21º Seminário Internacional de Alta Tecnologia

6 OUT 2016
TEATRO UNIMEP
Campus Taquaral · Piracicaba · SP

PRODUTOS INTELIGENTES E MANUFATURA INTELIGENTE

ANAIS

Editado por Klaus Schützer

21° Seminário Internacional de Alta Tecnologia

Produtos Inteligentes e Manufatura Inteligente

Editor

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06 de Outubro de 2016

Universidade Metodista de Piracicaba

Teatro UNIMEP – Campus Taquaral, Piracicaba, SP

SCPM
Lab. de Sistemas Computacionais
para Projeto e Manufatura
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Seminário Internacional de Alta Tecnologia (21. : 2016 : Piracicaba, SP)

S471a Anais do 21. Seminário Internacional de Alta Tecnologia, Piracicaba, SP, Brasil, 6 out., 2016 / editor Klaus Schützer. – Piracicaba: UNIMEP, 2016.
230 p. : il. ; 30 cm.

Tema central: Produtos inteligentes e Manufatura inteligente

ISSN 2175-9960

1. Seminários (Estudo) - Tecnologia de ponta. I. Schützer, Klaus. II. Título.

CDU – 62

Universidade Metodista de Piracicaba

A Universidade Metodista de Piracicaba (UNIMEP) é herdeira de uma tradição de mais de 267 anos em educação, iniciada em 1748, com a fundação da *Kingswood School*, primeira escola Metodista na Inglaterra. Desta semente inicial, a educação metodista se expandiu, alcançando atualmente mais de 800 instituições presentes em 80 países, em todos os continentes. Inúmeras delas são universidades renomadas, como a *Emory University* (Geórgia, EUA), *Duke University* (Carolina do Norte, EUA), *American University* (Washington DC, EUA), *Southern Methodist University* (Texas, EUA), *Roehampton University* (Londres, Reino Unido), *Africa University* (Zimbabwe), *Aoyama Gakuin University* (Tókio, Japão), *Hiroshima Jogakuin University* (Hiroshima, Japão), *Yonsei University* e *Ewha Womans University* (Seoul, Coréia do Sul), *Boston University* (Massachusetts, EUA) e a *Southwestern University* (Texas, EUA), dentre outras. Destas duas últimas, saíram cinco prêmios Nobel, quatro na área de medicina e um na área de química. Entre os ex-alunos, destacam-se personalidades como Martin Luther King, responsável pela revolução dos Direitos Humanos nos Estados Unidos, na década de 1960.

As instituições educacionais metodistas, no Brasil, reúnem duas universidades, dois centros universitários, duas faculdades e 18 colégios, que oferecem desde o Ensino Infantil até o Ensino Médio, além de três creches, uma instituição que oferece Educação Suplementar, uma escola de música, um centro cultural e um centro de estudos sobre Educação e Metodismo e também as unidades de Educação Teológica. Atualmente, são 50 instituições educacionais em 13 estados, além do Distrito Federal, totalizando mais de 53 mil alunos na Educação Básica, Ensino Técnico e Educação Superior nas modalidades presencial e a distância.

A UNIMEP, com aproximadamente 11.000 estudantes distribuídos em seus quatro campi, localizados nas cidades de Piracicaba, Santa Bárbara d'Oeste e Lins, matriculados em 50 cursos de graduação, incluindo os cursos superiores de tecnologia, 15 especializações (35 turmas), 5 mestrados e 4 doutorados, tem a certeza de estar oferecendo uma educação diferenciada e de qualidade, baseada nos princípios de sua Política Acadêmica, que tem como premissa a construção da cidadania como patrimônio da sociedade.

A UNIMEP possui inúmeras parcerias com universidades de renome das Américas do Sul, Central e do Norte, mantendo, também, parcerias e projetos com a Europa, Ásia e alguns países da África. Dentre as principais parceiras destaca-se a *Darmstadt University of Technology* na Alemanha, com a qual a UNIMEP desenvolve projetos de pesquisa, intercâmbio de professores e estudantes, além da organização conjunta deste Seminário Internacional.

Além da *Darmstadt University of Technology*, a UNIMEP mantém convênios com *Technische Universitat Berlin* (TUB), *Fraunhofer Institut für Produktionsanlagen und Konstruktionstechnik* (Fraunhofer IPK), *Hochschule RheinMain* (Alemanha); *Marietta College*, *Centenary College*, *Ferrum College*, *LaGrange College*, *Nebraska Wesleyan University*, *Oklahoma City University*, *Wesleyan College*, *West Virginia Wesleyan College* (Estados Unidos); *Universidad Católica del Norte* (Chile); *Universidad del Centro Educativo Latinoamericano* (Argentina); *Universidad Madero* (México); *Universidad del Sevilla* (Espanha); *Universidade do Algarve* (Portugal); *Aoyama Gakuin University*, *Nagasaki Wesleyan University* (Japão); e *Soochow University* (Taiwan), a qual também promove curso de mandarim, oferecido aos alunos da UNIMEP. A Assessoria para Assuntos Internacionais também realiza programas para aprendizado de línguas estrangeiras, como inglês e espanhol. Não só envia alunos para o exterior, mas também recebe muitos alunos para realizar estudos de curta ou longa duração, na graduação ou pós-graduação.

Mantendo a tradição de inovação e participação na comunidade, professores e alunos da UNIMEP têm se destacado nas pesquisas e publicações, no intenso aproveitamento dos mais de 100 laboratórios disponíveis, na prestação de serviços a empresas e à comunidade, no desenvolvimento de um ambiente de estudos que favorece a convivência e o trabalho conjunto, e no incentivo à busca das mais variadas oportunidades profissionais, através de estágios supervisionados e convênios com indústrias, órgãos públicos e universidades no Brasil e no exterior.

Faculdade de Engenharia, Arquitetura e Urbanismo

A Faculdade de Engenharia, Arquitetura e Urbanismo (FEAU), localizada em Santa Bárbara d'Oeste, oferece sete cursos de Engenharia (Produção, Controle e Automação, Mecânica, Alimentos, Química, Elétrica e Civil), Bacharelado em Química, Arquitetura e Urbanismo, Tecnologia em Processos Químicos, Tecnologia em Fabricação Mecânica (Automobilística) e dois cursos de Licenciatura em Química e Matemática, no campus Taquaral, em Piracicaba. Além disso, oferece um Programa de pós-graduação "stricto sensu" (Mestrado e Doutorado) em Engenharia de Produção.

Atualmente a FEAU tem cerca de 2.200 alunos nos cursos de graduação e pós-graduação. Conta também com um corpo docente de 92 professores, sendo cerca de 55% em regime de dedicação integral ou parcial. Cerca de 80% do corpo docente é titulado, sendo que 51 professores já concluíram o doutorado no Brasil ou no exterior. Este corpo docente tem possibilitado o desenvolvimento de diversos projetos de pesquisa com financiamento de órgãos governamentais (FAPESP, FINEP, CNPq, Capes, etc.), da iniciativa privada (Sandvik,

Indústrias Romi, Siemens PLM, Robert Bosch Ltda., Wolkswagen do Brasil Ltda., Hexagon Manufacturing Intelligence, Eletrocast, IBM entre outros) ou ainda de organismos externos (DAAD, DFG, etc.).

A FEAU conta com 36 laboratórios para ensino e/ou pesquisa, entre eles um dos mais modernos laboratórios para ensino de CAD e CAM dentre as universidades brasileiras, além de duas Salas Ambiente que representam uma nova proposta para o uso da informática no ensino da engenharia. Alguns de seus laboratórios de pesquisa têm se destacado no Brasil e no exterior pelo trabalho desenvolvido, como nas áreas de sistemas CAD/CAM e PLM, usinagem com altíssima velocidade, metrologia, materiais carbonosos, dentre outros.

A FEAU tem uma inserção bastante grande junto aos órgãos públicos, ONGs e no parque industrial e de serviços regionais, que compreende além da região de Piracicaba, a região Metropolitana de Campinas, através de convênios e projetos. A Incubadora de Empresas de Santa Bárbara d'Oeste é gerida pela FEAU. Além disso, a Faculdade mantém um forte contato internacional com Universidades e Instituições de Pesquisa principalmente na Alemanha, Espanha, Bélgica, EUA e Argentina, através de programas de intercâmbio entre professores, pesquisadores e alunos de graduação e pós-graduação.

Laboratório de Sistemas Computacionais para Projeto e Manufatura

O Laboratório de Sistemas Computacionais para Projeto e Manufatura (SCPM) é um dos mais de 30 laboratórios da Faculdade de Engenharia, Arquitetura e Urbanismo da Universidade Metodista de Piracicaba. Na sua maioria, esses laboratórios estão voltados primordialmente ao ensino, possibilitando aos estudantes um primeiro contato com a realidade que enfrentarão no mercado de trabalho.

O SCPM, no entanto, foi criado com foco na pesquisa, residindo aí o seu diferencial, ou seja, sua finalidade primeira é possibilitar o desenvolvimento científico, através de projetos a serem desenvolvidos pelos estudantes sob supervisão de professores. Esse é o papel que vem desempenhando ao longo dos seus mais de 20 anos de existência, sem descuidar da preservação da indissociabilidade das duas outras colunas de sustentação de uma universidade, ou seja, o ensino e a extensão.

As primeiras atividades de pesquisa do SCPM foram apoiadas em dois projetos, o KIT #123 - FBaseDsgn, financiado pela Comissão Europeia, e o projeto para implantação de infraestrutura, financiado pelo *Deutsche Ausgleichsbank*. Em torno desse trabalho aglutinou-se um grupo de alunos de graduação e pós-graduação que ajudou no planejamento e

organização da primeira versão do que se tornou o Seminário Internacional de Alta Tecnologia. O primeiro evento, em 1996, introduziu no Brasil a temática da “Usinagem com Altíssima Velocidade de Corte”, que hoje é aplicada em diversas empresas.

Este grupo de pesquisa criou também o Núcleo para Projeto e Manufatura Integrados (NPMI), incluído no Cadastro Nacional de Grupos de Pesquisa do CNPq desde 1995, e que oferece a interface para integração de outros professores e pesquisadores aos trabalhos desenvolvidos no SCPM, além de participar ativamente de projetos de pesquisa em parceira com outras universidades brasileiras.

O SCPM conta hoje com uma equipe de pesquisadores em tempo integral composta de um professor titular, doutorandos, mestrandos, alunos de iniciação científica e pessoal técnico de apoio. As atividades científicas desenvolvidas são financiadas na sua maioria com recursos gerados através de projetos de pesquisa nacionais e internacionais além da prestação de serviços e projetos em parceria com diversas empresas. A estratégia de desenvolver seus projetos de pesquisa o mais próximo possível das indústrias viabiliza uma rápida implementação dos resultados tecnológicos obtidos.

Reunir parceiros para desenvolver projetos mais arrojados tem sido a marca do trabalho do SCPM, o que resultou em parcerias estratégicas desde a sua criação com o *Institut für Produktionsmanagement, Technologie und Werkzeugmaschinen* (PTW) e com o *Fachgebiet Datenverarbeitung in der Konstruktion* (DiK), ambos da *Technische Universität Darmstadt* na Alemanha. Essas parcerias já resultaram em inúmeros projetos de pesquisa em conjunto e um contínuo intercâmbio de alunos de graduação, mestrado e doutorado, além de professores de ambos os lados.

Desde 2005 o SCPM possui também uma parceria com o *Institut für Werkzeugmaschinen und Fabrikbetrieb (IWF) da Technische Universität Berlin*, Alemanha, e mais recentemente com a *Hochschule RheinMain* em Rüsselsheim.

O SCPM dispõe de modernos recursos de hardware e software para o desenvolvimento dos trabalhos de pesquisa atuando em quatro linhas de pesquisa: manufatura inteligente e fábrica digital; desenvolvimento integrado do produto; usinagem com altíssima velocidade; monitoramento do processo de usinagem; além de oferecer suporte a pequenas e médias empresas para especificação, escolha e implementação de sistemas CAD/CAPP/CAM/PDM.

Adicionalmente o SCPM possui uma Máquina de Medir por Coordenadas e um Sistema de Calibração Laser Renishaw, que possibilitam o desenvolvimento de projetos de pesquisa tanto com o foco na integração digital da cadeia CAD/CAM/CAQ, como também no desenvolvimento de métodos para comparação da representação de superfícies complexas

nos sistemas CAD e o modelo real após a usinagem, permitindo a avaliação de estratégias de corte e métodos de interpolação da trajetória da ferramenta.

Procurando atender às novas necessidades de empresas de pequeno e médio porte, o SCPM iniciou trabalhos de pesquisa voltados ao Gerenciamento do Ciclo de Vida do Produto (*Product Data Management* - PDM; *Product Lifecycle Management* - PLM). E hoje possui um ambiente de desenvolvimento do produto com as características de uma indústria, chamado de Fábrica para o Ensino na Engenharia do Produto, desenvolvendo atividades de desenvolvimento do produto e simulações do processo de gerenciamento de dados do produto ao longo de todo o ciclo de desenvolvimento.

Ainda dentro de seu objetivo de trabalhar com sistemas computacionais que representem o estado da arte, o SCPM criou um grupo de trabalho para atuar no Planejamento Digital de Processos tendo como foco o desenvolvimento de competências para atuar na temática Fábrica Digital e hoje já realiza projetos de pesquisa nesta área com renomadas empresas.

O material didático desenvolvido pela equipe do SCPM nas áreas de projeto e manufatura auxiliados por computador tem sido utilizado não só nos cursos de engenharia da FEAU, mas também por muitas outras universidades de diferentes lugares do Brasil. Esta atuação pautada pelo trinômio pesquisa-ensino-extensão tem sido um importante processo re-alimentador de todo o trabalho.

Desta maneira, o SCPM, além de uma forte inserção na área de pesquisa, tem conseguido interagir de maneira positiva na definição das grades curriculares dos cursos de engenharia, trazendo o que existe de mais inovador em desenvolvimento integrado do produto contemplando desde a concepção até a manufatura.

Atualmente o SCPM desenvolve projetos financiados pela CAPES, CNPq e pelo BMBF-DLF.

Mesmo enfrentando as dificuldades e os desafios inerentes à conjuntura brasileira e a uma universidade particular, o projeto do SCPM visa uma formação ampla de seus pesquisadores e estudantes, enfatizando o aspecto da pesquisa e a inserção internacional de sua equipe através de intercâmbios, destacando-se assim dentro do projeto institucional como um moderno provedor de serviços, dedicado às necessidades dos alunos que atuam no laboratório, das indústrias com as quais tem desenvolvido projetos e da sociedade no seu todo.

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Parceiros SCPM

TECHNISCHE UNIVERSITÄT DARMSTADT

Fraunhofer IPK

Volkswagen

SIEMENS

Hochschule RheinMain

Principais Projetos em desenvolvimento no SCPM

Programa BRAGECRIM
Projeto SCoPE

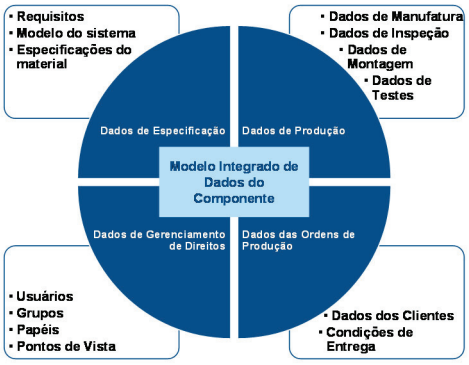
Lab. Sistemas Computacionais para Projeto e Manufatura
Prof. Dr.-Ing. K. Schützer
FEAU - UNIMEP

Smart Components within Smart Production Process and Environments

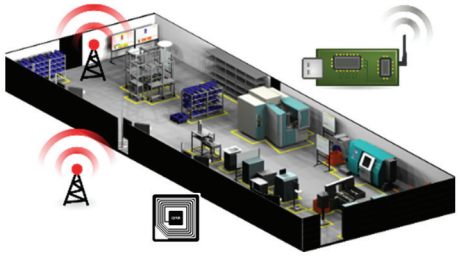
SCoPE

Componentes Inteligentes num Ambiente de Produção Inteligente

- **Objetivo:** Possibilitar a criação de sistemas de produção inteligentes que permitam a interação e troca mútua de informações entre componentes do produto e recursos de produção.



