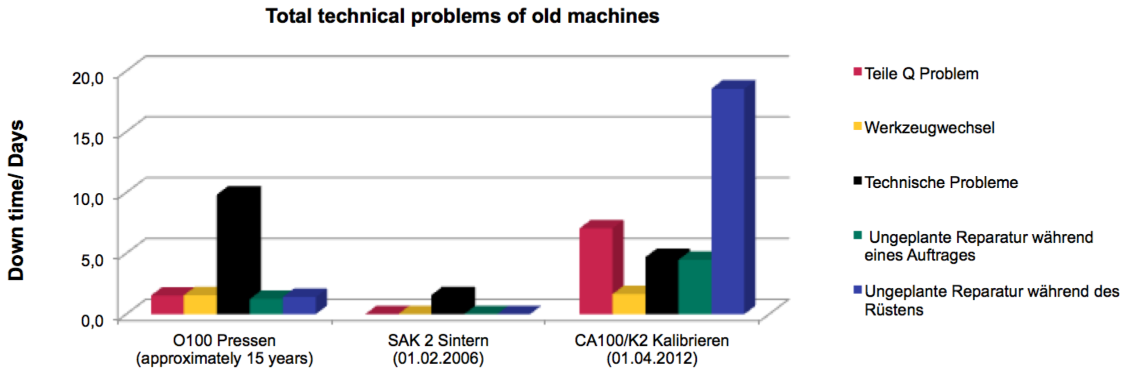
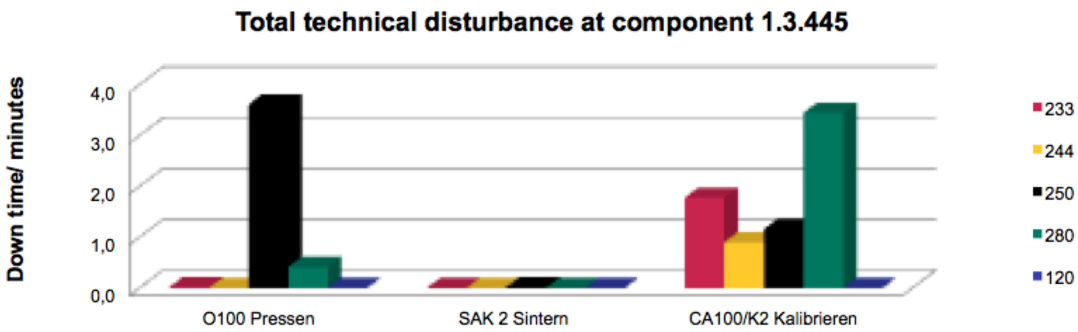



Figure 5.4   Production tracking sheet (MSA)

Most of the times (90%), the setters in the production could solve the technical problems of the machines alone. The maintenance personnel in the maintenance department take the responsibility only if the setters in the production have registered. Additionally, it is necessary to clarify that the technical problems is only the one of total disturbances in the production; for the maintenance department it is clearly different, the maintenance personnel deal with only technical problems.




(a)




(b)

Figure 5.5 The machine disturbances on production unit 4

In the Figure 5.5 and 5.6, the horizontal axis represents the three machines accompanying with six unplanned technical problems from total disturbances, which are the quality problem of component with code 233; post-processing of tool with code 240; tool changeover with code 244; technical problem with code 250; unplanned repair during the live production order with code 280; unplanned repair during setup with code 120. The analyzed machines are relatively old in the production. The vertical axis exhibits the duration of downtime of machines in the time unit of days (actual repaired time). Normally, the time unit of the registered working time on BDE is in minutes. The left Figure displays the downtime of machines due to technical reasons at PU4. The right Figure shows the technical disturbances in those three machines only when they produce the component 1.3.445 at PU4.

Figure 5.5 shows that the downtime due to the post-processing of tools (code: 240) is zero minutes in the period of analysis at PU 4; it could easily see that the disturbances in the oven can be negligible at PU4; for the component 1.3.445, the unplanned repair during the setup (code: 120) can be negligible in all the analyzed machines; the technical problem (code: 250) are the highest in the workstation 131M18 at PU4. There are different problems in the sizing, especially the unplanned repair (code: 280 and 120) due to mainly the complexity of mechatronic.

Figure 5.6 is the result of analysis of disturbances in the machine Dorst TPA250-3HP/4 (WS:131M19), BSO-8 Sinern (WS:132M25), and L400 IV Kalibrieren (WS:113M05). Those machines are quite new in the production.

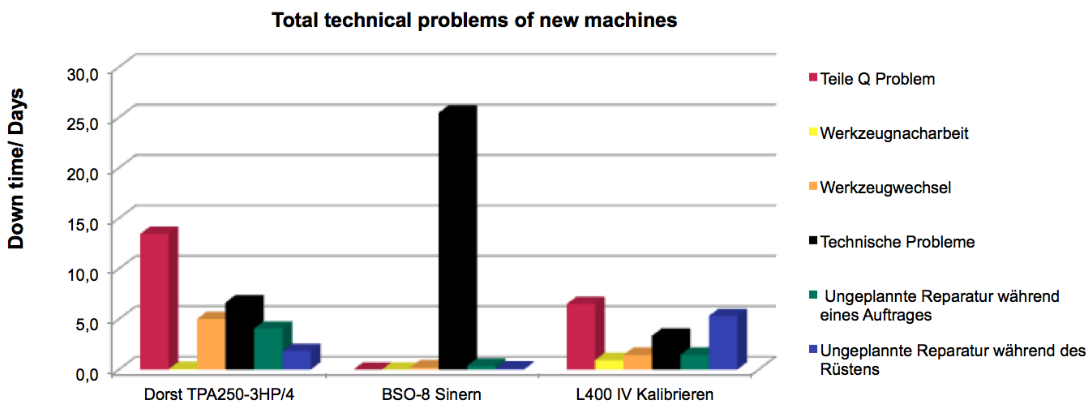



Figure 5.6 The result on analysis of unplanned maintenance time of machines

It is shown that the post-processing of tools (code: 240) can be negligible in all the machines. The disturbances in the oven could be negligible except the technical problem (code: 250) that is the highest one among all machines.

The reasons of the stoppage of the Powder Press vary. The quality problem of parts (code: 233) from this facility is the highest and the technical problem (code: 250) follows, which is normal for the new machine because it needs time to compatible with the surroundings.

The six portions of the disturbances in the Sizing Machine are quite similar from the Figure. Quality of components (code: 233) resulting in the stoppage of this facility is 28 hour longer than the unplanned repair during the set up (code: 120). Other disturbances in this facility are low and are negligible.

To sum up, oven with relative simple structure, which is equipped with lots of sensors, is the most stable equipment in the production. Furthermore, no matter whether the Powder Press is old or new, the technical problem plays a decisive role for the stoppage of the facilities. Because MSA makes lots of efforts on quality control, the interruption of the machines due to the quality problem of components usually occupied a small portion in total. At last, all the disturbances to the Sizing Machine cannot be ignored and it is difficult to judge which one is more important.

Thus, the further analysis will focus on the Powder Press in terms of technical problem, and on the Sizing Machine.

### 5.2.3 Disturbances in the Maintenance department

The analyzed facilities here are Dorst TPA250-3HP/4 Equipment with the number 1000006498 for compacting that is available in the production unit 1 on 01.11.2013, BSO-8 Equipment with number 1000004036 for sintering that is available in the production unit 4 on 01.08.2011, Lauffer 400-4 Equipment with the number 1000002496 for sizing. The newest oven, which is in the production unit 1 on 01.08.2014, has not enough data for evaluation. As described in the chapter 5.2.1, the MP-D250 IV Pressen, BSO 8 sintern and L400 IV Kalibrieren correspond to the workstation 131M19, 132M25 and 113M05 respectively. The workstations play no role in the maintenance department.

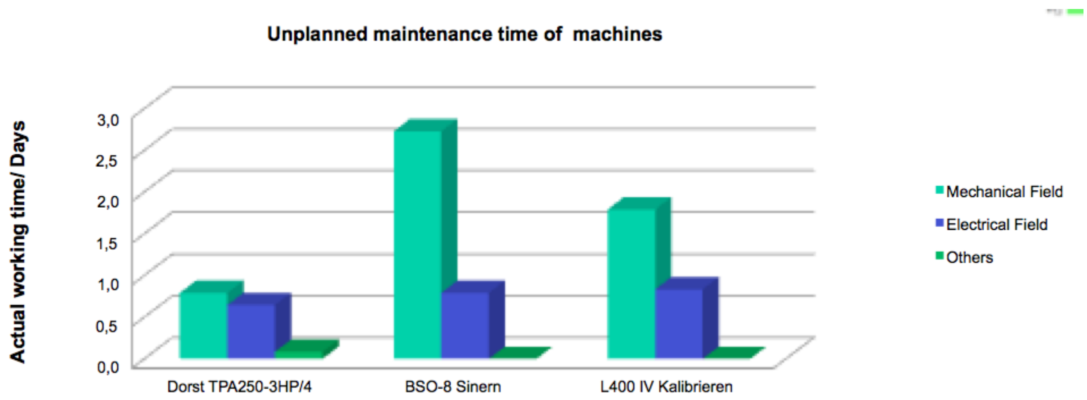



Figure 5.7 The result on analysis of unplanned maintenance time of machines from SAP

The source of the relevant data of the disturbances in the maintenance department is from SAP system.

The disturbances on SAP are subdivided into three different fields as follow:

- Mechanical field with defined code 110 where machinist and hydraulic technician (treated as no difference in the department) play roles.
- Electrical field with defined code 120 where electrician and programmer etc. play roles.
- Technical building system or others with code index 130 where plumber and panel-beater etc. play roles.

The horizontal axis of Figure 5.7 represents the three facilities accompanying with unplanned problems in three fields. The vertical axis exhibits actual repairing time of the maintenance personnel in the time unit of days. Normally, the time unit of the registered working time on SAP is in hour.

From the Figure it is clear that the oven occupied much more repairing time than the other two facilities, which will be correspond to the Figure 5.4 where the oven, particularly the technical problems, are quite the highest of all facilities. The oven requires more repairing time than the other two machines mainly due to R&D in quantity in last year. Another essential reason is to recognize the exact fault location. The special measuring tools getting the signals from the sensors in the oven covers only a rough range to users, such as heat error, which result in that checking occupies a large portion of repairing time. Additionally, it could be also the summed working time from several workers for a single problem. This reason is also adaptable for the other two facilities. The problems are mostly from gas and gas measuring device, the quality problem of components.

The actual working time of the maintenance personnel for the Sizing Machine occupied a middle portion as shown in the Figure. This facility, which is equipped with lots of sensors, provides lots of mixed electronic and mechanical problem together. The maintenance personnel spend usually one or two third of total time to search the problem according to the analysis.

This Figure also portrays that Dorst 250 has fewer problems. The final analysis is shown that 53% maintenance time comes from hydraulic couplings in the mechanical field with code 110 and the other 47% are from new machine compatibility. 45% error is from program and robot in the electrical field with code 120.

To sum up, even if the machines are equipped with sensors, the stoppage of facility is still high because the searching for the fault location needs huge time. In another words, the sensors do not really make the machines smart enough.

Additionally, the maintenance personnel will register their actual working time and a short description of the problem into SAP. They take the actions on the maintenance only if the setters in the production register.

Finally, the further analysis will show more the quick hydraulic coupling that is one of the parts of Dorst 250 - the Compacting Machine.

### 5.2.4 The Quick hydraulic Couplings

In this paper, there will make no difference between the quick hydraulic coupling and hydraulic coupling or coupling.

A quick coupling is a device that is used to connect or disconnect fluid lines without the use of tools or special devices. Quick couplings are designed to allow make and break of fluid line connections while acting as a pressure retaining device during system operation. In addition, hydraulic couplings are known as double shut-off couplings.

A quick coupling consists of a male half known as a plug, nipple or tip, and a female half known as a socket, coupler or body. The both are interrelated parts and interact with one another. A female half (socket) includes seals, lock mechanism etc., see the Figure 5.8 (Tuthill Coupling Group, 1999, P. 5). Double shut-off couplings have a check valve in both the socket and plug. They are used in systems where downstream spillage is undesirable. Working pressures of up to 10,000 PSI (689 bar) are common. Some special hydraulic coupling designs can reach 20,000 PSI (1378 bar), all depending upon design and material.

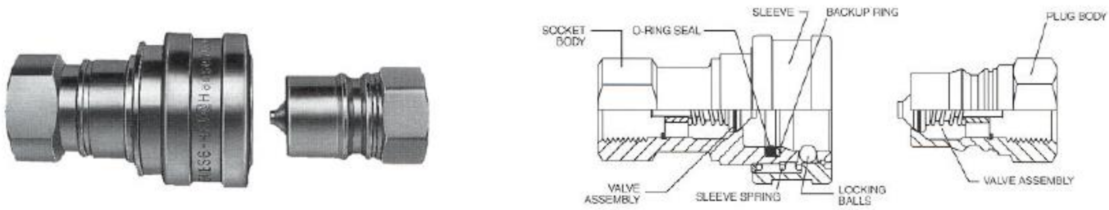



Figure 5.8 The structure of the quick coupling (Tuthill Coupling Group, 1999, P. 5)

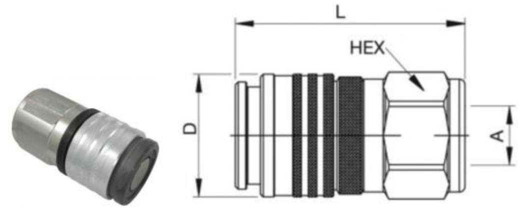



Figure 5.9 The quick coupling In the Dorst TPA250-3HP/4 (Maku, 2014)

At MSA, a compacting machine holds six quick hydraulic couplings, see the Figure 5.9. The coupling system of the FF series in the Dorst TPA250-3HP/4 has double shut-off, dry break and one hand operation (Maku, 2014). The ideal situation of this coupling system is that there is no oil loss during disconnection, and there are no air bubbles that are pushed into the system during connection.

The company or user naturally benefits those advantages from this product. Unfortunately at the same time it is recognized that the quick hydraulic couplings equipped in the Dorst TPA250-3HP/4 are often leaky due to the high pressure, frequently movement and powder dust. By the way, the couplings in some machine work well but they are smaller in comparison with the ones in the Dorst TPA250-3HP/4.

Since it is an integral part of the fluid system, the quick coupling is subject to all the dynamic forces and laws governing fluid systems. The primary function of a quick coupling in a fluid system is the retention of pressure and fluid in the system. Pascal's Law states that pressure acts equally in all directions and at right angles to the confining surfaces. This property of fluid under pressure can work both for and against the designer of quick couplings. Pressure capabilities of a quick coupling depend upon the ability of the sealing and pressure retaining parts to oppose the lines of force described by Pascal.

In the hydraulic system, sealing is for preventing leakage of the working medium and the external intrusion of dirt and foreign matter. The socket is constructed to provide a leak tight interface with the coupling. Leakage can be divided into internal and external leakage.

In the Dorst TPA250-3HP/4, the seal equipping in the quick hydraulic coupling is double O-ring composed of an elastomer (elastomeric rubber). Seals may also be categorized by how they interface with a sealing surface, such as face seal and diametral seal. The latter describes most O-ring and metal seals. This term describes a seal/sealing surface interface that maintains a line contact on a diameter. There are two seals in this coupling: body seal (locking ring) and valve seal. A body seal may be defined as a seal that prevents loss of medium at the interface of the two mating halves of a quick coupling in the connected position. A valve seal may be defined as a seal that prevents loss of medium and pressure from either half of a quick coupling in a disconnected position. Valve seals are installed in conjunction with a check valve assembly located inside the coupling. The valve seal mates with a body seat to form a completed seal. At MSA, the maintenance personnel sometimes only need to change one side of one coupling. So it means sometimes only one seal works not well.

Important characteristics of elastomers in quick couplings:

- Resistance to fluids: the fluid it is to contain must not affect the compound of the elastomer chemically.
- Hardness: the durometer or hardness rating of a seal indicates its relative compressibility. This characteristic is important because it governs how easily the material is deformed under pressure. Higher numerical ratings indicate greater degrees of hardness and greater resistance to deformation under pressure.
- Tear resistance: resistance to nicking and cutting of the seal by sharp edges that may pass over it.
- Abrasion resistance: resistance to scrapping and rubbing over a surface, especially important in dynamic seals.
- Compression set: the tendency of a seal to remain in a deformed shape after subjection to pressure. Memory of a seal is its capability to rebound to its original shape and is measured against elapsed time.
- Temperature: the physical effects of high and low temperatures may cause seal failure. High temperature may result in liquification of the elastomer while low temperatures (cryogenic) may cause crystallization and fracture of the seal.

To sum up, it is necessary to measure the strength of material of seal under the pressure 250 bar for checking when it will exceed to the elastic limit under conditions.

Furthermore, ball locking (the locking mechanism), which is the most common method of holding locking coupling halves together, is integrated into the quick hydraulic coupling equipped to the Dorst 250. The primary objective of the locking mechanism is to provide a positive method of retaining the plug in the socket while minimizing the effect of pressure on the mechanism.

There mainly are three factors to influence the coupling' locking mechanism function:

- Shock. Shock is very damaging to quick couplings since it can result in brinelling. Brinelling, which is the common problem of the ball locking, is caused when a load is applied to a ball bearing that exceeds the elastic limits of the steel and the raceways are permanently deformed. Brinelling creates measurable dents at each ball location. But this factor is not so common here because the environment of the coupling is stable.
- Side Load: A constant load exerted on the locking mechanism due to a heavy weight exerting force at a right angle to the center line of the socket/plug combination. Side loading can create differential wear on side loading the components of the mechanism as well as sealing problems. This is an important factor here.
- Impact Damage: Distortion of the sleeve, cams, or other parts in the coupling due to severe impact. This situation can make the locking devices inoperable. This factor will be negligible here.

To sum up, it is important to know the state of side load on the locking mechanism, which could see as a feedback on whether it is the time to change the seal/coupling or not. By doing so, the leaky could be avoided. The quick hydraulic couplings in the house are often leaky because of high pressure, which is probably due to the high side load on the O-ring.

Moreover, the invasion of the tiny dust particles, are mainly here powder dust, into the system, will cause or aggravate the wear of hydraulic components, and further lead to leakage. Thus, a leading task for the company is regularly to check oil quality and cleanliness.

At last, the changeover time will be fixed by analyzing the data above of the coupling along the calendar.

## 5.3 The Cyber-Physical Production System (CPPS) at MSA

The integrated smart sensor systems are the base of CPPS and are the decisive level to ensure the factory smart, see chapter 3.1.1. In other words, the smart factory will not be built up without integrated smart sensor systems or sensor network (industrial sensors embedded in one chip equipping with computation and communication). This immediately raises one question how expensive of such sensor network. Additionally, industrial modernization need for higher productivity has brought the production equipping with sophisticated devices and machines. The following challenge is how to monitor and manage such an enormous system of sensors and indicators, even if one chip is able to integrate many sensors. Take the example of a quick hydraulic coupling, which is one of the thousands of components in the compacting machine, will be integrated a smart sensor network (four sensors inside). Currently one such compacting machine has six quick hydraulic couplings. It means six such sensor networks are required for the couplings. In the production, each production unit of four in total has four Powder Presses (four dies). When we consider also the Sintering and Sizing machines, it will be difficult to correctly manage the data. Thus, when we try to build up CPPS, at same time we must start to think of handling the big data.