- Transformação de componentes físicos em portadores de informações;
- Integração de produtos, informações baseada em internet e tecnologias de comunicação.



- Incremento das possibilidades de rastreabilidade dos processos de fabricação de componentes individuais;
- Utilização dos dados de componentes individuais para formar pares otimizados de componentes em processos de montagem complexos.

Parceiros

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TECHNISCHE UNIVERSITÄT DARMSTADT
ESCOLA POLITÉCNICA DA USP
SCPM
LGI

Apoio

CAPES
DFG Deutsche Forschungsgemeinschaft

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Programa BRAGECRIM
Projeto Micro-O

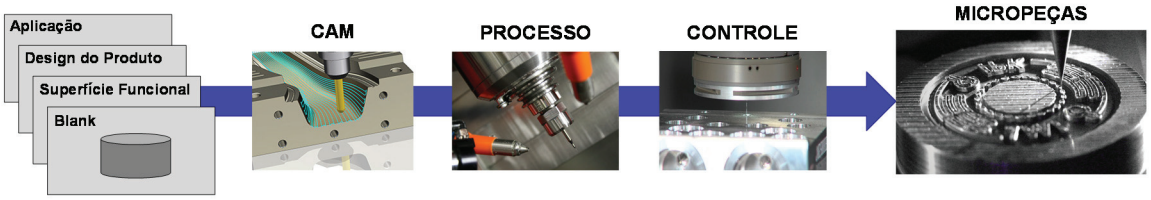
Lab. Sistemas Computacionais para Projeto e Manufatura
Prof. Dr.-Ing. K. Schützer
FEAU - UNIMEP

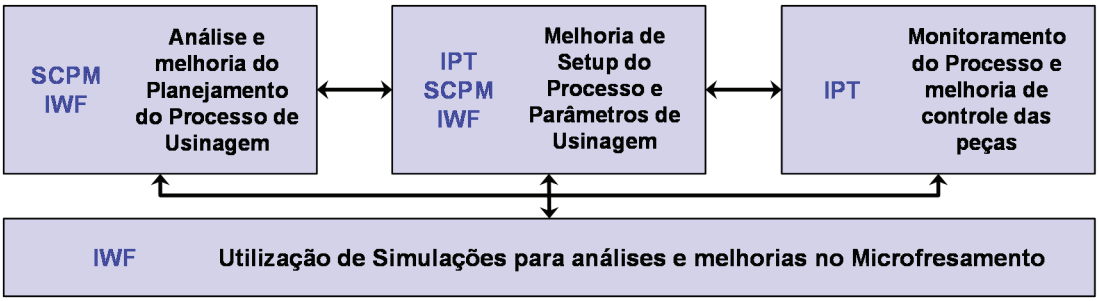
Micro-O: Micromilling Process Optimization

Otimização do Processo de Microfresamento

Objetivos

- Melhoria no planejamento do processo de corte, analisando os fatores que influenciam na precisão e no tempo da geração da trajetória da ferramenta e de setup do processo;
- Análise e melhoria das condições de corte para obtenção de melhores resultados em relação ao tempo de processo, segurança, desgaste da ferramenta, precisão e vibração na manufatura;
- Melhoria no processo de controle das peças para aumento da eficiência, reduzindo-se o tempo de medição e mantendo-se a precisão requerida;
- Utilização de simulações para dar suporte às análises e melhorias apontadas nos itens anteriores.





Parceiros

UNIMEP Universidade Metodista de Piracicaba
berlin
ipt INSTITUTO DE PESQUISAS TECNOLÓGICAS
SCPM
IWF
Universidade Federal do ABC

Apoio

CAPES
DFG Deutsche Forschungsgemeinschaft

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Fábrica Digital

Lab. Sistemas Computacionais para Projeto e Manufatura
Prof. Dr.-Ing. K. Schützer
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Objetivos

- Estudar ferramentas para implantação da Fábrica Digital: recursos, vantagens e problemas a serem superados;
- Construir, simular e comparar um modelo de Fábrica Digital com o processo de uma empresa real;
- Estudar o ambiente de Fábrica Digital para análise dos pontos fortes e fatores críticos de uma implantação real deste sistema;
- Estudar as ferramentas de Planejamento Digital;
- Estudar um método de Planejamento de Processo apropriado para a Fábrica Digital.

Parceiros

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Volkswagen
GROB
SIEMENS

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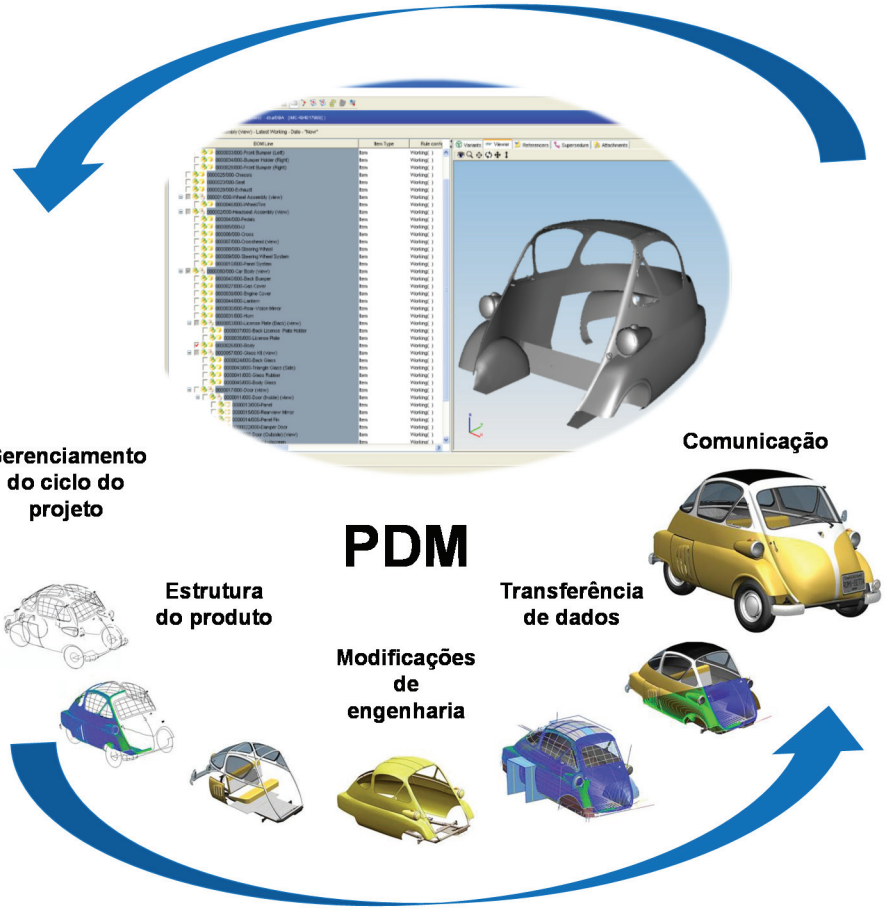
Fábrica Ensino: Processo de Desenvolvimento do Produto

Lab. Sistemas Computacionais para Projeto e Manufatura
Prof. Dr.-Ing. K. Schützer
FEAU - UNIMEP

Objetivos

- Desenvolver um ambiente de Desenvolvimento de Produto Integrado com suporte de PDM;
- Capacitar pessoal técnico na área de Desenvolvimento de Produto;
- Contribuir para o aperfeiçoamento técnico de alunos na Ferramenta PDM;
- Avaliar vantagens e desvantagens da Ferramenta PDM em um ambiente de Engenharia Simultânea;
- Criar estruturas e *workflows* para o Desenvolvimento Integrado do Produto;
- Gerenciamento de tarefas e recursos integrado ao PDM.



Realização

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Apresentação

O Laboratório de Sistemas Computacionais para Projeto e Manufatura (SCPM) realiza desde 1996 o **Seminário Internacional de Alta Tecnologia**, abordando temas focados em duas grandes áreas: Manufatura e Desenvolvimento Integrado do Produto, alternadamente.

Dentro desses temas, seu Comitê Científico busca as inovações que estão sendo implantadas com sucesso na indústria, e já no primeiro evento realizado trouxe para o Brasil o tema da Usinagem com Altíssima Velocidade de Corte (*High Speed Cutting* - HSC). Desde 2014 traz para a discussão os desafios apresentados pela chamada *Industrie 4.0* (Indústria 4.0, Manufatura Inteligente, etc.) tanto no desenvolvimento do produto como na produção.

Hoje este evento é reconhecido como um referencial no Brasil na divulgação de novas tecnologias e métodos de trabalho, devido à atualidade e ao nível técnico dos temas abordados, atraindo a atenção e a participação de pessoal técnico qualificado das mais renomadas empresas localizadas no Brasil e de professores e pesquisadores de diversas universidades.

Produtos e Manufatura Inteligentes - Desafios e Oportunidades para a indústria

No final da década de 90 e no início dos anos 2000 a indústria se deparou com os desafios da Manufatura Avançada, desafios estes que propunham uma integração e automatização dos processos produtivos. As empresas que aceitaram esses desafios e buscaram a integração e automatização de sua produção alcançaram ganhos significativos de produtividade.

Os desafios atuais avançam em direção à proposição da digitalização de todos os processos produtivos, o que significa ter um modelo digital do produto, do processo e dos meios de produção que reproduzam os processos reais, de tal forma que as informações sobre os processos produtivos estejam disponíveis em tempo real, permitindo a ação dos gestores sobre os modelos digitais e, através deles, a consequente aplicação das decisões nos sistemas reais.

O objetivo é permitir a produção de Produtos Inteligentes dentro de Fábricas Inteligentes, os quais são capazes de trocar informações de forma autonoma, para disparar ações e para controlar o componente parceiro de forma independente. Assim, Fábricas Inteligentes utilizam-se de abordagens completamente novas para a produção, dirigida e controlada por Sistemas Inteligentes. Os desafios apresentados pelo programa alemão *Industrie 4.0* propõem uma 4ª Revolução Industrial e desafiam as empresas e institutos de pesquisa em direcionar seus esforços na implementação de três características fundamentais:

- Integração horizontal através de cadeias de valor;
- Integração digital *end-to-end* da engenharia ao longo de toda a cadeia de valor;
- Integração vertical e sistemas de manufatura em rede.

A indústria de transformação já está no meio de um cenário de economia globalizada, o que leva as empresas a reduzir o tempo de comercialização de novos produtos, reduzir custos e atender as necessidades dos clientes, oferecendo uma ampla variedade de personalizações de produtos.

A adaptabilidade e o potencial de inovação estão se tornando fatores vitais para melhorar a competitividade dentro do ambiente exigente dos mercados atuais em constante mudança. Os desafios decorrentes da 4ª Revolução Industrial, assim como os desenvolvimentos considerados no âmbito da *Industrie 4.0*, trouxeram não só novas exigências a serem cumpridas, mas também enormes oportunidades para o desenvolvimento, bem como para a introdução de novas soluções, inclusive comerciais, que podem dar origem a mercados completamente novos. É este ambiente de novos desafios que denomina-se **Manufatura Inteligente**.

É com essa visão que convidamos as comunidades industrial e acadêmica brasileiras para participarem da 21ª edição do Seminário Internacional de Alta Tecnologia onde estaremos discutindo os desafios que se apresentam no desenvolvimento do produto e na manufatura com o objetivo de gerar novas ideias e soluções que serão determinantes para o sucesso das empresas. Entre os temas principais estão:

- Os desafios do programa Industrie 4.0 para o produto e produção;
- Produtos Inteligentes e Manufatura Inteligente;
- Produtos e componentes físico-cibernéticos;
- Sistemas de produção físico-cibernéticos;
- Abordagem multi-criterial para o desenvolvimento de produtos;
- Estratégias inovadoras de produção e de logística.

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Prof. Dr.-Ing. Reiner Anderl

Prof. Anderl was born in 1955 and studied mechanical engineering at the *Universität Karlsruhe*, Germany, where he received his diploma in 1979. He received the Dr.-Ing. degree in Mechanical Engineering at the *Universität Karlsruhe* in 1984. From 1984 to 1985 he served as technical manager of a medium sized company. He then returned as a senior engineer to the Institute for Applied Computer Science in Mechanical Engineering (RPK) at the *Universität Karlsruhe*. In 1991 he has habilitated and in 1992 he has received the Venia Legendi, which includes the authorization to teach CAD/CAM technology. In April 1993 he accepted the call for the professorship for computer integrated design (*Fachgebiet Datenverarbeitung in der Konstruktion, DiK*) at the faculty Mechanical Engineering, *Technische Universität Darmstadt*, Germany. At the *Technische Universität Darmstadt*, he served as the dekan (dean) of the faculty in Mechanical Engineering from 1999 until 2001, during which time the new bachelors and masters program in mechanical engineering, mechatronics, and computational engineering was defined and implemented; the first of such in Germany. He has served on numerous faculty and university committees and commissions, including serving as prodekan where he managed the mechanical engineering faculty business office. He is a member of the *Zentrale Evaluierungs- und Akkreditierungs-agentur* (ZEvA), a national accreditation council based in Hannover, Germany, where he works on issues related to bachelor and master program accreditation. Prof. Anderl has served as vice president at the *Technische Universität Darmstadt* from January 2005 until December 2010.

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DiK, TU Darmstadt

The Department of Computer Integrated Design (DiK) was founded in 1993 at the Faculty of Mechanical Engineering of *Technische Universität Darmstadt* and is since then directed by Prof. Dr.-Ing. Reiner Anderl. Task of DiK is to reflect the importance of information technology for mechanical engineering. Therefore, the Department represents an interface between these two disciplines. Information technology is seen as an integral part of engineering and its application with respect to teaching and research constantly advances at the department. Computerized methods and tools are developed to improve and redesign the entire product development process up to the usage of the product. The DiK operates in the field of basic and applied research as well as contract research. The skills acquired here directly transfer into the development of lectures for the Bachelor and Master programs. Core-competencies of the department include the areas *Industrie 4.0*, Information Integration, Virtual Product Creation, and Distributed and Cooperative Work.

Industrie 4.0 – Digital Transformation in Product Engineering and Production

Abstract

Industrie 4.0 is an initiative of the German High Tech strategy. The main target is to improve the added value in product engineering and production processes. The fundamental approach is to equip future products and future production resources with so-called cyber-physical systems. These cyber-physical systems are able to connect with each other and to communicate. Industrie 4.0 environments enable high flexibility, high adaptability and resilience. The contribution explains the fundamental principles of Industrie 4.0 and shows approaches how to apply these principles for the development of smart products and smart production environments. Furthermore a methodology is been presented explaining the implementation of Industrie 4.0 in industrial enterprises for both, for smart products and for smart production environments.

Keywords

Industrie 4.0; Smart Engineering; Smart Sensors; Smart Actuators; Safety and Security; Multidisciplinary Product Development; Mechatronics; Adaptronics.

1 Introduction

Industrie 4.0 has been created in 2010 [1, 2, 3, 4] as a significant part of the German High-Tech strategy and stands for the 4th industrial revolution. As explained before [5, 6] the main goal of *Industrie 4.0* is to fundamentally improve value chains all over the product lifecycle.