## 5.3.1 The Intelligence in the Machines

### 5.3.1.1 Foreword

Due to the similar theory on the intelligence in the machines from all production units at MSA, Production Unit 4 will be further discussed. As mentioned in chapter 2.2, PU4 has internal and external works that are explained in chapter 4. Additionally, the internal work involves three machines: compacting, sintering, and sizing machine, which are the main topic below.

### 5.3.1.2 The meaning of intelligence in the machine

The definition of intelligence is controversial. However, it is widely agreed that intelligence is one of the adjectives to describe ability of human beings on comprehension or perception.

The term intelligence is well-known to be defined in the realm of psychology: "*a very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience. It is not merely book learning, a narrow academic skill, or test-taking smarts. Rather, it reflects a broader and deeper capability for comprehending our surroundings—"catching on," "making sense" of things, or "figuring out" what to do*" (Gottfredson, 1994). This definition has been proven that intelligence can be only used to describe humans although some non-human animals and plants are recognized that they are able to perceive surroundings. Nevertheless, they are of one or several abilities that are defined above.

The intelligence in the machine, which is firstly called the ghost in the machine by Ryle, means that the representation of a person as a ghost mysteriously ensconced in a machine. The Ryle's argument is original a philosophical debate against Cartesian Dualism on the grounds that mental processes (mind) could be isolated from physical processes (body) (Ryle, 1949).

Based on Ryle, the intelligence is possible to be added into the machine, this is, humans could practically formulate all the visions up and machines put practical reasoning into action. The difference between intelligent person and machine exists: the intelligent person is not only able to make causal inferences in accordance with psychological laws but also able to take them into action; the intelligent machine make inferences on the basis of a sequence of embedded hidden mental processes that drive from humans and then enable the actions. Akerkar has explained that the main difference between human and machine intelligence comes from the fact that a human being perceives everything as a pattern that is in storage and recall automatically give robustness and fault tolerance for the human system that is the base of memory and reproduction of other data, whereas for a machine everything is data inclusive of the artificial pattern that are Figured out by humans and embedded in the machine (Akerkar, 2005, P. 212ff). For the machine, the recall will only happen when the relevant pattern has earlier been embedded.

#### 5.3.1.3 The intelligence in the machine

As mentioned above, human could let machine be smart. The degree of intelligence in the machine primarily depends on how much human allows them. This is theoretically right because humans, here particularly maintenance personnel at company, would like to let all machines in the production as smart as possible. Nevertheless, the ways or mediums so far in reality are not possible to transfer every wish from people to machines, and further let them perform perfectly actions. As previous chapters described, Industrie 4.0 introduces one technology Cyber-physic System (CPS) that is proven that is able to accomplish this transfer.

Now we should discuss the embedded system, particularly sensors, because a successful CPS mainly depends on how smart the sensors are. They are the base of the intelligent machines that could tell what they feel and/ or what problem they are going to have at exact location.

#### 5.3.1.4 The smarter elements of the intelligent machine

All the sensors at MSA are the normal industrial sensors. One of examples of such industrial sensors is depicted in the Figure 5.10 (a).

Two solutions are explained to make the machines smart in the view of Industrie 4.0.

The industrial sensors are referred to as the existing sensors and the additional sensors in all the machines in the production according to the information from maintenance department at MSA.

(1) The existing sensors stand for the sensors that have already existed in the machines although some of them are not used yet. For example, in the sizing machine there exists flow rate sensor and water flow and heat sensor and so on, but they are not used. However, the maintenance personnel expect that those sensors take action and then they could get informed earlier if the problems come.

(2) The additional sensors are the expected signals (wishes) of maintenance personnel that could make the machines smarter, such as noise sensor for motor and pump in the sizing

machine, particle counter in the compacting machine, and localized band and gas sensor in the oven and so on.

**Solution 1:**

The objective of this solution is to focus on those industrial sensors in order to analyze whether they can be the base to let currently the machines in the production at MSA perform as expected or be possible to be intelligent. Additionally, for the additional sensors firstly it is required to be chosen according to demands. Here I will take the quick hydraulic coupling as an example to explain the way for choosing.

A sensor or sensor element is a device that detects events or changes in quantities and provides a corresponding output, such as voltage. A sensor's sensitivity indicates how much the sensor's generally as an electrical or optical signal; for example, a thermocouple converts temperature to an output changes when the input quantity being measured changes. Sensors need to be designed/selected to have a small effect on what is measured. Many sensing elements have the problem of cross-sensitivity; i.e. besides their sensitivity for the measurand, they also show an undesired sensitivity for other physical quantities. Moreover, besides the desired electrical output signal, they also show parasitic electrical effects. This could be solved by the applied technologies, such as the three-signal technique (a continuous auto-calibration technique that eliminates offset and gain errors of the interface circuit), indirect A/D conversion based on the use of a first-order oscillator, dynamic voltage division, dynamic element matching, advanced chopping, synchronous detection and two-port measurement techniques (Meijer, 2008, P. 50).

We start with considering to integrate industrial sensor (normal sensor in the market) that are targeted at a cost-driven, medium volume, industrial sensor market into some parts in the machine, such as quick hydraulic couplings currently without any equipped sensors (additional sensors are required) in the compacting machine. Based on chapter 5.3, this part requires three industrial sensors in the socket and one in the plug because the socket is the main part of a quick coupling. For almost all types of sensing elements, the packaging problem is a main design issue: to perform its basic function, the contact between the sensing element and the physical or chemical environments should be as good as possible, while, on the other hand, this close contact could be the reason of degradation or damaging of the sensing element. Therefore, firstly the sensors must carefully be chosen and/or packaged on the basis of basic functions of it and the required demands on it, and further take into account the media for transferring.

The conditions of the sensors for the coupling here are as follows:

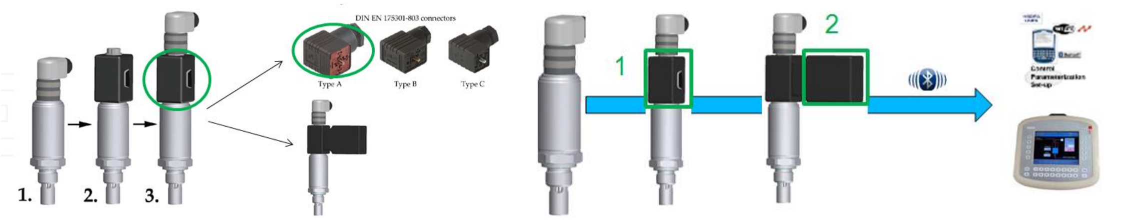
- Precondition (in harsh operating conditions): The sensor is unaffected by shock or vibration or by flow conditions. At the same time, sensor measurements are not affected by particulates in the oil.

- The sensor is provided with a G¾ thread (depends on the size of the coupling) and can be integrated in the bore of the coupling. Optionally the sensor can be used as immersion sensor for analyzing the quality of hydraulic oil.
- The measured parameters: the strength of material of double O-rings, side load on the locking mechanism (locking ball), and the quality of the hydraulic fluid.
- Four sensors for one quick hydraulic coupling due to the double shut-off couplings.

After selecting out the sensors for the coupling, the data from sensors need to be further transferred. Data could be gathered either automatically over wired data acquisition systems or in modern factories by wireless using wireless sensor networks and/or mobile robots for data collection as depicted in the Figure 3.5.

For the traditional data transfer, firstly, sensors often need special measuring tools, such as oscilloscopes or more sophisticated sensor signal conditioning equipment for checking the correct operation of the industrial sensors. Such measuring equipment is often expensive and inflexible and can be used only for a specific type or brand of industrial sensors (Parker Hannifin Corporation, 2012). Additionally, as long as the measurement is required, the cables must be connected because most measuring tools have wired connection to the sensors (HYDAC ELECTRONIC GMBH, 2012). Secondly, each measuring tool has its own user interface, which is often awkward and tool-specific. Such a measuring tool is used, for example, in the field of industrial signal conditioning of hydraulic systems and is shown in the Figure 5.9. (Tašner et al., 2013), which make the production even more complex. Lastly, the automation system in the machine, such as manipulators, robots and mobile robots, is equipped with numerous sensors for their correct operation. The causes of faults in such system are hard to detect and isolate, especially if the error appears only during operation. Therefore, advanced algorithms are being developed for FDI (Fault Detection and Isolation) (Hsiao & Weng, 2012). Such algorithms often provide the operator with general error descriptions, for example 'heat/ CO error' in the oven. However, they do not provide the exact fault location within the subsystem. Maintenance personnel often use trial and error approaches to find out which component has failed. Such methods can be time consuming, see the chapter 4.1 and 5.1.

Radio communication, as another way to transfer the information from industrial sensors to the higher levels, is proven to be able to eliminate all the difficulties from the traditional transfer as mentioned above. The complexity can be immediate reduced in comparison with cable connection. The cost would probably be reduced when the mature wireless communication is successfully transferred from consumer electronics into industrial environments. Moreover, this transfer is on the way as mentioned in previous chapters. FDI will improve because wireless is reachable in the whole area and does not exist connection limitation. The basic idea is to add wireless access to existing industrial sensors, details in chapter 5.2.3, so that data can be read wirelessly when needed, with no effect on the existing sensor connection. The wireless connectivity of existing industrial sensors can be extended to a smart device without stopping its normal operation for maintenance use via radio technologies, such as Bluetooth, ZigBee, Wlan etc. (Garroppo et al., 2011, P. 1ff). Bluetooth has been chosen here as the appropriate protocol for wireless measurements because most modern smart devices have Bluetooth and Wi-Fi built-in and therefore no additional hardware is required for these two wireless protocols. Under the consideration of power consumption and range operations, Bluetooth is the best choice in comparison with Wi-Fi. All the radio technologies that Industrie 4.0 mentions are listed in the Appendix D.




. (a) (b)

Figure 5.10 The sensing system with the extended link via Bluetooth

(modified from Tašner, Les, & Lovrec, 2013)

Figure 5.10 (a) portrays the principle of how the information from industrial sensor can be diagnosed via Bluetooth. “1” from the left side of the Figure (a) is one of the normal industrial sensors. The black block in the middle of the Figure refers to as the connector module that is attached to the sensor, and that is the medium between sensor and Bluetooth module. The Bluetooth/main module can be connected to the connector module when it is required. For example, the operator gets a general error alarm and then a diagnosis is required for recognizing the exact fault location. This solution is economic because the main module is flexible, which make it possible to be shared in several connector modules. It is also adaptable to the parts with rare failures. However, this concept does not solve the reality of searching for the exact fault location and FDI is still there.

Figure 5.10 (b) portrays the principle of how the information from industrial sensor can be transferred into smart devices via Bluetooth. When the sensor recognizes a failure and the signal is sent to the smart devices, such as smartphone and/or tablet. The transfer of data, which will be achieved via adding a connector and main module to the related special sensors, see “1” and “2” in the Figure 5.10 (b) (Tašner et al., 2012), is the same as Figure (a). It means that the type of sensor must correspond with the one of the connector modules. The main module adds to the connector module that stores all the sensor prosperities only if the data from a specific sensor needs to be measured. A wireless is achieved by equipping them with a

Bluetooth module, which digitizes the data and passes it to any Bluetooth capable smart device, such as smartphone, tablet, for further processing, evaluation and logging.

The satisfied benefit from Figure (b) is that FDI is handled.

The above is only one possibility for making the existing sensors that are equipped to the parts that usually have rare problems, such as some parts in the oven. Another is to integrate the main module and connectors together but the main module is in sleeping mode if there is no error. The parts of the machine equipping those sensors often have problems, such as a quick hydraulic coupling on the assumption that the sensors have already existed. When the error emerges, which will wake the main module up that could send a signal to Personal Digital Assistant (PDA), such as smart phone, of related shift worker. The shift worker has to switch on the smart device, such as iPad, to get and check the data, which will save the energy because the error will not emerge all the time and there is not necessary to always acquire the sensor status.

Figure 5.10 clearly shows the connector and main module is the information bridge between sensor and smart devices. The sensor here is one of the seal sensors equipping to a hydraulic coupling.

However, the rising challenges are that the industrial sensor must provide enough place for mounting the connector module, and that they have to be visible.

**Solution 2:**

The objective of signals for maintenance personnel is to negotiate with spare department, production etc., and further to organize all the maintenance as planned and as much as possible to improve TPM activities.

Nevertheless, even if they could manage all the repairing works earlier via various monitoring methods that are generally used for plant and machinery, such as visual monitoring in terms of color, shape, texture via measuring overall appearance; performance monitoring in terms of uniformity of rate, quality level, uniformity of quality via the measurement of rate of output; vibration and sound-level/noise monitoring in terms of frequency content, signal wave-from, signal statistics via measuring overall vibration and noise level; wear-debris monitoring in terms of size-distribution, shape of debris and chemical composition via amount of debris, the precision is still missing because the most items as mentioned above primarily depend on the maintenance personnel' experiences (Bikash, 1998, P. 30ff). For example, people could only judge the band in the oven could be broken soon, but when it is out exactly is difficult to tell. Additionally, the on-line monitoring the MSA uses, for example in the oven, enables timely and/or conditional alarm that offers only a rough area and is not possible to provide exact fault location.

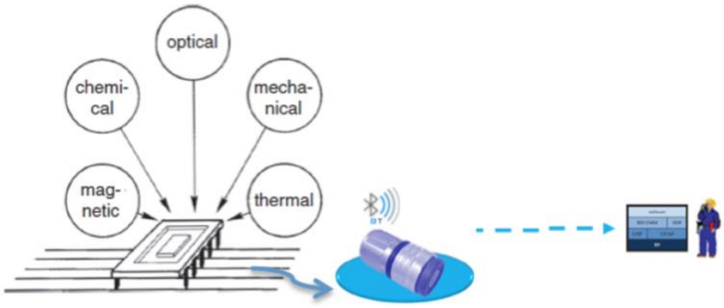



Figure 5.11 The integrated smart sensor system integrated Bluetooth

(modified from Meijer, 2008, P. 10)

Now it is time to think about the integrated smart sensor systems. In smart sensor systems, the functions of sensors and their interfaces are combined in an overall design. These functions include sensing, signal conditioning, analog-to digital (A/D) conversion, bus interfacing and data processing. Also, functions at a higher hierarchical level can be included, such as self-testing, auto-calibration, data evaluation and identification.

We still take the example of quick hydraulic coupling. As mentioned several parameters need to be measured for avoiding the leaky. Now we could integrate all the required parameters into one chip equipping with computation and communication for setting up an integrated smart sensor system or a sensor network, which simplifies the management. The communication protocol is radio technologies, such as Bluetooth. This networked system is depicted in the Figure 5.11.

When such network sensors equipping with a highly integrated, low-power and low-cost processor are extended a wireless communication and embedded to each component of machines.

Figure 5.12 shows an outlook of intelligent machines in the production at MSA. Those three smart machines could make inferences about underlying and/or hidden issues of them via the embedded knowledge (sensor equipping with computation and communication etc.) from various experts, and further take the results into actions, such as to inform the maintenance personnel for changeover and so on.

It is based on the three machines and network sensors as depicted in Figure 5.11, for example. Additionally, the previous two items are the existing sensors in the machine; the latter two are the additional sensors. Those signals from both types of sensors can be also noted as prognostic or indicative parameters. In comparison with the traditional monitoring methods of those parameters, the difference here is that smart machines perceive, measure, analyze, and finally give the conclusions of parts, such as what is about to happen and why and when and how and so on, not maintenance personnel any more. However, they are still predominant because they formulate the various patterns up and embed the intelligence in the machine.

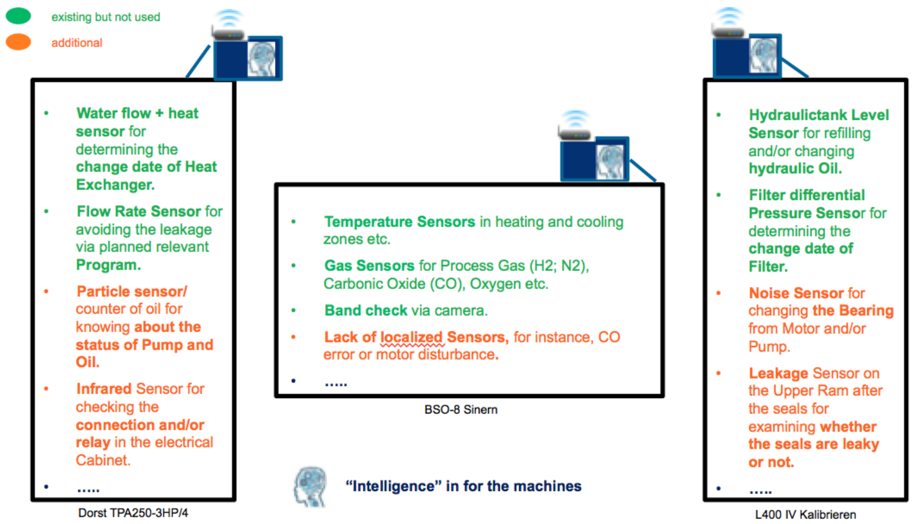



Figure 5.12 The intelligence in the machine via radio communication

The compacting machine:

- Water flow + heat sensor for determining the change date of Heat Exchanger.
- Flow Rate Sensor for avoiding the leakage via planned relevant Program.
- Particle sensor/counter of oil for knowing about the status of Pump and Oil.
- Infrared Sensor for checking the connection and/or relay in the electrical Cabinet.

…

The oven (the sintering machine)

- Temperature Sensors in heating and cooling zones etc.
- Gas Sensors for Process Gas (H2; N2), Carbonic Oxide (CO), and Oxygen etc.
- Band check via camera.
- Lack of localized Sensors, for instance, CO error or motor disturbance.

…

The sizing machine:

- Hydraulic tank Level Sensor for refilling and/or changing hydraulic Oil.
- Filter differential Pressure Sensor for determining the change date of Filter.
- Noise Sensor for changing the Bearing from Motor and/or Pump.
- Leakage Sensor on the Upper Ram after the seals for examining whether the seals are leaky or not.

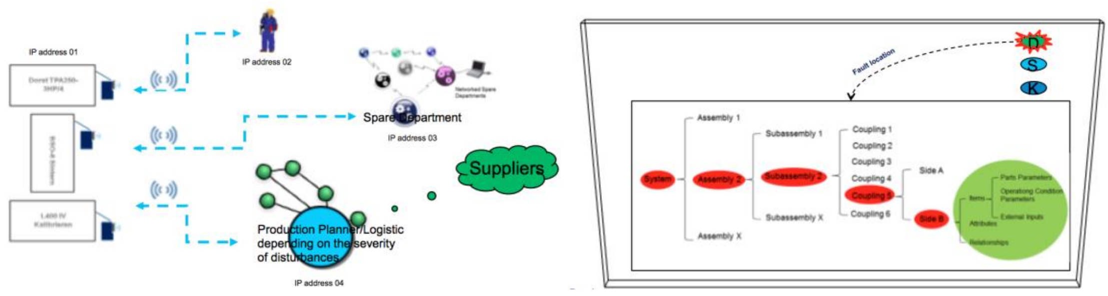
…

It is beyond doubt that the industrial production will benefit from such intelligent machines. That is also the reason why manufacturers expect Industrie 4.0 of which the vision is let smart machine be possible for industry use.

The crucial rising challenge from this solution is the return of investment on the sensor networks.