While *Industrie 4.0* is impacting the industry and in particular the manufacturing industry, the process of the so-called digital transformation of the ecomomy has gained a major importance. Due to the "Digital Strategy 2025" which was published in March 2016 by the German Federal Ministry of Economic Affairs and Engery [7], 10 major steps have been defined to shape the future. These steps comprise:

1. Creating a gigabit optical fibre network for Germany by 2025;
2. Launching the New Start-up Era: Assisting start-ups and encouraging cooperation between young companies and established companies;
3. Creating a regulatory framework for more investment and innovation;
4. Encouraging "smart networks" in key commercial infrastructure areas of our economy;
5. Strengthening data security and developing informational autonomy;
6. Enabling new business models for SMEs, the skilled craft sector and services;
7. Utilising Industry 4.0 to modernise Germany as a production location;
8. Creating excellence in digital technology research, development and innovation;
9. Introducing digital education to all phases of life and;
10. Creating a Digital Agency as a modern centre of excellence.

For implementing *Industrie 4.0* in industry, the *Plattform Industrie 4.0* [8] has been founded. This *Plattform* Industrie 4.0 has been originally established in 2013 under the umbrella of three Germany industrial associations BITKOM, VDMA and ZVEI [8]. In April 2015 this *Plattform Industrie 4.0* was migrated to a much broader organisation supported by the German Federal Ministry of Education and Research (BMBF) and the German Federal Ministry of Economic Affairs and Engery (BMWi). The *Plattform Industrie 4.0* performs quite a remarkable number of activities [8] and has established 5 working groups. These working groups comprise:

- Working group 1: Reference architectures, standards and norms;
- Working group 2: Research and innovation;
- Working group 3: Security of networked systems;

- Working group 4: Legal framework and;
- Working group 5: Work, education and training.

The status of implementing *Industrie 4.0* in industry is documented exemplarily in so-called implementation maps. Three implementation maps have been created containing showcases for:

- Use cases;
- Test beds and;
- Consulting and information offerings.

Besides the *Plattform Industrie 4.0* the German Federal Ministry of Economic Affairs and Energy has also funded the establishment of so-called “Competence Centers for Small and medium Sized Industries”. Figure 1 gives an overview about the 10 established “Competence Centers for Small and medium Sized Industries”.

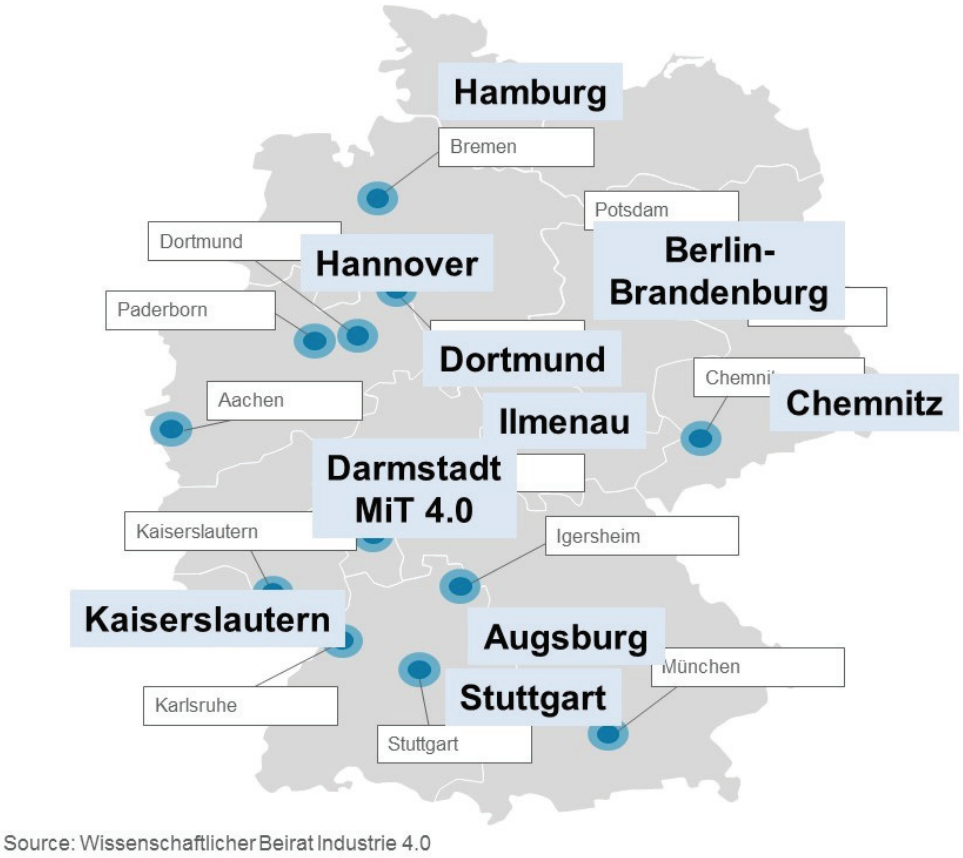

Figure 1: Overview Competence Centers for Small and medium Sized Industries

One of these Competence Centers for Small and medium Sized Industries has been established at TU Darmstadt in close cooperation with Darmstadt Chamber of Industry and Commerce and the Frankfurt Rhein-Main Chamber of Handicrafts.

Industrie 4.0 is an important initiative for performing the digital transformation in product engineering and production. Therefore this contribution first introduces the main technical approaches of *Industrie 4.0* and then it explains industrial use cases as they are implemented in the Efficient Factory 4.0 of TU Darmstadt. Furthermore the mapping into industry as performed by the TU Darmstadt Competence Centers for Small and medium Sized Industries is presented as well as the implementation guideline promoted by VDMA.

2 Fundamental Approaches of *Industrie 4.0* Technology

The technical approach of *Industrie 4.0* is based on the transformation of advanced mechatronic and adaptronic control systems to so-called cycber-physical systems which enable connectivity e.g. through the integration of an IP-address (internet protocal address). Connectivity is a major pre-requisit for the systems´ communication ability. Cyber-phyiscal systems are applied to production environments and are therefore called cyber-physical production systems which are then capable to enable system to system communication as well as communication with human users. *Industrie 4.0* includes a strategy which covers two approaches, the vertical and the horizontal integration. Vertical integration aims at a seamless bi-directional digital information flow from design and planning to shop floor operation while horizontal integration enables inter-system conectivity and communication.

The fundamental approaches of *Industrie 4.0* have been described in [9] and comprise in particular RAMI 4.0 (Reference Architecture Model *Industrie 4.0*, [10]) and the *Industrie 4.0* component. RAMI 4.0 provides an architectural concept consisting of three dimensions, the Lifecycle and Value Stream dimeansion, the Hierarchy Levels dimension and the integration dimension (figure 2).

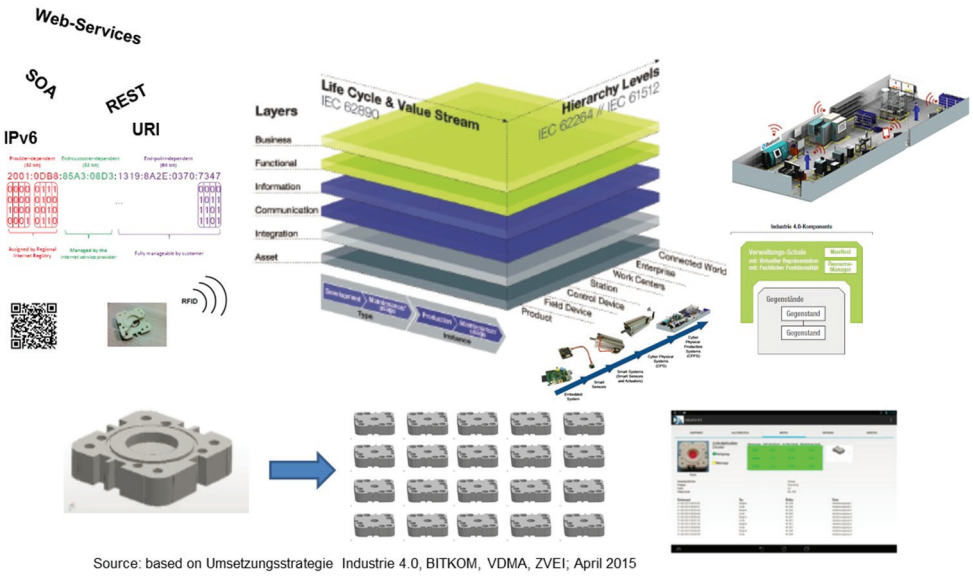

Figure 2: RAMI 4.0 – Reference Architecture Model Industrie 4.0 [based on 5 and 9]

The Lifecycle and Value Stream dimension aims at digitally representing *Industrie 4.0* components for enabling vertical integration-(e.g. *Industrie 4.0* workpieces, assemblies, products). The main approach is to represent *Industrie 4.0* components as so-called “kinds” which means a general and non-individualized digital representation as defined e.g. during product development as a 3-dimensional product model, and as so-called “types” which provide the digital representation of each physically produced *Industrie 4.0* object. Both digital representation approaches are referenced and ideally represent the real existing *Industrie 4.0* component.

The Hierarchy Levels dimension describes a aggregation hierarchy of *Industrie 4.0* components. Starting with the *Industrie 4.0* component “product”, the hierarchy levels continue with production specific elements comprising field device, control device, station, work center, enterprise and finally the connected world. The idea behind this approach is that a product or an assembly or even a single part is used as an *Industrie 4.0* component which is able to communicate with the production specific *Industrie 4.0* components e.g. for controling its own production process.

The integration dimension defines six layers comprising asset, integration, communication, information, functional and business. The goal of this dimension is to enable a powerful and systematic integration for *Industrie 4.0* objects into a target environment e.g. a production environment. Assets (e.g. *Industrie 4.0* objects) are equipped with connectivity technology, inparticular with an internet protocol address enabling communication through internet technology. Also other connectivity technologies are possible, such as Bluetooth or Near Field Communication or even optical identification such as barcode or QR-code. The communication layer provides basic communication services which are enhanced through semantic enrichment in the information layer. The functional layer provides specific functionality e.g. to control the asset while the business layer contains specific features to adopt appropriate business models.

In the context of *Industrie 4.0* the approach of introducing the *Industrie 4.0* component plays a major role. The approach of an *Industrie 4.0* component defines that a real object which is part of an *Industrie 4.0* environment is equipped with a so-called Administration Shell [11]. This Administration Shell might consist of software and/or data which descibes the real object including its status, its functionality and management data. Through the management shell the real object becomes part of the *Industrie 4.0* environment and it is enabled to connect and to communicate. Figure 3 describes the concept of the *Industrie 4.0* component.

Based on the definition of *Industrie 4.0* components a production environment is to be developed which fulfills requirements of industrial use case scenarios. A number of representative use case scenarios have been developed in the Efficient Factory 4.0.

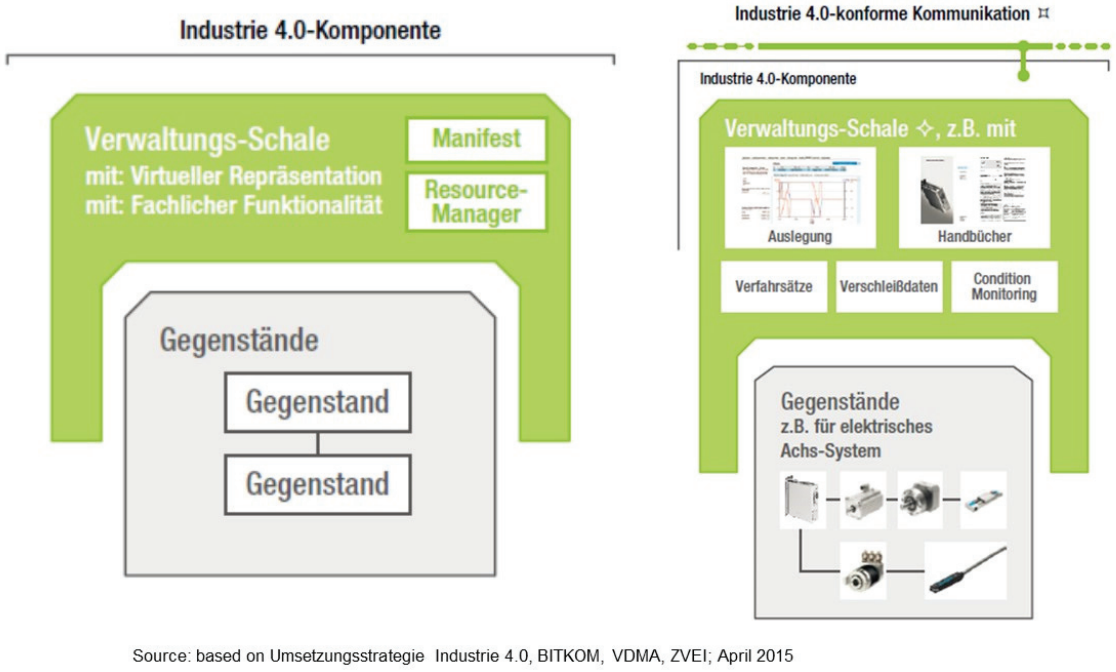

Figure 3: Approach of the Industrie 4.0 component [9]

3 Use Case Scenarios of the "Efficient Factory 4.0"

The Efficient Factory 4.0 has been developed and established at TU Darmstadt based on a project funded by the Hessian Ministry of Economics, Energy, Transport and Regional Development. The Efficient Factory 4.0 was a joint project where the departments PTW (*Institut für Produktionsmanagement, Technologie und Werkzeugmaschinen*) and DiK (*Fachgebiet Datenverarbeitung in der Konstruktion*) collaborate together with an industrial consortium consiting of 12 companies [12,13].

The Efficient Factory 4.0 has been established as a real manufacturing environment on the TU Darmstadt campus Lichtwiese and is based on the CiP-facilities (Center for industrial Productivity, the process learning factory). Figure 4 gives an overview about the Efficient Factory 4.0 where a real production of a pneumatic-cylinder is performed.

The project consortium has developed five use cases comprising *Industrie 4.0* objects as information carriers, paperless integrated quality assurance, value stream improvement and real-time capable production controlling, condition and energy monitoring as well as flexible intelligent worker assistance systems.

Industrie 4.0 components as information carriers are intended to create a digital representation of *Industrie 4.0* components. A comprehensive description of this approach is given in [14], its research details are explained in [15]. With respect to products to be produced, this approach introduces the concept of digital twins which digitally represent manufactured components over their lifecycle. Relating to the lifecycle phase production, the digital representation starts with

representing raw material or semi-manufactured products, continuing with representing workpieces and assemblies and finally representing produced, quality assured and tested products. It is important to mention that each individual manufactured component contains a unique identity. Figure 5 illustrates the concept of manufactured components as information carriers.