## 5.3.2 The Information Flow based on Smart Machines at MSA

Industrie 4.0 says that vertical networking, end-to-end engineering and horizontal integration across the entire value network of increasingly smart products and systems should be implemented in the manufacturing environment, see the chapter 4.1. The hotizontal integration has already been explained in chapter 4. In this chapter, we only focus on the vertical integration. It is defined as the integration from the actuator and sensor, to production and planning control via the extended communication link such as Bluetooth, further to the manufacturing execution system (MES) and enterprise resource planning (ERP) via WLAN, for example.




(a) (b)

Figure 5.13 The information flow of sensors equipping on a quick hydraulic coupling via Bluetooth

Industrie 4.0 says also everything, down to the smallest piece of equipment, has to build in intelligence. It means that the parts, like quick hydraulic coupling that is only one of the thoughts of parts of a compacting machine, has to be smart for analyzing the task data in real-time. A sensing system in the parts must be built and then an autonomous actuator-sensor network can be formulated up.

Figure 5.13 shows a pattern of information flow based on three different smart machines: the compacting machine, the sintering machine, and the sizing machine. The medium is based on radio technologies. Every involved device is assigned a unique Internet Protocol (IP) address for communication.

The basic idea of this information flow is that the shift worker' smart phone will ring, see the Figure above (a) and inform him about a problem at a quick hydraulic coupling # 2B (6 in total, A and B for both side) in a compacting machine, for example, when he is working at shift. He checks several parameters on his smart phone screen and decides to better diagnose the problem on the smart device like iPad, see the Figure above (b). Then, he switches on iPad, links it to the coupling #2B via radio technologies, such as Bluetooth, and performs several checks. Finally he learns that the quality of hydraulic oil is too low, which result in medium brinelling on the seal. The machine has drawn a inference according to the earlier embedded pattern and suggests to change the seal/coupling assembly inside three days. This information will be sent to various relevant people via individual Internet Protocol (IP) addresses. It means that different people will get different information. Some will be informed in more details and some get few, maybe only several words, which is for avoiding the redundant contents.

For example, in this case, the spares department synchronized gets this information in more details of the part, can be seen the green area of Figure 5.13 (b), and could immediately check the availability of a spare part. If there is no one in the stock, they could check whether other sites have this part in stock through the network or not. No matter what situation it is, the order will be organized on time.

The signal will not need to inform the production planner because there is no standstill on the machine, further on the production order. What is really necessary is the maintenance personnel have to negotiate with the production planner for the changeover of this part in terms of time unit. If the seal has severe brinelling and need immediately to changeover, in this case, the production planning and control and logistics must be informed at the same time. If the spare part is not available in one shift, at the center of production planning and control, the external suppliers will be informed that will add huge value into the production (see VSM in chapter 2.2.4).

This information will also go to the maintenance department in order to increase the overall equipment effectiveness of plant equipment (TPM), to further drive an improvement of OEE.

Additionally, the measured information will transfer the data to BDE for further analysis and archiving via field-bus.

## 5.4 Summary

The vision of the analysis on disturbances in maintenance department is to drive the unplanned downtime due to technical reasons into productive runtime. The main objective is to the fullest extent reduce unplanned repairing time of maintenance personnel via the technologies that Industrie 4.0 introduces. In addition, it will be also interesting to see how it looks like if the traditional problems will be solved via Industie 4.0 and how Industrie 4.0 breaks through the production limit, such as batch production and so on.

The downtime in this facility due to technical reasons (code: 250) occupied relatively large proportion both in new and old facility. It will grow along the time due to rate of ware. In the new facility the quality problem generally plays an important role due to new machine set up. The disturbances in the oven can normally be negligible, exclusive of some special items such as R&D etc. There exist a variety of problems in the Sizing machines, and grow along the time. Because of the sophisticated structure of the machine, it is difficult to work out which disturbance are more important or comes out more often. Therefore, I will take the example of compacting machines O100 Pressen (old) and Dorst 250 (new) here to Figure the capacity utilization in order to portray the objective and vision via CU.

In the Workstation Dorst 250, unplanned downtime due to technical reasons lasts 44.700,64 minutes in total, as depicted in Figure 5.14. The data comes from BDE in the production.

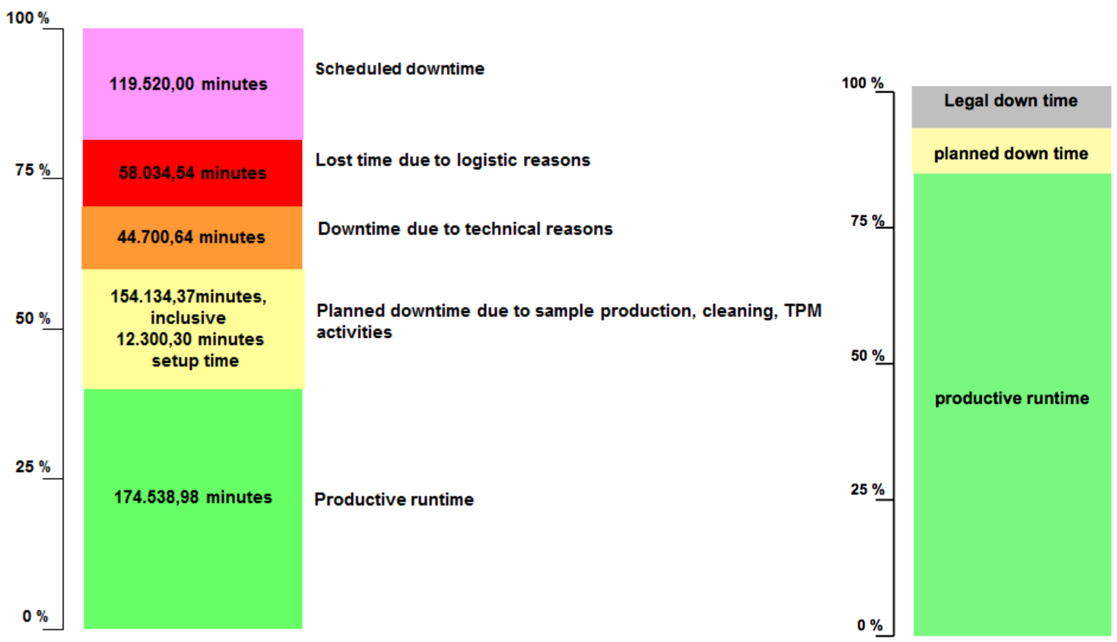



Figure 5.14 CU in Dorst 250 (left side) and objective of Industrie 4.0 at MSA (right side)

In the maintenance department, total downtime, which is registered in SAP, is 4.290,00 minutes including 2.190,00 minutes downtime and 2.100,00 of planned downtime.

It is clear to see that 42.510,64 minutes is done by setters in the production. It means the setter (Einsteller in German) plays really an essential role in the machine routine maintenance. For the new facility the analysis was carried out that their working/repairing time occupied 96% of total and the maintenance personnel hold a portion of 4%. So far, the concept of TPM has been proven that it works perfect at MSA.

53% of 1.140,00 minutes is from quick hydraulic couplings in the mechanical field and another 47% is from new machine compatibility. 45% error is from program and robot in the electrical field. The unplanned downtime can be negligible in the technical building system as shown in the Figure 5.5.

Find out the exactly fault location, which occupied a large portion in the Figure because the sensing system is not complete and the industrial sensor has no intelligence. Those are not smart enough and transfer only a signal to measuring tools in a rough range. Fortunately, the chapter 5.4 has given the solutions in point view of Industrie 4.0. One solution is for the industrial sensors. Another is building up the sensor networks in the production.

To sum up, with the solutions as described in chapter 5.4, 66.67% unplanned down time has been eliminated in the mechanical field and another 33.33% will switch into the planned downtime as described in yellow in Figure of Capacity Utilization. The loss time can be also removed that is primarily discussed in a VSM. This result is depicted in the Figure 5.5.2.

# 6. Conclusiones and Outlook

Adapting one or some potentials of Industrie 4.0 to MSA is not reasonable because the technologies that Industrie 4.0 includes are closed linked together resulting in the insignificant benefits for MSA.

To sum up, Industrie 4.0 has still long way to go. Most of the technologies that Industrie 4.0 introduces only mature in the consumer market. That is why in the realm of industry area Industrie 4.0 faces lots of challenges, such as standardization, managing complex systems, delivering a comprehensive board infrastructure for industry, safety and security and so on. The details are described in 2.1.2.

Firstly, Cyber-Physical Systems (CPS) is introduced on production systems concerning flexibility and reconfigurability. The basis of CPS is how powerful the embedded system at lowest level of automation pyramid. This embedded system further depends on how smart of the sensor in the production. Currently one of the biggest challenges is the cost on such smart sensors. When they charge only several cents, the companies will benefit more than now. Another challenge is the reliability and security of the extended radio communication technologies, such as RFID, Bluetooth. Additionally, the smart devices from consumer market for industry use need to be developed. The analysis and test for the existing standards are also necessary.

Secondly, SOA as a powerful decentralized software architectures is primary employed in the business domain (ERP). For the automation applications the research on SOA should be going on. Currently DPWS is chosen as service technology in the field device because it is able to define a profile specifically targeted for SOA in the lowest level.

Thirdly, HMI is developing in the shape of transferring of smart communication technologies from consumer market into factory environments. Those technologies have experimentally been proven that they are a promising approach for the industrial plants via offering flexibility. Some industrial apps have been developed but they are limited to handbooks for product catalogues. A reference architecture for the „app concepts“, such as App Store, is still missing today.

Lastly, it is still necessary to learn from the CIM era in the center of human being. The vision of Industrie 3.0 was totally automation system in the production without any operators, which should be clarified in Industrie 4.0 within which humans are not superfluous. The human being will always play the role from the planning through the operation to the maintenance in the whole automation pyramid. The difference with nowadays is the nature of responsibility of people will change. The future systems will focus on humans and their abilities.