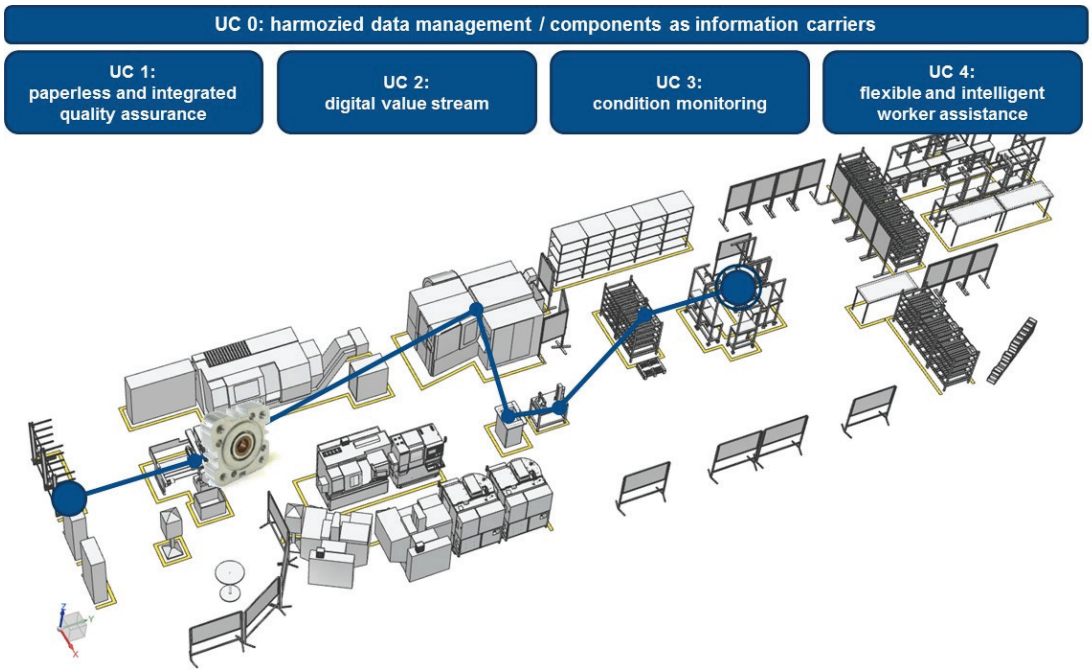

Figure 4: Overview about the Efficient Factory 4.0

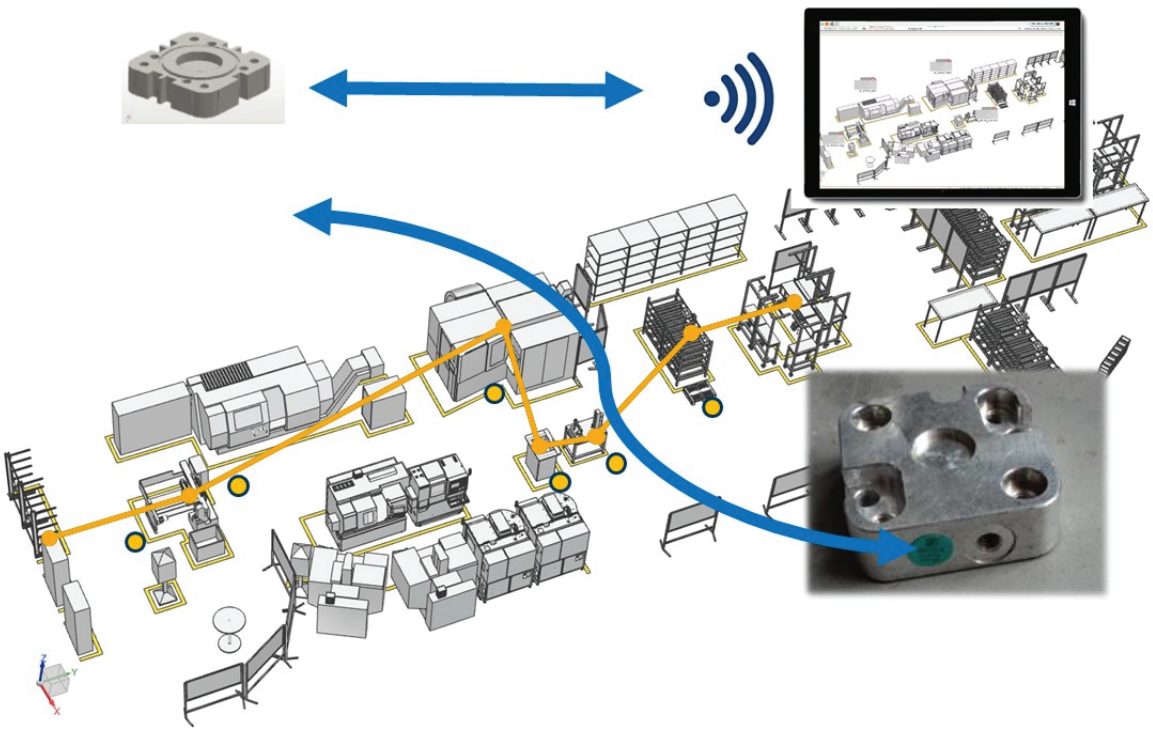

Figure 5: Manufactured components as information carriers

Besides manufactured components as information carriers further *Industrie 4.0* components such as sensor and control devices as well as further aggregated *Industrie 4.0* components are also represented digitally and contain a unique identity. Taking into account the digital representation of *Industrie 4.0* objects, a homogeneous and consistent data management has been implemented which is a fundamental concept for enabling connectivity and communication between *Industrie 4.0* objects.

The digital representation of produced components is available as a digital component model where quality data resulting from measurement and testing procedures as well as quality checking routines are added. As the digital component model corresponds to the digital product model defined during the product design process, it has become possible to verify and to validate the produced quality. Such verification e.g. refers to a comparison of a as-is manufactured dimension with the normal size and its tolerance which is allocated to the normal size.

As components as information carriers are also tiedly refering to the manufacturing process, value stream anaylsis and improvement is implemented as well as real-time capable production controlling. This approach allows e.g. value stream monitoring as well as value stream backtracing. As a result e.g. manufacturing operation times as well as exposure times are listed and provide a detailed basis for value stream analysis and improvement. Furthermore real-time capable production controlling is improved e.g. by choosing alternative manufacturing processes in case of machine tool failure.

Condition and energy monitoring provide use cases which enable the visualisation of current states of the manufacturing environment. Condition monitoring aims at reflecting production equipment states e.g. machine tools, tools, assemly lines or transport units. Due to integrated sensing technology these *Industrie 4.0* components provide sensor data which are analysed directly to generate information about proper and safe production operations and which are stored remotely to provide an appropriate data basis for prognosis provison e.g. with repect to predictive maintenance recommendations. Energy monitoring informs about the energy consumption of production operations (e.g. manufacturing operations such as cutting). Energy monitoring data is to be used for an optimized engergy distribution during production activities and for documenting the energy consumption of production operations over time. This documentation is to be used for ecologically optimizing production processes.

A significant advantage in an *Industrie 4.0* environment is provided through flexible intelligent worker assistance systems. Flexible intelligent worker assistance systems are characterized by two major features. On the one hand flexible intelligent worker assistance systems are able to identify the relevant production task e.g. tasks of an assembling process. This is performed by interpreting the identification of the respective part information and drawing process conclusions due to the knowledge of interlinked production data sets. On the other hand flexible intelligent worker assistance systems know about the workers performance profile

which enables an adaption of the flexible intelligent worker assistance system to the workers´ abilities.

Based on these five representative use cases the Efficient Factory 4.0 provides an advanced platform for experimenting with *Industrie 4.0* equipment and new value added processes as well as for educating for both, students and industrial personal. For intensifying the transformation of *Industrie 4.0* approaches to industry and in particular to the small and medium sized industry, the Darmstadt Competence Center for Small and Medium Sized Industries has been established.

4 Transfering *Industrie 4.0* to Industry – Darmstadt Competence Center for Small and Medium Sized Industries

The Darmstadt Competence Center for Small and Medium Sized Industries uses the Efficient Factory 4.0 as an *Industrie 4.0* technology backbone and provides a specific competence profile as well as a strategy for transfering scientific *Industrie 4.0* knowledge into small and medium sized industry. The competence profile of the Darmstadt Competence Center for Small and Medium Sized Industries and its strategy for bringing *Industrie 4.0* into industrial practice is explained in figure 6.

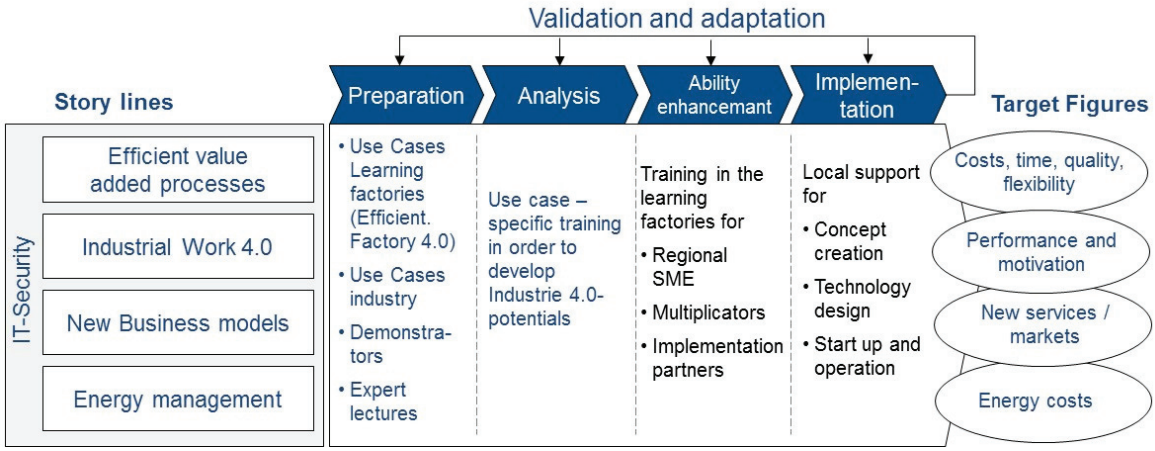

Figure 6: Darmstadt Competence Centers for Small and medium Sized Industries

The competence profile covers four main story lines and additionally a cross sectional story line. The four main story lines comprise establishing efficient added value processes, organizing new working environments and working styles, introducing new business models and implementing engergy management. The cross sectional story line covers IT-security, safety, privacy and knowledge protection. This cross sectional story line provides important basics which are relevant for each of the four main story lines.

Establishing efficient added value processes explains how added value processes are analysed and improved. An important prerequisite is the knowledge about production

processes and the assessment of process activities aiming at the identification of value creation activities. Furthermore optimization approaches of added value processes are discussed and best practices examples are explained.

The new working environments and working styles play an important role for the transformation to *Industrie 4.0*. New working environments are based on the RAMI 4.0 reference architecture model and the use of *Industrie 4.0* components. In this context flexible intelligent worker assistance systems are introduced and explained. Shop floor personal needs to be trained continuously and needs to adapt to the inter-system communication additionally including communication with the shop floor personal. This approaches lead to new workings styles which require more flexibility and holistic thinking.

Industrie 4.0 aims at added value improvement over the whole lifecycle. This also opens the door to new business models. New business models are strongly using internet technology and the ability to identify new business opportunities. Such new business models are exemplarily explained e.g. through the use of App-technology, platform concepts, selling product performance instead of product hardware or hybrid business approaches which comprise both product selling as well as selling product services.

Energy management is a major challenge in modern production technology. Through new *Industrie 4.0* components energy consumption is monitored and documented continuously. Due to gathered energy consumption data sets a profound engergy consumption analysis is performed which enables optimization of the energy consumption.

The cross-sectional story line deals with IT-security, safety, privacy and knowledge protection. IT-security provides security profiles for typical manufacturing processes as developed by the National Reference Project IUNO [16], consisting of a well adjusted set of IT-security methods including technologies such as passwording, fire walls, encryption, digital signatures, restrictive configuration as well as ERM (enterprise rights management). Safety methods aim at keeping the production environment continuously in safe operation modes. In this context resilience approaches are used to ensure the production systems´ reliability. Privacy has gained an increasing importance due to shop floor personal being an integral part of the *Industrie 4.0* environment. As production data plays an important role in an *Industrie 4.0* knowledge protection has also gained an increasing importance. Severals methods for knowledge protection are used such as encryption and decryption, digital watermarks or identity management for *Industrie 4.0* components.

The strategy for transfering scientific *Industrie 4.0* knowledge into small and medium sized industry provides a roadmap consisting of four successive phases. These phases aim at preparing enterprises for *Industrie 4.0* and comprise awareness creation, analysis of existing *Industrie 4.0* abilities, ability enhancement and *Industrie 4.0* implementation.

During the awareness creation phase information about *Industrie 4.0*, its goals, its major technologies and its consequenses and impact on enterprises are explained. During analysis

of existing *Industrie 4.0* abilities and ability enhancement a profound analysis of already existing *Industrie 4.0* performance is conducted and a profile for ability enhancement is developed. Resulting from this profile for ability enhancement detailed implementation plans are derived, typically containing a schedule, a technology transformation and investment plan, an organisational migration plan and a training plan to udate personal skills. In addition to the implementation plan, the strategic development of new business models is achieved.

A major task of this strategy for transfering scientific *Industrie 4.0* knowledge into small and medium sized industry is the analysis of existing *Industrie 4.0* abilities and ability enhancement development. These phases are strongly supported by applying the VDMA *Industrie 4.0* Implementation Guideline.

5 VDMA *Industrie 4.0* Implementation Guideline

The VDMA *Industrie 4.0* Implementation Guideline has been published in June 2015 by VDMA (*Verband Deutscher Maschinen- und Anlagenbau*) [16,17]. The main approach of this implementation guideline is the definition of so-called tool boxes. The tool boxes are presented as matrices, e.g. a matrix for products and a matrix for production.

The matrices are structured in rows and columns. The rows represent application areas and the columns represent *Industrie 4.0* performance levels. Application areas and performance levels are derived from the basic approach for *Industrie 4.0* as defined by the RAMI 4.0 (reference architecture model *Industrie 4.0*). The RAMI 4.0 terminology, however, has been mapped into a terminology which is used in industrial product development and industrial production. Application areas describe topics of interest in the context of *Industrie 4.0*, for industrial product development as well as for industrial production. Performance levels describe technological approaches which are structured into a sequence reaching from none or low *Industrie 4.0* performance to high *industrie 4.0* performance. For each matrix 6 application areas and 5 performance levels have been defined. Figure 7 illustrates the matrices for products and production.

During the analysis of existing *Industrie 4.0* abilities a profound analysis is conducted enterprise internally by using a questionaire and by interviewing key personal. The result of this evaluation leads to a profile which identifies for each application area the performance level. This identification is presented within the toolboxes as red dots and the collectivity of the red dots describe the existing *Industrie 4.0* abilities, with respect to products and with respect to production.

For the development of ability enhancement, intensive, enterprise specific workshops are organized. During these workshops target profiles are being derived from the identified profiles for products and for production. Of course, if an enterprise offers several product lines, the

target profiles are developed for each of the product lines. Very similarily this approach is applied to production. The result of the development of target profiles is shown in figure 8.