In addition, the vision of Industrie 4.0 can be summed up as embedding the intelligence into machine. Additionally, humans have to always be in the center of machines because they are the original positive stimulation in the machines. That is also why the smart machines are usually called as artificial intelligence that is described the simulation of intelligence in machines.

Industrie 4.0 provides a new industrial control systems equipping with a high interoperability and adaptability of networked automation devices, which let it possible to make a quantum leap in the production and free from the disturbing cycle between improvement and complexity in order to accomplish completely lean production. A quantum leap especially means that the full capacity output of key machines is achieved at MSA, that is, in the graph of capacity utilization (CU) there exists only two segments: productive runtime and legal down time. This is depicted in the Figure 6.1.

As explained in chapter 4, lost time due to logistic reasons can be partly eliminated and partly shipped to planned downtime. The chapter 5 portrays the solution for eliminating the unplanned downtime due to technical reasons. With those solutions the unplanned downtime can be partly eliminated and partly shipped to planned downtime. So far, the graph of CU includes only three segments: legal down time, planned down time, and productive runtime.

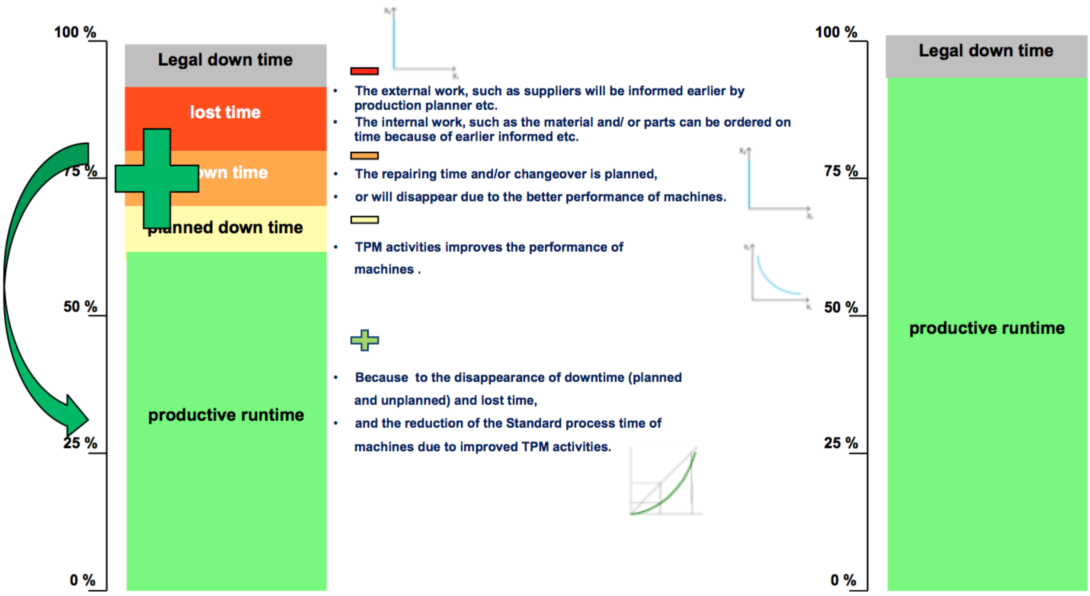



Figure 6.1 The outlook of Capacity Utilization

Due to the technologies that Industrie 4.0 connects seamless in a profit-driven way, TPM, which stands for total effectiveness, total maintenance, and total participation, could perfectly perform on the reduction in the number of unexpected equipment failures, in the direct costs of maintenance, in quality costs – both internal failure costs due to defective products and defects in production processes and external failure costs in the form of a significant reduction in customer complaints and adjustment claim, in work-in-process inventory, and a significant increase in labor productivity in terms of the value added per worker. Therefore, along to the gradually improved TPM activities the planned down time will fade out.

Finally, the machines can run in full capacity, and further lean production is completely achieved.

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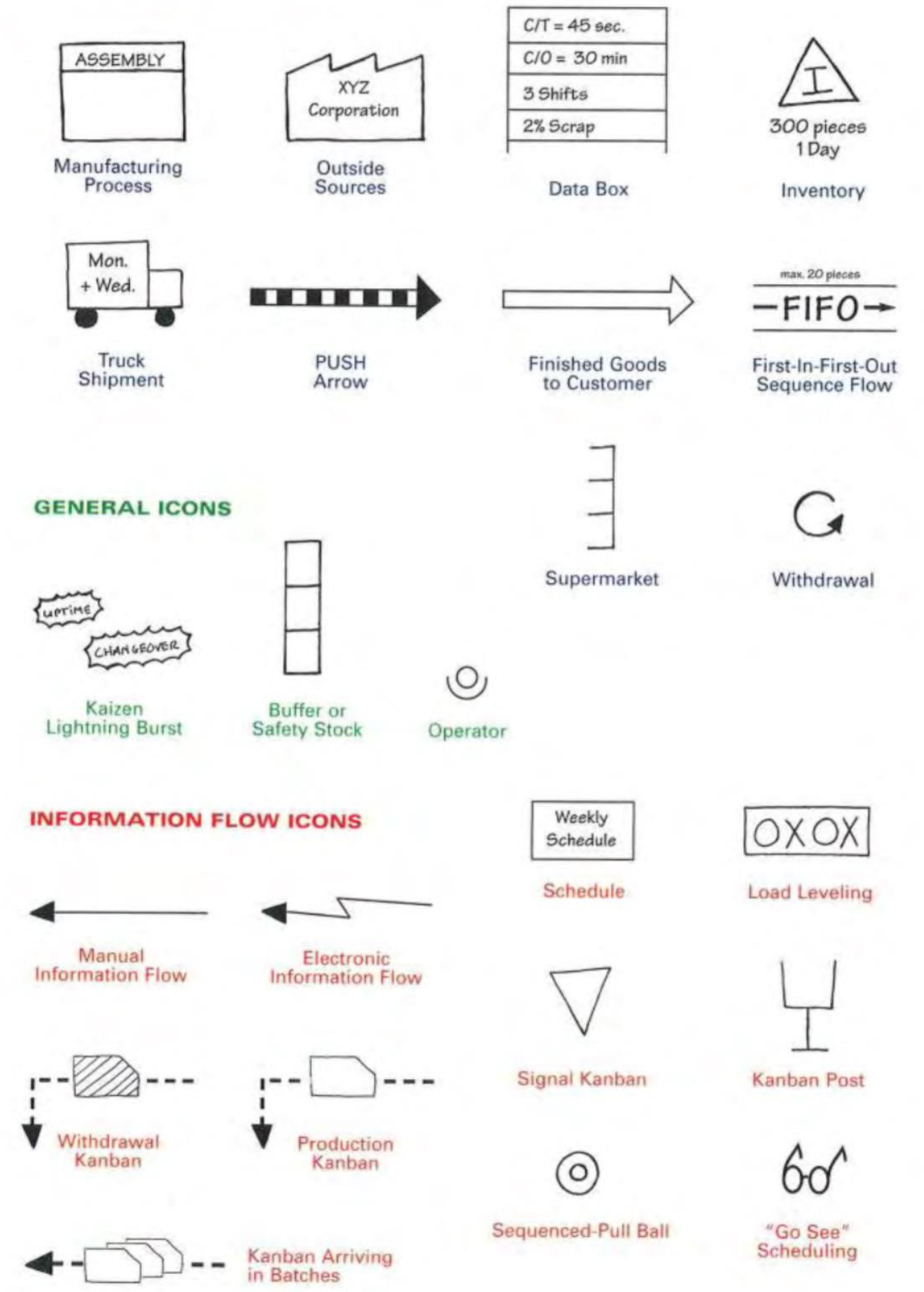
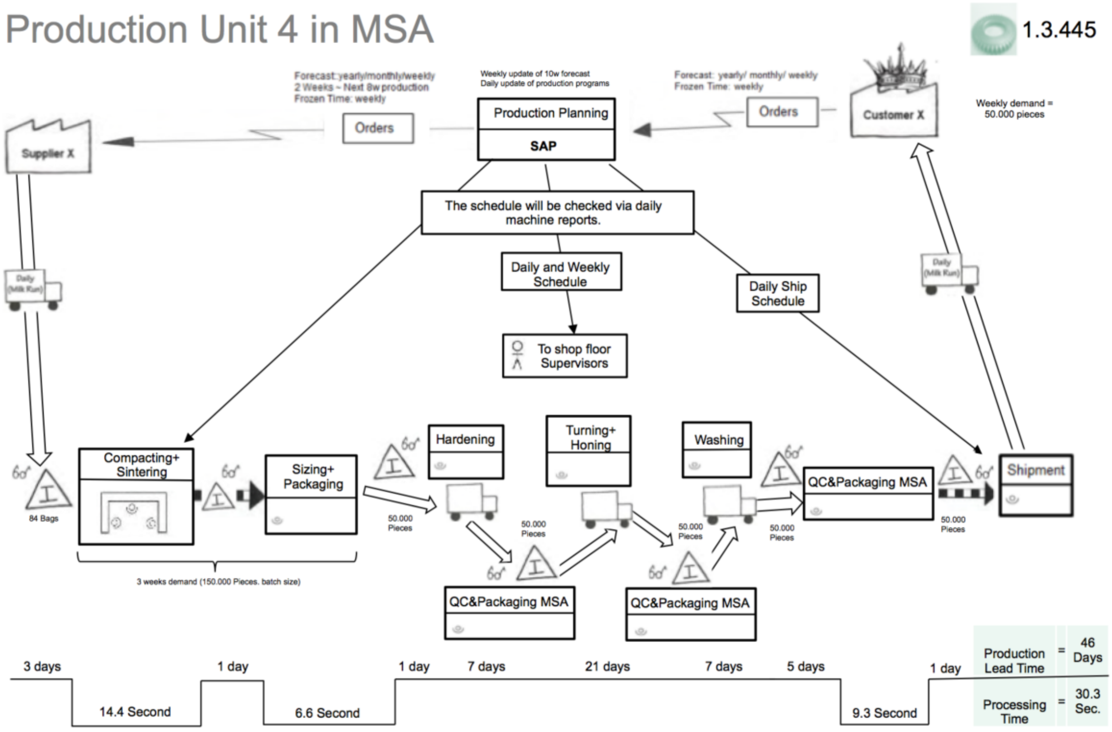
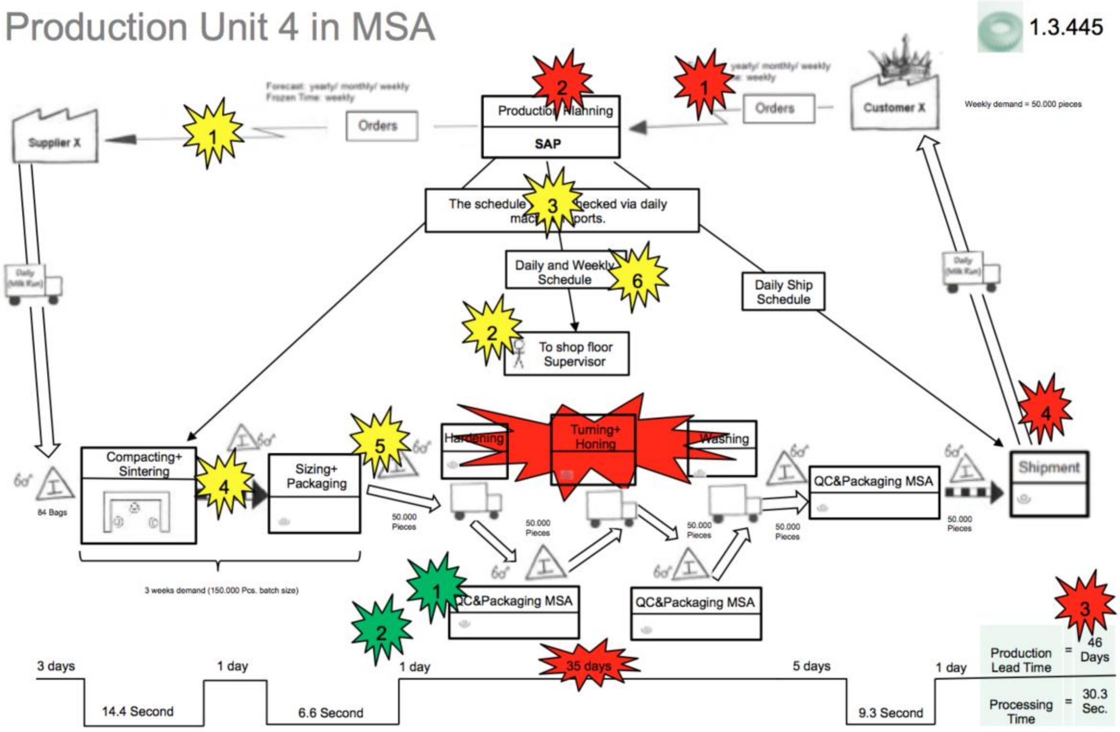
## Appendix A: Material Flow Icons