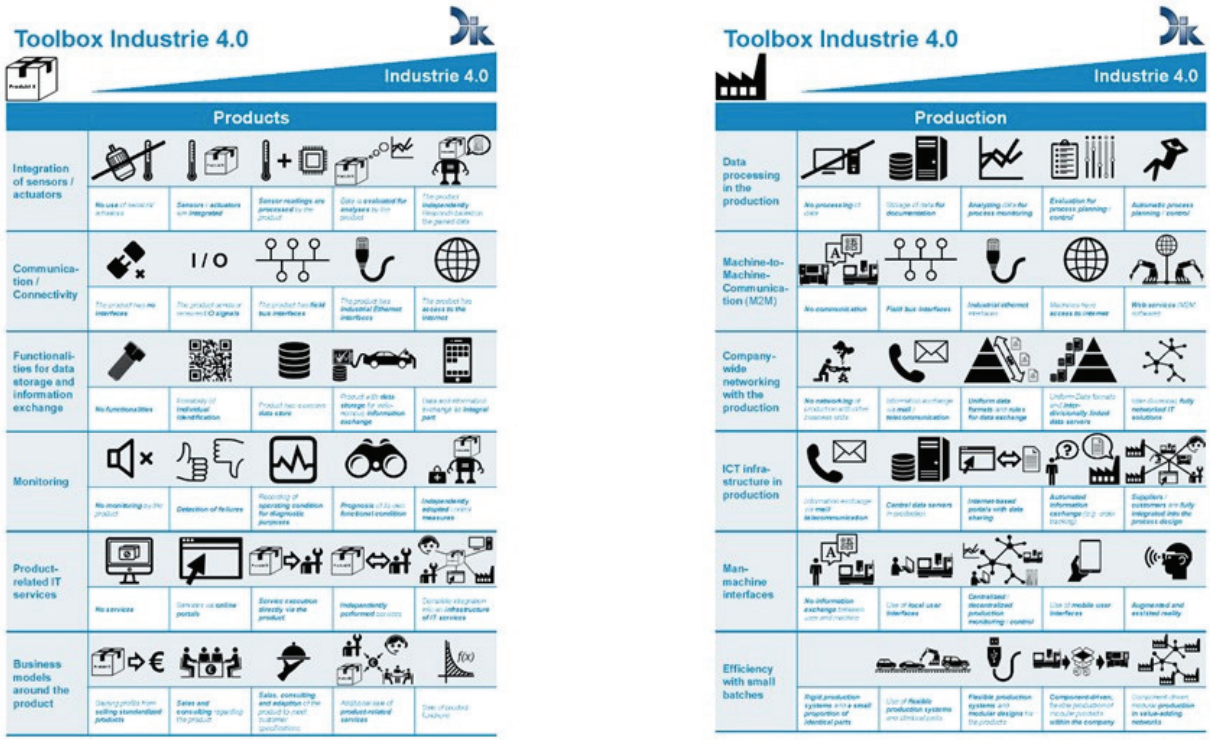

Figure 7: Toolboxes of the VDMA Industrie 4.0 Implementation Guideline for products and production

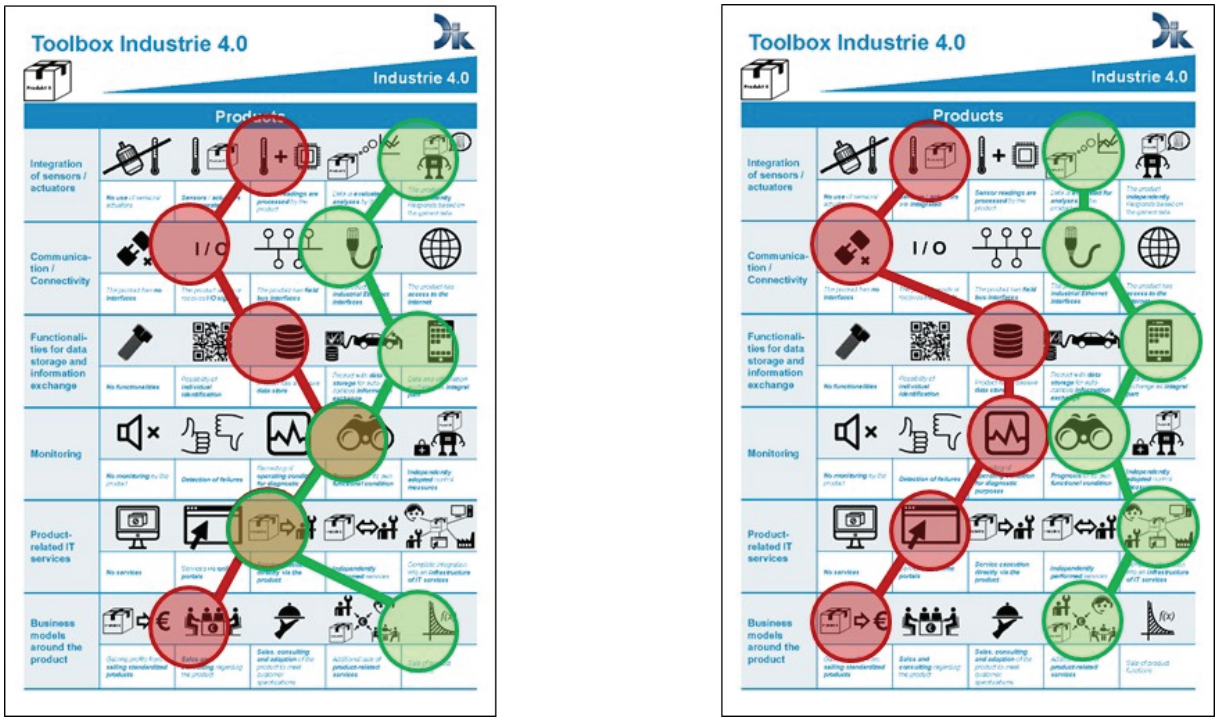

Figure 8: Target profiles for products and for production

These toolboxes provide a detailed analysis of *Industrie 4.0* capabilities achieved and a well argued development of target profiles for products and for production. Based on these results the enterprise strategy for transforming the enterprise towards *Industrie 4.0* is ceated also taking into account potential new business models, enterprise culture and entrepreneural goals.

6 Summary

The *Industrie 4.0* initiative has created awareness in industry siginificantly and in particular in the manufacturing industry. Even if a strong impact is dedicated to the manufacturing industry, *Industrie 4.0* is also effecting nearly every other industrial branch and future activities will demonstrate *Industrie 4.0´*s impact for a wide range of indutrial branches. In industry awareness about a strong change is happening is created increasingly and has strong effects to industrial enterprises. The digital transformation has become a necessary prerequisite to strenghten industrial competitiveness, in praticular with respect to product engineering and production.

This contribution has given an insight view into the fundamental approaches of *Industrie 4.0* and its application in five representative use cases implemented in the Efficient Factory 4.0 at TU Darmstadt. Based on the knowledge gained from the Efficient Factory 4.0 the TU Darmstadt Competence Center for Small and Medium Sized Industries has been established for knowledge transfer to industry. The performance profile of this competence center consists of story lines and a strategy for transfering scientific *Industrie 4.0* knowledge into small and medium sized industry. Four main story lines and an additional cross sectional story line have been implemented. The strategy for transfering scientific *Industrie 4.0* knowledge into small and medium sized industry is based on a roadmap consisting of four successive phases. An important approach contributing to this strategy is the application of the VDMA Implementation Guideline.

Future work is aiming at the develoment of competence creation strategies for preparing enterprise personal to adapt to new working styles and to interact with *Industrie 4.0* environments. Futhermore the development of a *Industrie 4.0* maturity model is necessary for strategically enabling enterprises to better execute the digital transformation in their intire business.

7 Acknowledgements

The author wants to thank funding organisations for their ongoing and remarkable support of *Industrie 4.0* research. Many thanks inpraticular for the German Federal Ministry of Education and Research (BMBF) for funding projects IUNO, SmartF-IT and the Board of Academic Advisors; the German Federal Ministry of Economic Affairs and Energy (BMWi) for funding the

Darmstadt Competence Centers for Small and medium Sized Industries; the Hessen State Ministry of Higher Education, Research and the Arts for funding CASED (Center for Advanced Security Research Darmstadt), the Hessian State Ministry of Economics, Energy, Transport and Regional Development for funding the Efficient Factory 4.0, VDMA for funding the VDMA *Industrie 4.0* Implementation Guideline and last not least DFG (*Deutsche Forschungsgemeinschaft*) and CAPES (*Ministério da Educação*) for jointly funding the BRAGECRIM – Smart Components within Smart Production Processes and Environments (SCoPE) Project.

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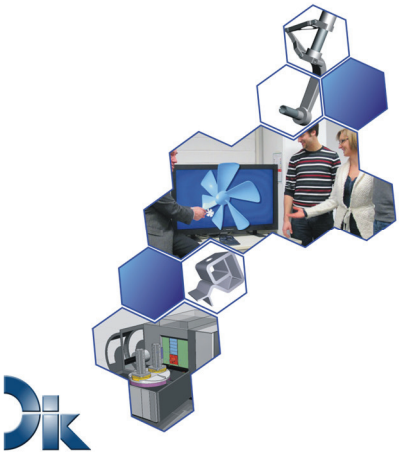

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Industrie 4.0 – Digital Transformation in Product Engineering and Production

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Development of information and communication technology (1)

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Hypermedia hyperlinked documents	Multimedia hyperlinked media	Socialmedia (1) networking people
YAHOO! (1995)	Google (1998)	facebook (2004)
NETSCAPE AOL (1985,1997,1998)	Alibaba.com Global trade starts here.™ (1999)	YouTube (2005)
MOSAIC ebay (1995) amazon (1994)		twitter (2006)
World Wide Web	**Java, UML, XML**	**Web Services**
Web	**Web 1.0**	**Web 2.0**
1995	2000	2005

Source: Dr. Dais, Bosch

Development of information and communication technology (2)

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Socialmedia (2) networking companies	Cyber-Physical Media interconnected and communicating systems	Future Media
	PLATTFORM INDUSTRIE 4.0 Plattform INDUSTRIE 4.0	?
App technology	Industrie 4.0 component	
Web 3.0	Web A.B	Web X.Y
2010	2015	2020

Approaches for smart systems

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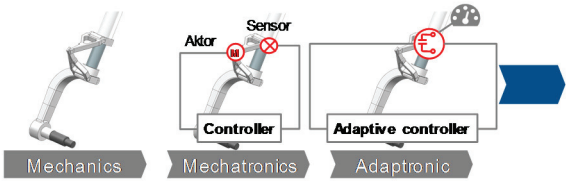
Improvement of the added value Based on functional integration



Further improvement of the added value based on cyber-physical systems

Networked and communicating systems

Smart Plant

Smart Factory

Source: TU Darmstadt, Effiziente Fabrik 4.0

Smart City

Source: TU Darmstadt

Smart Grid

Source: TU Darmstadt, ESE

Smart Products

Smart Logistics

Smart Home

Cyber-physical systems support networking and communication

- Condition Monitoring

- Systems and Structural Health Monitoring

- Remote Diagnosis and Control

- Tracking and Tracing

Competence Centers Industrie 4.0 in Germany

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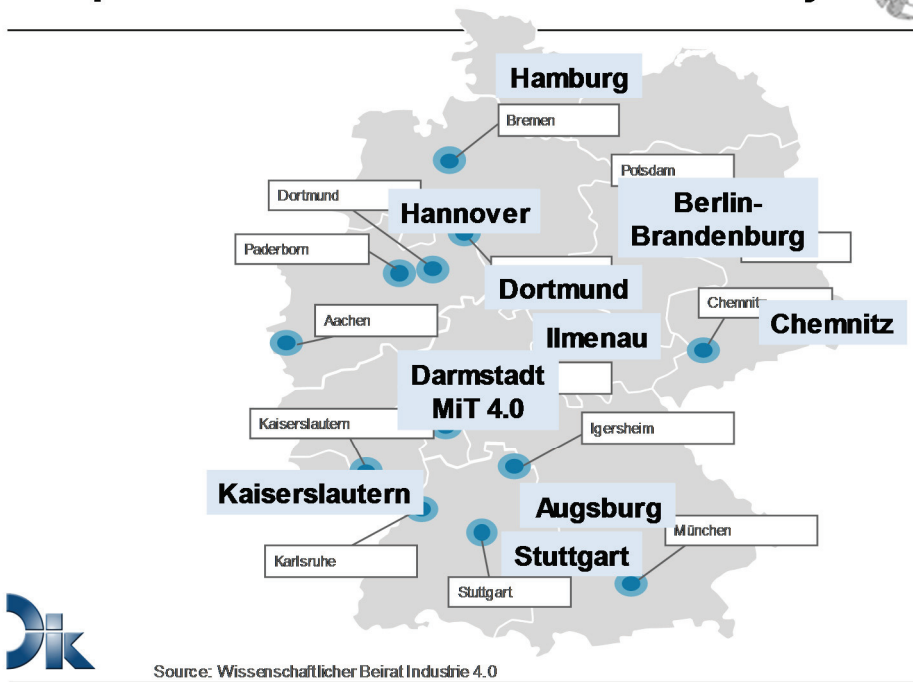

Source: Wissenschaftlicher Beirat Industrie 4.0

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Plattform Industrie 4.0

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Chair
Ministers Gabriel, Wanka
Representatives of commerce, trade unions, science

Technical/practical expertise decision-making	Policy guidance, society, multipliers	Activities on the market
Steering body (companies) • Chaired by business representatives, participation of Economic Affairs and Research Ministries • Chairs of working groups, other guests/ promoters Industrial strategy development, technical coordination, decision-making and implementation	**Strategy group (Government, business, unions, science)** • Chaired by StS Machnig, StS Schütte • Representatives of steering body • Representatives of Federal Chancellery, Interior Ministry • Representatives of the Länder • Representatives of associations (VDMA, ZVEI, BITKOM, BDI, VDA, BDEW) • Representatives of trade union (IG Metall) • Representatives of science (Fraunhofer) Agenda setting, political steering, multipliers	**Industrial consortia and initiatives** Implementation on the market: test beds, examples of applications **International standardisation** Consortia, standardisation bodies, DKE and others
Working groups • Reference architecture, standardisation • Research and innovation • Security of networked systems • Legal framework • Labour, training • Others as required Working units with technical/practical expertise; participating ministries: Economic Affairs, Research, Interior, Justice, Labour	**Board of Academic Advisers**	

Secretariat as service provider
Network coordination, organisation, project management, internal and external communication

Implementation recommendations for Industrie 4.0 Effective: April 14, 2015

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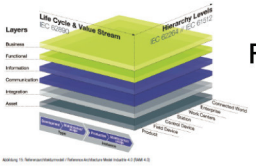
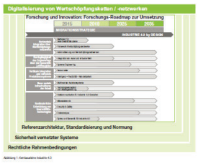
BITKOM VDMA ZVEI

Umsetzungsstrategie Industrie 4.0
Ergebnisbericht der Plattform Industrie 4.0

Industrie 4.0 component



RAMI 4.0



Research roadmap

Referenzarchitektur für Industrie 4.0 – RAMI 4.0

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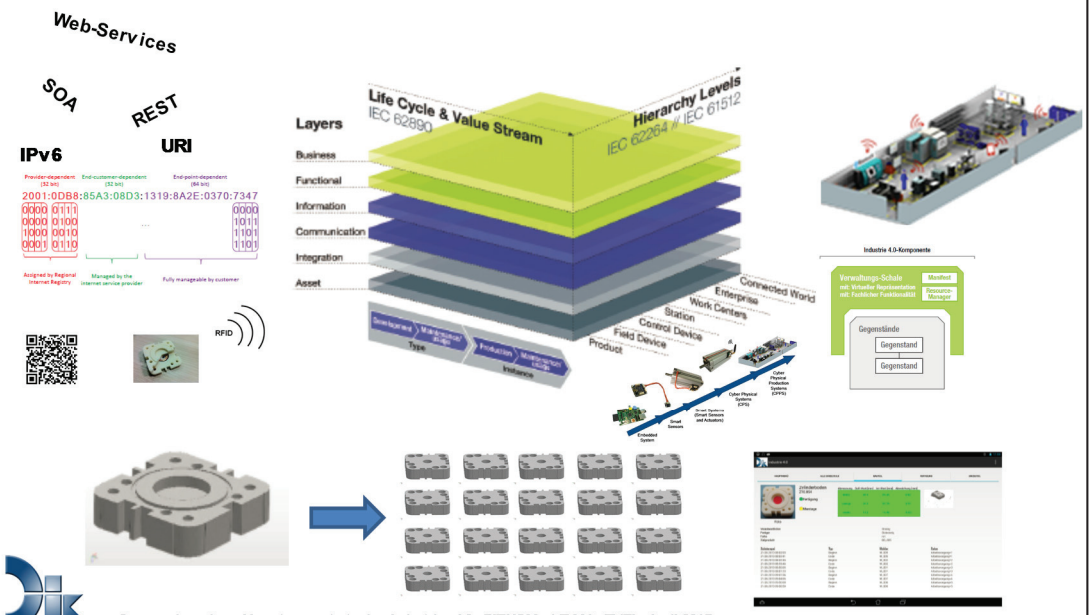