# Appendix B: Value Stream Mapping of PU4



# Appendix C: Disturbances

## Arbeitsgangstörungen

| | | |
|---|---|---|
| 112 | Maschinenreinigung | Allgemeine Maschinenreinigung während laufendem Auftrag (zB SIMM durch Werker). |
| 143 | Einstellermangel Musterfertigung | Stillstand der Anlage während einer Musterfertigung aufgrund Einstellermangel (im Normalfall **2+3 Schicht** während Musterproduktion) |
| 214 | Warten auf Freigabe | Warten auf Freigabe, obwohl die Anlage bereits aufgerüstet ist und produzieren könnte (Warten auf Schliffe, Sinterfreigabe,..). |
| 221 | Einstellermangel | Es ist kein Einsteller vorhanden, um Störungen zu beheben. |
| 222 | Mitarbeitermangel | Die Anlage kann wegen Personalmangel nicht betrieben werden (während der Pause: 262!) |
| 230 | Materialmangel | Dieser Störgrund trifft nur zu, wenn der Stillstand **ungeplant** durch fehlende Bauteile (für zB mech. Bearbeitung etc) oder Pulver beim Pressen verursacht wird. |
| 232 | Hilfs- und Betriebs-mittelmangel | Stillstand der Anlage wegen fehlender Hilfs- u. Betriebsstoffen (zB Gebinde, Öl, Kassetten). |
| 233 | Teile Q-Problem | Stillstand der Anlage aufgrund eines Q-Problems am Bauteil (Maß, Dichte, Risse,..) |
| 240 | Werkzeugnacharbeit | Werkzeug kann in der Anlage nachgearbeitet (zB poliert) werden. |
| 244 | Werkzeugwechsel | Das Werkzeug muss aus der Anlage genommen oder gewechselt werden. |
| 250 | Technische Probleme | Probleme an der Anlage, die vom Einsteller/ Schichtverantwortlichen behoben werden können zB Würfelstörungen, Probleme mit der Automatik. |
| 261 | Auftragsmangel | = geplanter Stillstand während einem Auftrag. „Haben wir Arbeit für die Anlage?“ → „Nein“ Materialmangel ist kein Auftragsmangel! |
| 262 | Pause | Personalmangel aufgrund der Pause. |
| 263 | Sonntag/Feiertag | Wenn der **selbe Auftrag** nach dem Sonntag/Feiertag weiterbearbeitet wird |
| 280 | Ungeplante Reparatur | Ungeplante Reparatur während eines Auftrages, bei der die Instandhaltung benötigt wird. |
| 290 | Verkettung | „Störgrund“ dient zur Erfassung von Zeiten von Anlagen die nicht automatisiert rückmelden: |
| 291 | Ofen ausfahren | = Zeit, in der keine neuen Teile mehr in den Ofen gefahren werden und der Ofen nur noch ausgefahren wird. Auch bei der Presse eingeben, wenn eine verkettete Presse abgestellt wird um den Ofen bis Schichtende leer zu fahren! |

## Arbeitsplatzstörungen

| | | |
|---|---|---|
| 110 | Geplante IH und Reparatur | Geplante IH-Arbeiten, Reparaturen, Wartungen, Maschinenreinigungen… |
| 120 | Ungeplante Reparatur | Ungeplante Reparaturen (auch während des Rüstens) |
| 140 | Muster | Musterfertigung **ohne** Auftrag (**nur** wenn es keinen Auftrag gibt → zB R&D) |
| 265 | Sonntag/Feiertag/Urlaub | Wenn ein **anderer Auftrag** nach dem Sonntag/Feiertag weiterbearbeitet wird |
| 85 | Auftragsmangel | =geplanter Stillstand, wenn danach auf einem **anderen Auftrag** weiter produziert wird |
| 132 | Werkzeugumbau | Direktumrüstungen, da kein freier Adapter zum Vorrüsten vorhanden ist. |

SP2-BK; 24.04.2014

# Appendix D: Myths and Realities of OEE

| *Mytn* | *Reality* |
| --- | --- |
| OEE is a management tool to use as a benchmark | This misses the benefit of OEE as a shopfloor problem-solving tool |
| OEE should be calculated automatically by computer | The computation approach is far less important than the interpretation. While calculating manually, you can be asking why? |
| OEE on non-bottleneck equipment is unimportant | OEE provides a route to guide problem solving. The main requirement is for an objective measure of hidden losses even on equipment elsewhere in the chain |
| OEE is not useful because it does not consider planned utilization losses | OEE is one measure, but not the only one used by TPM. Others include productivity, cost, quality, delivery, safety, morale and environment |
| We don't need any more output, so why raise OEE | Management's job is to maximize the value generated from the company's assets. This includes business development. Accepting a low OEE defies commercial common sense |

# Appendix E: List of Network Technologies

TABLE I
COMPARISON OF THE BLUETOOTH, UWB, ZIGBEE, AND WI-FI PROTOCOLS

| Standard | Bluetooth | UWB | ZigBee | Wi-Fi |
|---|---|---|---|---|
| IEEE spec. | 802.15.1 | 802.15.3a * | 802.15.4 | 802.11a/b/g |
| Frequency band | 2.4 GHz | 3.1-10.6 GHz | 868/915 MHz; 2.4 GHz | 2.4 GHz; 5 GHz |
| Max signal rate | 1 Mb/s | 110 Mb/s | 250 Kb/s | 54 Mb/s |
| Nominal range | 10 m | 10 m | 10 - 100 m | 100 m |
| Nominal TX power | 0 - 10 dBm | -41.3 dBm/MHz | (-25) - 0 dBm | 15 - 20 dBm |
| Number of RF channels | 79 | (1-15) | 1/10; 16 | 14 (2.4 GHz) |
| Channel bandwidth | 1 MHz | 500 MHz - 7.5 GHz | 0.3/0.6 MHz; 2 MHz | 22 MHz |
| Modulation type | GFSK | BPSK, QPSK | BPSK (+ ASK), O-QPSK | BPSK, QPSK COFDM, CCK, M-QAM |
| Spreading | FHSS | DS-UWB, MB-OFDM | DSSS | DSSS, CCK, OFDM |
| Coexistence mechanism | Adaptive freq. hopping | Adaptive freq. hopping | Dynamic freq. selection | Dynamic freq. selection, transmit power control (802.11h) |
| Basic cell | Piconet | Piconet | Star | BSS |
| Extension of the basic cell | Scatternet | Peer-to-peer | Cluster tree, Mesh | ESS |
| Max number of cell nodes | 8 | 8 | > 65000 | 2007 |
| Encryption | E0 stream cipher | AES block cipher (CTR, counter mode) | AES block cipher (CTR, counter mode) | RC4 stream cipher (WEP), AES block cipher |
| Authentication | Shared secret | CBC-MAC (CCM) | CBC-MAC (ext. of CCM) | WPA2 (802.11i) |
| Data protection | 16-bit CRC | 32-bit CRC | 16-bit CRC | 32-bit CRC |

* Unapproved draft.
• Acronyms: ASK (amplitude shift keying), GFSK (Gaussian frequency SK), BPSK/QPSK (binary/quardrature phase SK), O-QPSK (offset-QPSK), OFDM (orthogonal frequency division multiplexing), COFDM (coded OFDM), MB-OFDM (multiband OFDM), M-QAM (M-ary quadrature amplitude modulation), CCK (complementary code keying), FHSS/DSSS (frequency hopping/direct sequence spread spectrum), BSS/ESS (basic/extended service set), AES (advanced encryption standard), WEP (wired equivalent privacy), WPA (Wi-Fi protected access), CBC-MAC (cipher block chaining message authentication code), CCM (CTR with CBC-MAC), CRC (cyclic redundancy check).

# Appendix F: Sensor Parameters

Table (a): Sensor Paramers

1. mechanical parameters of solids
   - acceleration
   - angle
   - area
   - diameter
   - distance
   - elasticity
   - expansion
   - filling level
   - force
   - form
   - gradient
   - hardness
   - height
   - length
   - mass
   - mass flow rate
   - moment
   - movement
   - orientation
   - pitch
   - position
   - pressure
   - proximity
   - revolutions per minute
   - rotating velocity
   - roughness
   - tension
   - torque
   - torsion
   - velocity
   - vibration
   - way
   - weight

2. mechanical parameters of fluids and gases
   - density
   - flow direction
   - flow velocity
   - level
   - pressure
   - rate of flow
   - vacuum
   - viscosity
   - volume

3. thermal parameters
   - enthalpy
   - entropy
   - temperature
   - thermal capacity
   - thermal conduction
   - thermal expansion
   - thermal radiation
   - thermal radiation temperature

4. optical parameters
   - color
   - image
   - light polarization
   - light wave-length
   - luminance
   - luminous intensity
   - reflection
   - refractive index

5. acoustic parameters
   - sound frequency
   - sound intensity
   - sound polarization
   - sound pressure
   - sound velocity
   - time of travel

6. nuclear radiation
   - ionization degree
   - mass absorption
   - radiation dose
   - radiation energy
   - radiation flux
   - radiation type

7. magnetic & electrical parameters
   - capacity
   - charge
   - current
   - dielectric constant
   - electric field
   - electric power
   - electric resistance
   - frequency
   - inductivity
   - magnetic field
   - phase

8. chemical parameters
   - cloudiness
   - composition
   - concentration
   - dust concentration
   - electrical conductivity
   - humidity
   - ice
   - impurities
   - ionization degree
   - molar weight
   - particle form
   - particle size
   - percentage of foreign matter
   - pH-value
   - polymerization degree
   - reaction rate
   - rendox potential
   - thermal conductivity
   - water content

9. other significant parameters
   - frequency
   - pulse duration
   - quantity
   - time

Table (b): Non-standard sensor signals

| | |
|---|---|
| Voltage: | Thermo Couple, Bandgap Voltage |
| Current: | Bip. trans., P.S.D., Radiation Detector |
| Resistance: | Strain-Gauge Bridge, Hall Sensor |
| Capacitance: | Humidity, Tactile, Accelerometer |
| Inductance: | (difficult on-chip) |

# Appendix G: Questionnaire for VSM

## Questionnaire

1. Do you make weekly schedule or daily order to the production line in the company?

2. How would you transfer your weekly schedule/ daily order to the responsible person (supervisors) in the production line? Are there four responsible people in our production line?

3. How would you control weather or not your schedule has been done well? If you could see the relating information automatically from internet about production status, do you know which software you are using now?

4. How do the supervisors in the production line inform you when there come problems, e.g. Stock problems, machine broken? (Via phone, mail…)

5. Which communication tools you are using now in company with suppliers, customers? (Via mail or phone call, or is there an electrical data interchange behind?)

# Appendix H: Questionnaire for Parameters in PPC

## Fragebogen

Könntest du bitte mir erzählen, was deine Aufgaben bei der Firma sind?
Ich weiß nur, dass du abhängig von Lieferant auf PU 4 bist.

1.
2.
3.

Könntest du bitte mir erzählen, über welche Informationen du dich von Lieferant interessierst?

1.
2.
3.

Könntest du bitte mir erzählen, über welche Informationen du dich von die Maschinen (Pressen/ Sintering/ Sizing/) interessierst?

1.
2.
3.

Könntest du bitte mir erzählen, welche Art von Informationen von irgendwo (ich weiß nicht) du hast, die mit deiner Arbeit verbunden sind?

Es gibt ein smartes System. Es kann dir helfen, die spezialen wichtigen Informationen für Sie zu bekommen. Jetzt brauche ich Ihre Hilfe. Ich muss wissen, was Sie brauchen.

# Appendix I: Weighted Criteria

| | | Smart Production/ Smart Material/ Smart Product/ CPS | | | HMI - PLC | Basics/ Inputs of SOA-PLC | | Planning Model | Ontology (library) |
|---|---|---|---|---|---|---|---|---|---|
| Criteria | Rating | RFID | ZigBee | Sensors | UID | Process Model | Plant Layout | The Service Structure | |
| COMPATIBILITY | 1,5 | - | | | | Unknown in a abstrbt level or laked information | | | |
| SW STANDARD | 1,5 | varies | IEEE 802.15.4 | varies | MS-DOS; Linux; QNX | SOA | SOA | SysML | - |
| GROUNDS | 1,0 | Basics for CPS | Basics for CPS | Basics for CPS | Ubiquitous Communication | Core control prodedure in Industry 4.0. | | | |
| ROI | 2,0 | A new level of flexibility, interoperability, and adaptability within automation systems; Ideal interconnection inside Automation Pyramid; | | | | | | | |
| POSSIBILITY | 2,0 | High | High | High | Medium | High | High | High | Medium |
| MOUNTABILITY | 1,0 | Uncomplicated | Medium | Complicated | Easy | Abstract level | | | |
| EXEMPLAR | 1,0 | In Reality | | | Rare | Rare | | | |

| | | Smart Production/ Smart Material/ Smart Product/ CPS | | | HMI - PLC | Basics/ Inputs of SOA-PLC | | Planning Model | Ontology (library) |
|---|---|---|---|---|---|---|---|---|---|
| Criteria | Rating | RFID | ZigBee | Sensors | UID | Process Model | Plant Layout | The Service Structure | |
| COMPATIBILITY | 1,5 | 2 | 2 | 3 | 2 | 1 | 1 | 1 | 1 |
| SW STANDARD | 1,5 | 4 | 3 | 4 | 4 | 2 | 2 | 2 | 1 |
| GROUNDS | 2,0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| ROI | 2,0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| POSSIBILITY | 2,0 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 3 |
| INSTALLABILITY | 1,0 | 2 | 3 | 1 | 4 | 4 | 4 | 4 | 4 |
| EXEMPLAR | 1,0 | 3 | 3 | 3 | 1 | 1 | 1 | 1 | 1 |

| | | Smart Production/ | | | HMI - PLC | Basics/ Inputs of SOA- | | Planning Model | Ontology (library) |
|---|---|---|---|---|---|---|---|---|---|
| Criteria | Rating | RFID | ZigBee | Sensors | UID | Process Model | Plant Layout | The Service Structure | |
| COMPATIBILITY | 1,5 | 3 | 3 | 4,5 | 3 | 1,5 | 1,5 | 1,5 | 1,5 |
| SW STANDARD | 1,5 | 6 | 4,5 | 6 | 6 | 3 | 3 | 3 | 1,5 |
| GROUNDS | 2,0 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| ROI | 2,0 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| POSSIBILITY | 2,0 | 8 | 8 | 8 | 6 | 8 | 8 | 8 | 6 |
| INSTALLABILITY | 1,0 | 2 | 3 | 1 | 4 | 4 | 4 | 4 | 4 |
| EXEMPLAR | 1,0 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 1 |
| | | 37 | 36,5 | 38,5 | 36 | 33,5 | 33,5 | 33,5 | 30 |

UID: Universal Interface Device
HMI: Human Machine Interface
CPS: Cyber- Physical system
**Basics/ Inputs of SOA-PLC: documentation the process description of required production process and demands on the realization of the process steps for the SOA-PLC in MSA**
**Planning Model: Documentation the Service Structure based on the Hardware Structure if the machine specification is available.**
The Hardware Structure: definition of the field devices and how they are structured to higher units, like modules or production cells.
The Service Structure: the structure of the control software is depicted that contains basic and composed services.
The Service Orchestration: control procedure based on process model and service structure.
**Ontology: Documentation on Different Forms of Knowledge Representation**

| Score Value | Definition | | | | |
|---|---|---|---|---|---|
| 4 | the decline phase | developed | very high | perfect | easy |
| 3 | the maturity phase | partly developing | high | good | uncomplicated |
| 2 | the ascent phase | - | medium | - | - |
| 1 | R&D | developing | low | not good | complicated |

| Items | Definition | Score Value |
|---|---|---|
| COMPATIBILITY | The compatible extent with the existing technology in MSA | perfect, good, not good |
| SW STANDARD | The extent of software application | developed, partly developed, developing |
| GROUNDS | The pressure for employing the technology | high, medium, low |
| ROI | The extent of benefits to company resulting from the investment | high, medium, low |
| POSSIBILITY | The extent of technological availability for the company | high, medium, low |
| INSTALLABILITY | The ability for amounting/ adopting the technology | easy, uncomplicated, complicated |
| EXEMPLAR | The technology in reality | the decline phase, the maturity phase, the ascent phase, R&D |

| Score Value | Definition |
|---|---|
| 2,0 | very important |
| 1,5 | important |
| 1,0 | balanced |
| 0,5 | partly satisfied |