Source: based on Umsetzungsstrategie Industrie 4.0, BITKOM, VDMA, ZVEI; April 2015

Industrie 4.0 Component

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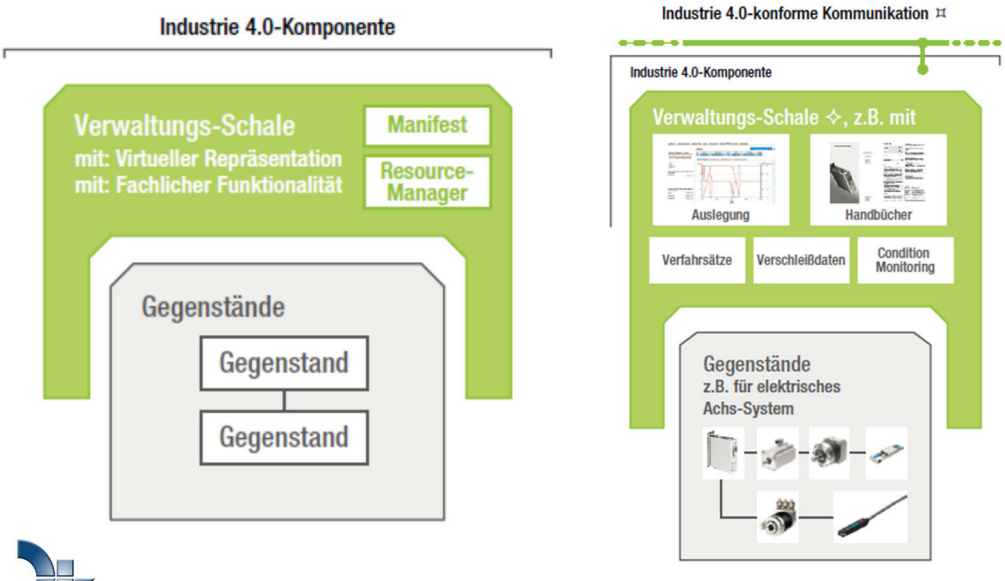

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Model factory for Industrie 4.0
Unique selling point TU Darmstadt: Effiziente Fabrik 4.0

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- Build on existing, real production system

  ↓

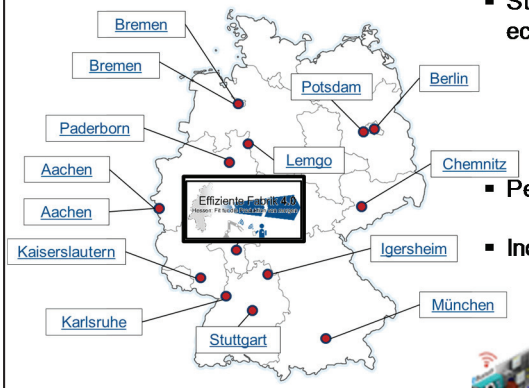
  Brown instead of Green Field

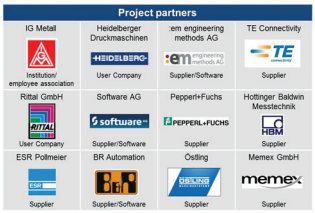
- Statistical system for the organizational and economic evaluation

  ↓

  Quantification of benefits via before/after comparison

- People are the focus
- Industrial use cases (application scenarios)





Uses Cases – Efficient Factory 4.0

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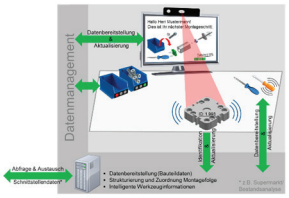
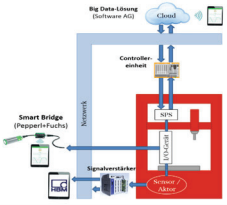


Use Case 4

- **Flexible intelligent worker assistance systems**



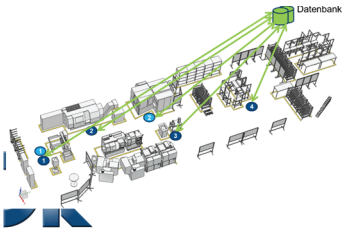
Use Case 1

- **Paperless and integrated quality assurance**

- Components as information carriers
- Unified data management

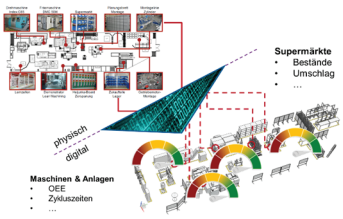
Use Case 3

- **Condition and energy monitoring**



Use Case 2

- **Digital value stream**
- **Real-time capable production controlling**



Industrie 4.0 Components as Information Carriers

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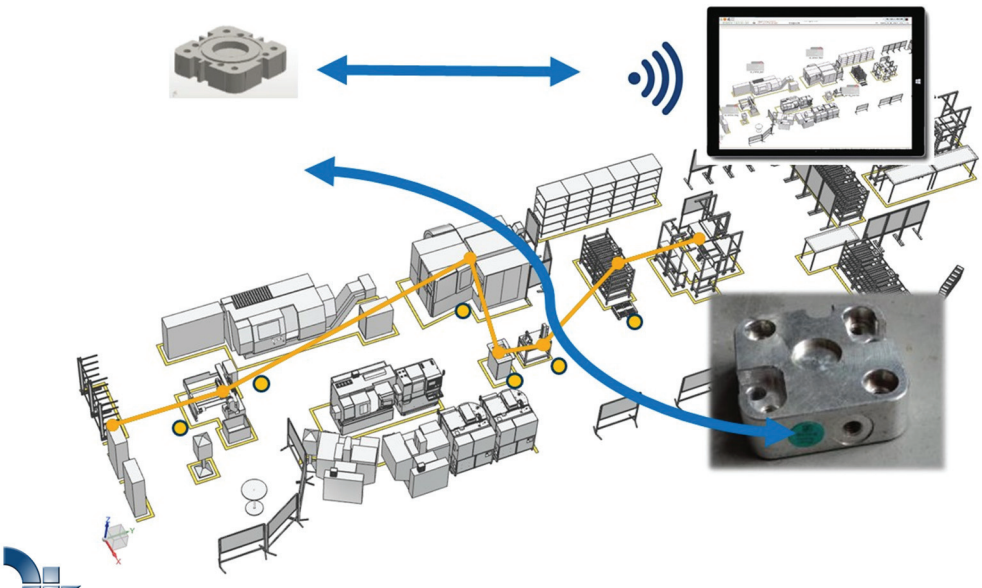

Uses Cases – Efficient Factory 4.0

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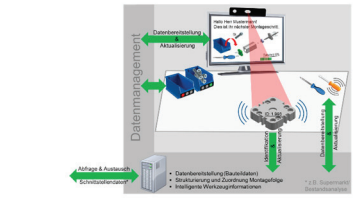
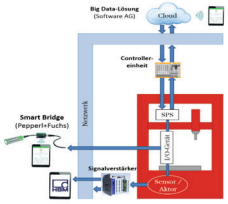
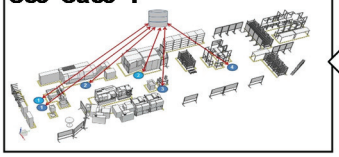


Use Case 4

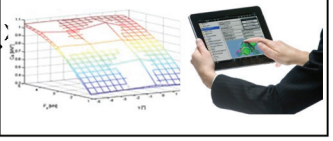


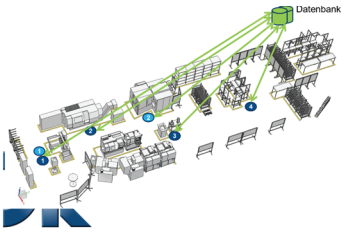
Use Case 1



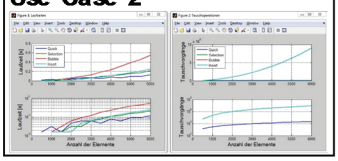
- Components as information carriers
- Unified data management

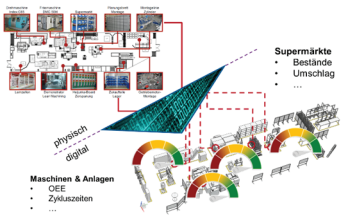
Use Case 3





Use Case 2





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Darmstadt Competence Center for Small and medium Sized Industry (MiT 4.0)

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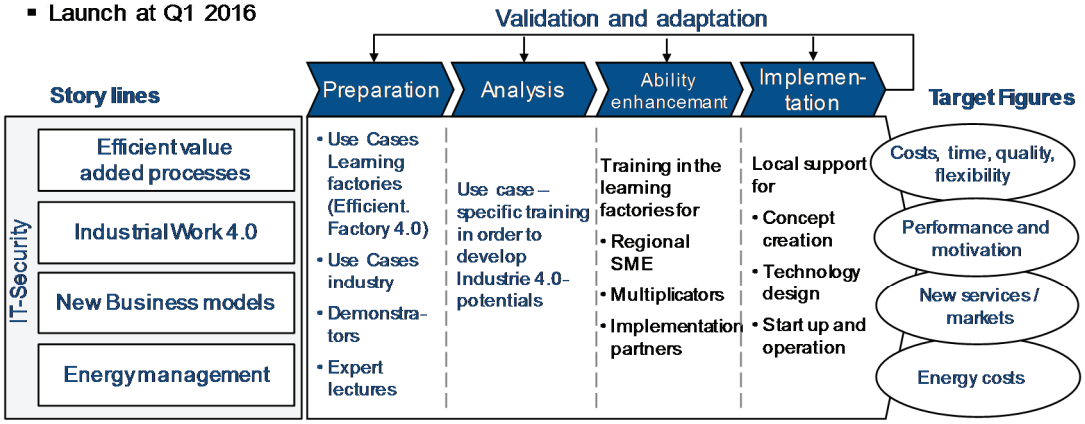
- The service portfolio includes a target group-oriented competence development. For this purpose, different plotlines and instruments for SME-friendly exchange in MiT 4.0 are defined.
- Launch at Q1 2016



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VDMA guideline Industrie 4.0

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Initial situation:

- 86% of German SMEs have recognized the potential of Industrie 4.0 (Source: Commerzbank AG)
- Visions of Industrie 4.0 are intangible and too general for the industry
- Way to realize Industrie 4.0 is unknown for the industry

Objectives:

- Break down the visions of Industrie 4.0 on realizable development stages for product ideas and production improvements
- Understanding Industrie 4.0 as a pioneer of new business models
- Sketch and support path to successful implementation

VDMA guideline Industrie 4.0: Toolbox Industrie 4.0

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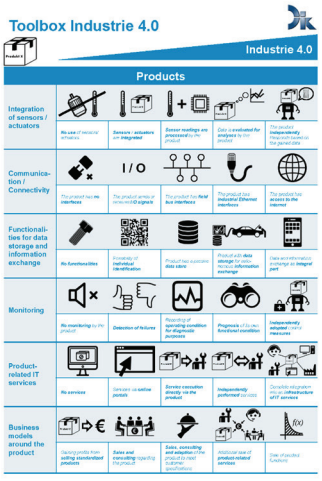
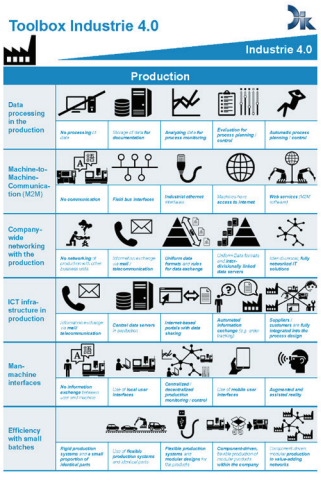
- The key element of the guideline Industrie 4.0 is the **Toolbox Industrie 4.0**
- The Toolbox Industrie 4.0 is used to analyze the company's competences and to generate strategies for approaching Industrie 4.0.





Source: Leitfaden Industrie 4.0 – Orientierungshilfe zur Einführung in den Mittelstand, VDMA

VDM guideline Industrie 4.0: Toolbox Industrie 4.0

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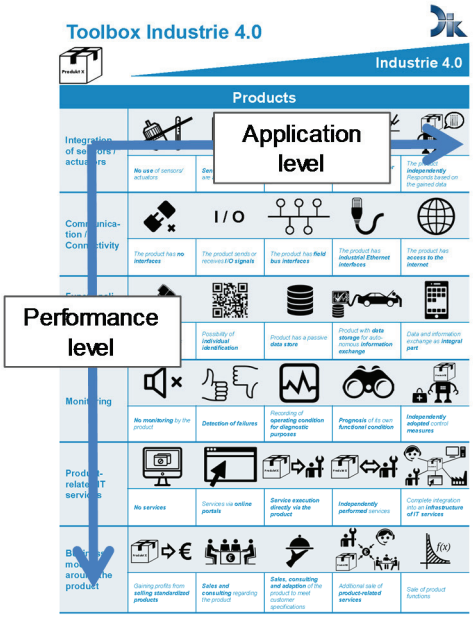
Structure of the toolbox:

- Application level:
  - Six application levels to identify themes for ideas in the field of Industrie 4.0.
  - The combination provides the functionality.
- Performance level:
  - Five technological, building on one another performance levels for positioning and strategy development.
  - The highest level represents the vision Industrie 4.0.



Source: Leitfaden Industrie 4.0 – Orientierungshilfe zur Einführung in den Mittelstand, VDMA

VDMA guideline Industrie 4.0: Toolbox Products

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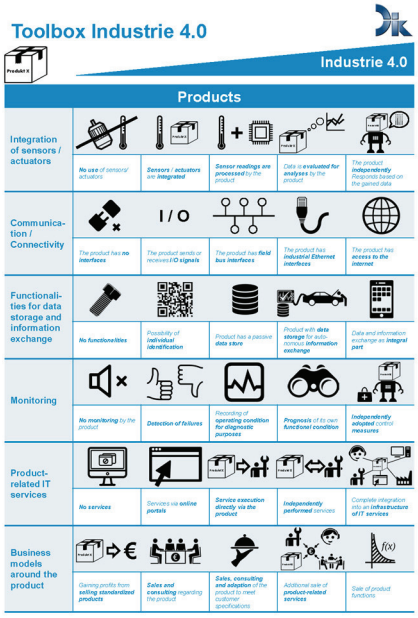
- Application levels:
  - Integration of sensors / actuators
  - Communication / Connectivity
  - Functionalities for data storage and information exchange
  - Monitoring
  - Product-related IT services
  - Business models around the product



Source: Leitfaden Industrie 4.0 – Orientierungshilfe zur Einführung in den Mittelstand, VDMA

VDMA guideline Industrie 4.0: Toolbox Production

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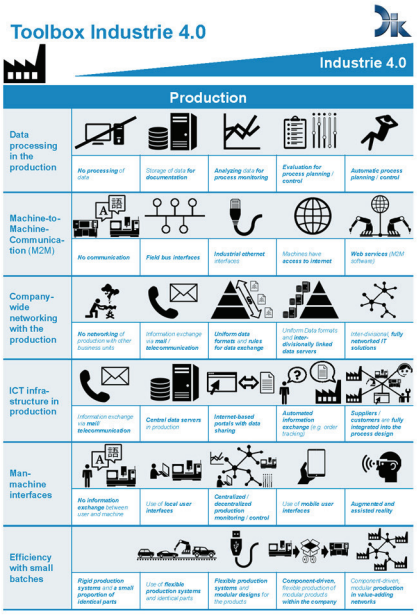
- Application levels:
  - Data processing in production
  - Machine-to-Machine- Communication (M2M)
  - Company-wide networking with the production
  - ICT infrastructure in production
  - Human Machine Interfaces
  - Efficiency for small batches



Source: Leitfaden Industrie 4.0 – Orientierungshilfe zur Einführung in den Mittelstand, VDMA

VDMA guideline Industrie 4.0: Results for products und production

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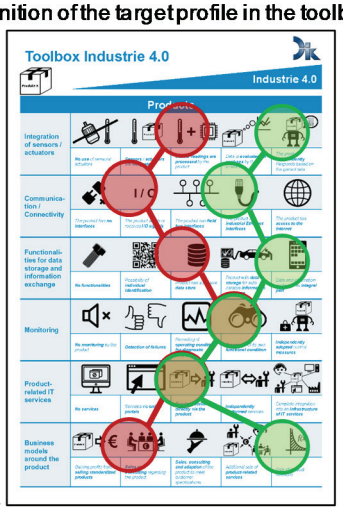
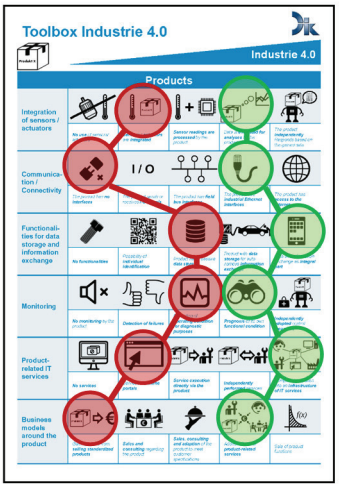
Procedure:

1. Classification with respect to performance levels of the Toolbox Industrie 4.0
2. Identification of the existing performance profile in the toolbox
3. Definition of the target profile in the toolbox





Source: Leitfaden Industrie 4.0 – Orientierungshilfe zur Einführung in den Mittelstand, VDMA

Production, products, business models: Industrie 4.0 development trends

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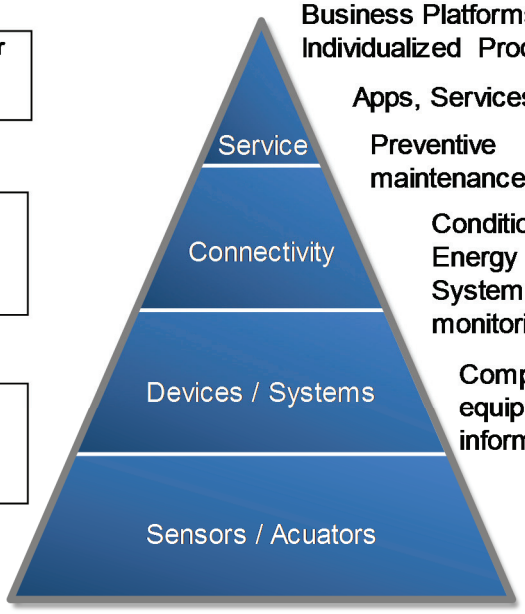
New approaches for internet-based business models

New level of organization and management of the value added chain

Interlinked and communicating systems



Business Platforms, B2B Marketplace
Individualized Products and Production,
Apps, Services instead of products

Preventive maintenance
Component tracking

Condition monitoring
Energy monitoring
System and structural monitoring

Components and equipment act as information carriers

Addressing
Localization
Identification

Bluetooth
RFID

Industrie 4.0 – Digital Transformation in Product Engineering and Production

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1. Introduction
2. Fundamental Approaches of Industrie 4.0 technology
   - RAMI 4.0 (Reference Architecture Model Industrie 4.0)
   - Industrie 4.0 Component
3. Use Case Scenarios of the "Efficient Factory 4.0"
   - Industrial Use Cases
   - Industrie 4.0 Components as Information Carriers
4. Transferring Industrie 4.0 to Industry –
   - Darmstadt Competence Center for Small and Medium Sized Industries
   - Story Lines and Strategy
5. The VDMA Industrie 4.0 Implementation Guideline
   - Toolbox Products and Toolbox Production
   - Target Profiles towards Industrie 4.0
6. **Summary**

Summary

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- Industrie 4.0 provides new impulses for the development and application of cyber-physical systems on the way to the internet of things, of services and data.
- Industrie 4.0 still requires research and development initiatives, nevertheless applicable solutions are already visible.
- Impulses for the Industry:
  - Customization through customer and market interaction
  - New ICT infrastructures
  - Innovative business models through integrated product and service quality
- Current state of debate:
  - Politics: Politicians have recognized the importance of Industrie 4.0 at the federal level and the state level and became active (Plattform Industrie 4.0, IT summit, European initiatives)
  - Industry: The industry has organized itself through the platform industry 4.0
  - Society: Change of the working environment! Increasing digitization and computerization through Industrie 4.0 requires training and continuous qualification of employees

➢ ***Industrie 4.0 offers to companies a serious vision, that has to be evaluated and implemented company-specific.***

Thank you!

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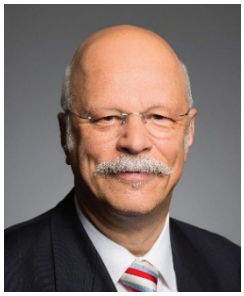

Univ.-Prof. Dr.-Ing. Dr. h.c. Sándor Vajna

Univ.-Prof. Dr.-Ing. Dr. h.c. Sándor Vajna received both his Diploma degree and his Doctor's degree in Mechanical Engineering from Karlsruhe University. He has 12 years of experience within industry in management positions in research & development, consulting, and international lecturing on Product Development, Design Methodology, CAx, Process Reengineering, Engineering Systems Integration, CIM (now PLM), and Data Processing. In 1994, he was promoted to Full Professor of the Chair of Information Technologies in Mechanical Engineering at the *Otto-von-Guericke University in Magdeburg*. His research areas include Integrated Design Engineering (with an own Master of Science Course), the Autogenetic Design Theory, Dynamic Process Navigation, knowledgebased product modelling, and the holistic evaluation of economical benefits of Engineering processes and the application of new technologies (Benefit Asset Pricing Model).

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The main research of the Chair of Information Technologies in Mechanical Engineering is *Integrated Design Engineering* (IDE) to develop products interdisciplinary and holistically, to use attributes to describe product behaviour and performance, and to simulate the whole product life in advance on order to take decisions at the latest possible time. The *Autogenetic Design Theory* treats design as an optimisation process driven by evolutionary procedures in an inverse solution space. *Dynamic Modelling and Navigation* models and manages successfully Engineering processes and projects. The economic viability of technologies and products is evaluated with the *Benefit Asset Pricing Model* (www.bapm.de). All research work is verified by industrial applications. Teaching: Our own IDE Master Study Course (www.ide-master.de). B.Sc.: Engineering Information Technologies, CAx Basics, and Integrated Product Development. M.Sc.: CAx Applications, CAx Management, Product Modelling, Business Science for Engineers, and Project Management. External: Product Development for Economists (Mannheim University).

Integrated Design Engineering – a holistic, interdisciplinary, and multi-criteria approach for the development of any kind of products

Abstract

Integrated Design Engineering (IDE) is a human-centred and multidisciplinary development approach that integrates stakeholders, products and their lifecycle phases, processes, organisations, knowledge, and information. One of the features of IDE is to describe both performance capability and performance behaviour of a product with different, but equivalent and equally important attributes. These are structured into product attributes, performance attributes, and economic attributes. Due to this diversity IDE attributes offer significantly more and better ways to describe and to develop a product exactly according to various requirements. They are based both on the needs and on desires of customers as well as on the different environments in which the product is to be used and to the respective conditions of which the product must comply. This paper describes the IDE attributes and gives an overview how to work with them.

Keywords

Multidisciplinary Development Approach; Product Performance; Product Behaviour; Product Life Cycle; Product Attributes; Fulfilment Attributes; Economic Attributes.

1 Basics of Integrated Design Engineering

IDE is a human centred, multi-criteria, interdisciplinary, and holistic approach for the development of any kind of products. Products may be physical objects (discrete or continuous), software, methods, procedures, or other immaterial objects, respectively. IDE takes into account the whole product life cycle, and is based on different types of integration (including generalization and integration of stakeholders, products, processes, departments, knowledge, and methods, respectively).

In IDE, stakeholders comprise customers, providers, sponsors, and persons concerned.

- Customers may be divided into buyers and users. These two are usually the same person or insti-tution when it comes to investment goods. However, these can be separated people or institutions, e.g. in the case of a health insurance that, as a buyer, provides a wheelchair to a handicapped person as user1 and a person, who pushes the wheelchair, as user2. The interests of the buyer do not necessarily correspond always with the interests of the user(s). In the case of the wheelchair, the buyer wants a cheap, durable, and robust device that may be used by difference parties. The users would appreciate a customized chair that e.g. is not too heavy and that may easily be pushed;
- Providers can be developers, (direct) manufacturers, suppliers, and / or distributors;
- A sponsor supports customers and / or providers. Reasons for sponsoring may range from philan-thropy to concrete economical and / or political interests;
- Persons concerned can be impeded by the application of the product in any kind of environment, e.g. when listening to loud music in a train via earphones that have an open characteristics the audible musical noise bothers the neighbour.

Basic activities within the IDE procedure model are researching, developing, designing, and integration, modelling, configuration, and synthesising as well as evaluating, comparing, selecting and completing. Applying these activities in developing products result in activity patterns, which are self-similar on any level of concept, specification, and realisation. There is not a prescribed sequence of activities in this model. In fact, the basic activities are event-driven, as they are processed dynamically according to the actual state of product emergence in context with the actual state of requirements [Vajn-2014].

Requirements for a product in the broadest sense merge together both needs, wishes, and expectations of customers with the conditions for product existence in a given or changing environment (legal, social, etc.) [Otto-2013]. To fulfil the requirements, a product disposes of individual characteristics that make up its respective performance capability and performance behaviour.

Most of actual design methods are focussed on function fulfilment, to which all other goals have to subordinate. However, it has turned out that functional fulfilment alone is not sufficient enough to meet the requirements and expectations of customers (especially in the consumer goods industry). In fact, the measure of a (longer-term) customer satisfaction is the *overall performance* of a product [JoAF-1995]. In a buyer's market with many alternative products of comparable performance, the decision is no longer made in favour of a product only by objective reasons, but increasingly by emotional reasons (e.g. spontaneous “gusto” for a product shape, "coolness" of a product), by sustainability issues, by the existence of simple interfaces and usages. In IDE, therefore, features, properties, characteristics, and natures of a product are described and created using eleven different *attributes* of the product.

Attributes are always present, in every product, and throughout its whole life cycle. In principle, they describe performance capability and performance behaviour of a product as the result of their actual appearance, their state, and their interaction. The description may change along the development process. In IDE, the final realisation of each attribute is decided as late as possible. Herewith, on the one hand, a product developer in IDE is not restricted in his creativity during design and development of the product, thus can deploy his concepts freely and act individually. On the other hand, advances in technologies, organizations, and processes can always be included as soon as reasonable in the realisation of the attributes. As needed, and mostly based on specific customer requirements, the precise realisation of the product can be pre-determined.

All attributes are *equal* and have all the same relevance, importance, and value. However, they are not similar, because there is always more than one equal opportunity for the realisation of a requirement, if more than one domain, e.g. mechatronics, is included [VaKB-2011]. All attributes are mutually supportive in a symbiotic manner to create the best possible solution under the current circumstances.

- From the customer's (= buyer, user, sponsor, etc.) point of view the attributes describe the anticipations of the customers to both capability and behaviour of the product performance that result from the different customer needs, expectations, and wishes as well as from the conditions of the environment in which the product is to be used. Attributes from the customer's view form the target attribute profile;
- From the provider's (= manufacturer, seller, distributor) point of view the attributes describe the capability and performance offer of the product. Especially in the consumer goods market, this offer can also be influenced in the broadest sense by guidelines based on various customer requirements or conditions of the product environment. Attributes from the provider's view form the as-is attribute profile.

2 Attributes in IDE

There are eleven attributes in IDE to describe performance capabilities and performance behaviour of a product. These are divided into three groups, the product attributes, the fulfilment attributes, and the economic attributes. The respective names of the attributes were selected in a way that easy measurability and simple assessment are already reflected in the names (most of them have the "ability" syllable in their names). This wording shall support the easy attribute evaluation and the uncomplex comparison with other products.

2.1 Product Attributes

The first six attributes describe capabilities and behaviour of a product based on requirements, involving influences and constraints of the product life cycle and of the application environments. They embody as well the (usually unconscious) expectations of a customer. This type of expectation is powered by recurring experiences that led to the same or (quite) similar results (as an example: It can be assumed that the lever mounted left of the steering wheel in a car is the signal lever if the car is designed for right-hand driving).

The six product attributes are Product Design, Functionality, Handleability, Producibility or alternatively Availability, Maintainability and Sustainability.

- *Product Design* endows objects with culture, identity, aura, and presence. This attribute describes shape, appearance, look-and-feel and aesthetics of a product, in short the visual and emotional "charisma" of a product as key interfaces to the user. Product Design provides the fulfilment of requirements such as sensuality and sensibility, in order to realise product properties that meet the individual needs and possibilities of the user. In every case, however, the human is the one and only measure of such creative work, never the technology. Form does not necessarily follow function any more, as functions alone are not able to provide the individual sensual experience of a product. The product developer can influence Product Design directly by freely choosing shape, material, colour, structure, and surface characteristics. According to the CPM / PDD theory of Weber [Webe-2011] Product Design is a characteristic of a product, unless a customer requests it explicitly as a product property;

- *Functionality* is the ability of a product to transform functional requirements into corresponding user-related functions and it describes the ability of the product to fulfil adequately either a specific requirement or a set of any requirements, regardless of whether these can be realised as mechanical, electrical, electronic, hydraulic, optical, or software functions, or combinations of these. In short, it covers all direct and indirect functions and their interplay that a product provides for the usage;

- *Handleability* describes in a broader sense performance, usefulness, and quality of the interfaces between user and product. A powerful and versatile handleability is essential for the success of the product. Therefore, it has to be intuitive, reasonable, and

understandable. Handleability, on the one hand, is closely connected to Product Design, because this attribute influences the handling of the product at least by shape, material, colour, and surface texture. On the other hand, it influences Functionality, since the functions can only made available to the user via the interfaces provided (it goes without saying that in IDE products are adapted to humans and not vice versa).

The attributes Product Design, Functionality, Handleability, and Maintainability can be summarized under the generic term "usability", i.e. the focus on the sufficient and appropriate usage of a product, by the intended user and within the planned application context.

The following two attributes Producibility and Availability typically occur alternatively in the attribute profile, depending on who (customer, provider) is requesting it. Usually, they are mutually exclusive. Both attributes are directly affected by the product developer and thus are characteristics, unless a customer requests them explicitly as a product property.

- *Producibility* provides information on whether, how and on what terms of technical, organizational, logistical and financial means a product can be produced (= manufactured, assembled, tested, etc.). This can be executed internally with the available options of the provider or the product has to be produced externally. Another option is to add manufacturing equipment, if the possible profitability of the product is promising. Producibility is primarily of interest for the provider, because, if a product is not producible, it cannot be delivered to a customer or to the market, and thus cannot generate profitability;

- *Availability* means on the one hand that the product is available for the customer, is supplied to him and installed within the agreed period of time. On the other hand, it means that the product is always ready for use in the intended application area, according to the requirements and during the expected lifetime (i.e. readiness for usage). Customers usually are interested in Availability, because a customer wants to obtain a product at his particular point in time. He neither can nor will buy a product that cannot be produced. Exceptions are those customers who are interested in e.g. a fair and sustainable manufacturing of the product;

- *Maintainability* describes the ability and the ease with which a product can be modified for rapid correction of error states, because of new requirements, to improve maintenance, or to adapt to a changed environment [ISO 25000]. These actions must be possible without limitations to put the product back into the usable state and to ensure its availability;

- *Sustainability* means that a product respects ecological requirements to be as important as technical, social, and economic requirements. This leads to a balance of economic, social, and environmental targets [Beys-2012]. Sustainability demonstrates the high responsibility of product development because it creates in its phases the conditions for

a sustainable product (Hubka already required in 1976 from the product designer an ethical responsibility to society and economy [Hubk-1976]).

2.2 Fulfilment Attributes

The fulfilment of requirements by every attribute and their interplay is as well dependent of the respective viewpoints. From the provider's view, the main focus is obviously on the realisation of the product. This is considered in IDE with the tripartition of type, degree and excellence of fulfilment:

- The type of fulfilment refers to the way of how a requirement was realized, e.g. by selecting a suitable technical mode of implementation out of a set of alternatives that result from the manufacturing possibilities of the provider (what was realized how and with what?);
- The degree of fulfilment describes the relationship between a requirement and its (proportional) realisation (what was realized to what extent?);
- The excellence of fulfilment describes both nature and value of the fulfilment, which means that it rates both the type and the degree of fulfilment (how sound was it fulfilled?).

One example for this tripartition is a multi-function switch on the steering wheel of a car, which enables the operation of blinkers, wipers, and different lighting functions.

- Fulfilment type: The switch may consist of metal or plastic and it may include mechanical or electronic switches;
- Fulfilment degree: The number of functions realized in the switch (e.g. steps for varying the length of the interval between two movements of the wiper), which may differ depending on the respective level of extras;
- Fulfilment excellence: This is manifested in ease of operation, precise latching, repeatability, and durability both of the switching steps and the entire switch.

Type, degree, and quality of fulfilment depend on the current requirements for the product, on the current conceptions, goals, factors, and boundary conditions of the company, e.g. corporate strategy and corporate identity, on profitability expectations and Code of Conduct (Corporate Social Responsibility). The rating of the respective fulfilment takes place in relation to the requirements or to an agreed standard. This results in subjective outcomes in relation to each requirement. However, the more precise requirements and conditions are formulated, the less scope is left for the respective fulfilment (until the exact presetting).

For the customer, however, another tripartition, the tripartition of safety, reliability, and quality of the product is of importance as, especially in the customer goods market, the interest of how a product is realised, usually is not always in the focus of the customer. The combinations of

the three types of fulfilment are represented by the attributes safety, reliability, and quality, Figure 1.

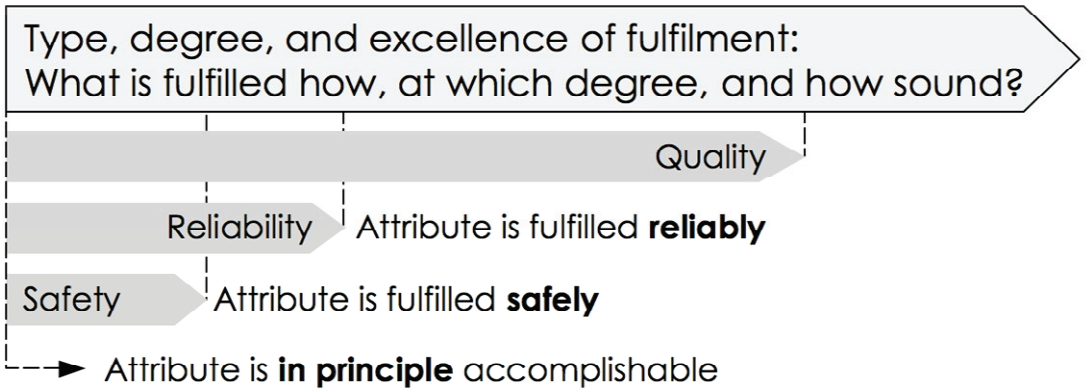

Figure 1: Different forms of requirements fulfilment

- *Safety* describes the specific combination of fulfilments that the product attributes must meet at least to assure that the product never can harm the user (or another person concerned) when it is used in the intended way (including a certain tolerance against misuse). It may well be the case that Safety requires a higher fulfilment than e.g. is needed to fulfil Reliability. For the entire product and its components, Safety of the entire product corresponds, on the one hand, to the interaction of the individual Safety attributes of the components, on the other hand, to the degree and the excellence of the interaction of the components within the product. It also means to prevent the propagation of the failure of one component to further failures of other components or of the product, regardless of whether a person is involved or not. Safety can be understood as fixed or knockout criterion, because if a product does not fulfil the safety requirements, it cannot be used under any circumstances;

- *Reliability* is the combination of fulfilments to ensure that a product will behave always reliably for its intended purpose and that it can be used with a certain tolerance against misuse (robustness). This has to be ensured during or after an application [DIN-40041], over its specified or expected lifetime, or in a given time interval under given conditions. Reliability is understood here as the ability for utilizing (which is not the same as "usability") as well as the readiness for use. The reliability of a product and its components corresponds to both the sum of the individual reliabilities, the (additive) interplay of the individual reliabilities as well as their synergistic co-operation within the entire product. Reliability can also be interpreted as a minimum criterion, i.e. the lower limit of fulfilments;

- *Quality* describes the actual level of excellence of the product, i.e. nature, suitability and value of the combination of the fulfilment of product requirements. This definition is in accordance with the definition of ISO 9000:2005. According to this standard, quality is

the totality of characteristics of an entity, with which (in terms of their suitability) defined needs and implied needs are satisfied [DIN-9000]. Quality never is an absolute value, but always the relationship between requirements and their manifold fulfilments, always depending on the respective frame of reference. Such a reference frame is usually made up by the totality of the requirements to the product, its possible application environments with their inherent conditions, and further environments (legal, social, etc.). Quality is not just a physical quantity, but also the sum of relevant characteristics and properties in a particular environment (respecting the aspect of manifoldness). The importance of Quality varies along the product life cycle [EhMe-2013]. It can be understood as the sum of nice-to-have criterions, thus always having the subjective dimension.

2.3 Economic Attributes

The third group of attributes contains the tangible and the ideational aspects and thus (in the broadest sense) the economic aspects of the product, i.e. profitability and added value or overvalue, respectively.

- *Profitability* describes the economic aspect of the product from the perspective of the provider. It is the ratio of the attainable profit from the attribute profile of the product in relation to the expenditures needed to realize this profile in a billing period. The expected profitability is, for the provider, one of the main reasons to opt for development and production of a product;

- *Added Value* (or Overvalue) is the relation between the as-is profile of the product attributes that exist in different fulfilments, and the expenditures for procurement, application, maintenance, and disposal for the product. For the customer, Added Value does not describe only the financial increase in value (e.g. by a cheap price or low usage costs), but also the ideational increase of value through possession and use of the product, such as prestige and status, attitude to life and a certain preference (e.g. for a specific provider, for a specific product, or for certain innovations). While the Added Value for customers in the investment goods industry is measured mainly financially, the ideational reasons play an increasingly important role with customers in the consumer goods industry.

Profitability and Added Value must both be present at each product. Only if the provider can expect a reasonable return, he will manufacture the product. Only if the product provides him an adequate and suitable added value, this customer will buy this product.

2.4 Attributes and their Context

The three groups of attributes have the following context, Figure 2.

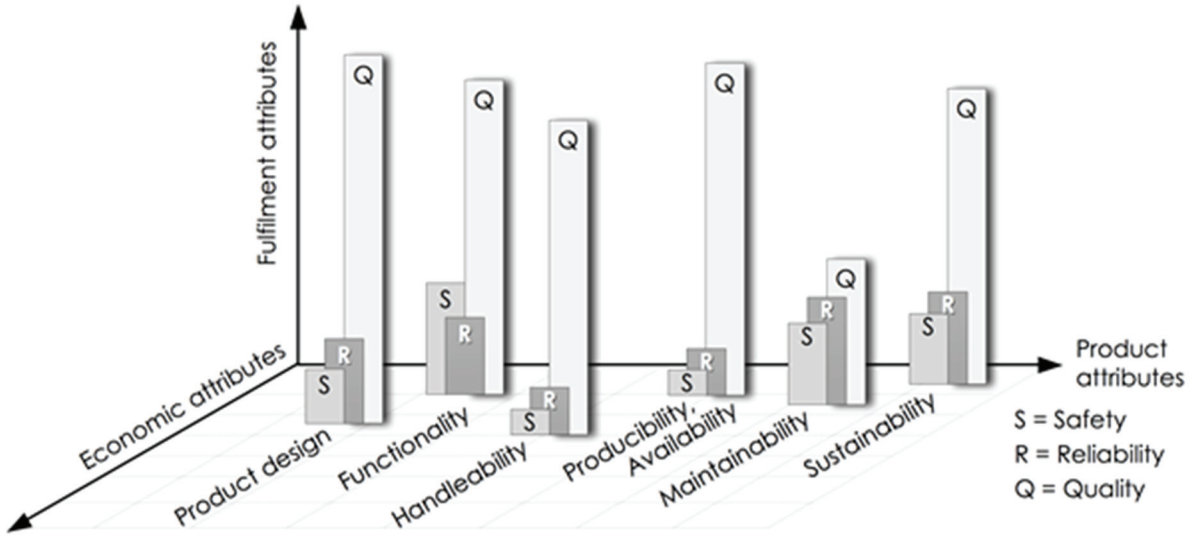

Figure 2: Context of attributes, fulfilment combinations, and economic attributes

As shown above, Safety must be above the knockout criterion and Reliability must fulfil the minimum criterion, otherwise the product cannot be used. However, it is possible (as with the Functionality attribute in Figure 2) that, to achieve reliability, a lower fulfilment can be sufficient than to fulfil the knockout criterion for safety. The individual attributes and their respective fulfilments lead to different profitabilities and added values. This is illustrated by their different positions in Figure 2.

All attributes influence each other to varying degrees, whereby stronger effects result from the attributes Product Design and Producibility / Availability, because both are directly affected by the product developer (left side of Figure 3). Thus, these two attributes are to be preferred when product changes have to be performed, because they have the highest impact (and thus may save adaptation efforts) as long as the corresponding boundary conditions are observed, which can be modelled, for example, with design rules or with the approaches of DfX [Meer-1994].

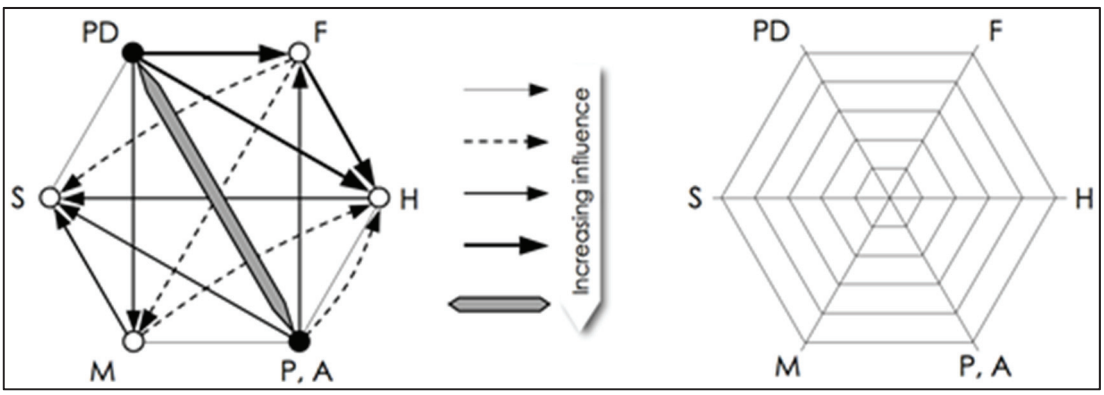

Figure 3: Left side: Different influences from and to attributes. Right side: Basic spider diagram (PD: Product Design, F: Functionality, H: Handleability, P: Producibility, A: Availability, M: Maintainability, S: Sustainability)

In order to provide a simple way of modelling the attribute context for the separation between the target attribute profile (which the customer dictates) and the actual profile (which is the result of the provider's work) the spider diagram is introduced. It is spanned by the six product attributes (right side of Figure 3), in which the fulfilment increases from the inside to the outside of the diagram.

3 Working with Attributes

Working with IDE attributes is in the focus of the actual research of the author. Resulting procedures are incorporated into the processing of multidisciplinary product development projects that serve as a test environment. Currently, the following steps to work with attributes have been identified:

- Generating product requirements from the needs, desires, and expectations both of customers and of the market in connection with the conditions of the environments in which the product is to be used. The result is a description of the necessary product performance and its behaviour that can be prioritized and weighted;
- Mapping the desired product performance and its behaviour on the product attributes for generating the target attribute profile. Currently, this is carried out with an adapted form of Quality Function Deployment. Further options are researched as well, e.g. the CIM model with its multiple assignment possibilities [VPJN-1989]. The fulfilment attributes describe the expected performance of the six product attributes, whereas the economic attributes assess the performance. The assessment is based on the cost-benefit analysis, the Balanced Scorecard [KaNo-1997] and the multi-criteria BAPM method [Scha-2004]. Result is the target attribute profile from the customer's perspective. Possible requirements, e.g. how to fulfil a particular product attribute in a prescribed way, are considered in the fulfilment attributes and the economic attributes;
- Creating the as-is attribute profile of a (potential) product, according to the possibilities of the provider, based on a request of a customer or from the market. This is followed by the comparison of the target profile and the as-is profile and the assessment of the fulfilments. A distinction is made according to the type of product. If it is a capital good, there should not be a difference between the as-is and the target profile. If it is a customer good, there may be differences as long as the minimum target profile of the intended market is fulfilled. These (possibly desired) differences can be used e.g. to better differentiate the product against potential competitors.

These steps have to be repeated when changes occur at the needs situation, the market, or the application environments with their respective boundary conditions.

Figure 4 shows three types of attribute profiles.

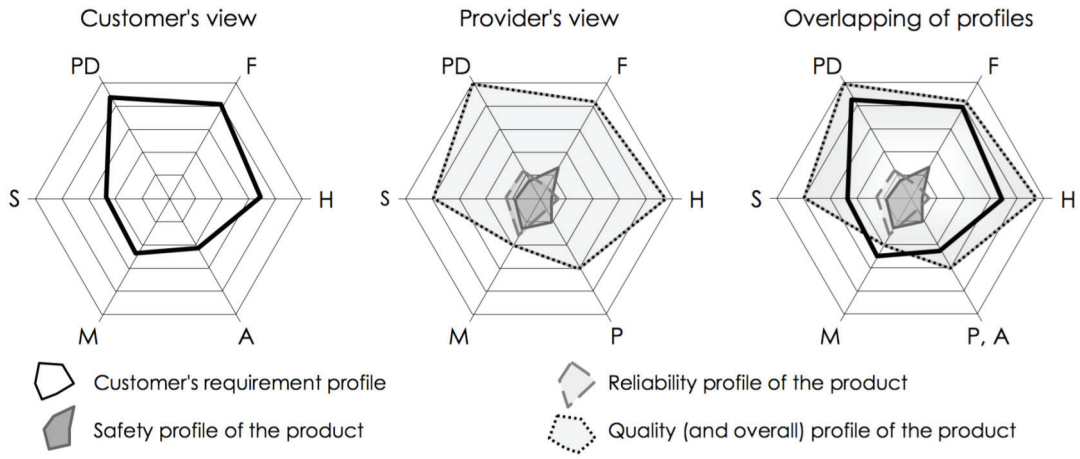

Figure 4: Spider diagrams with target profile (customer's view), as-is profile (provider's view), and the overlapped profiles (PD: Product Design, F: Functionality, H: Handleability, P: Producibility, A: Availability, M: Maintainability, S: Sustainability)

- The *customer's view* shows the customer's requirement profile for the product (or for a class of comparable products e.g. from competitors) in a given market (which does not need to be the market where the customer is located) at a given time or period. This is the target profile. For the customer, the availability of the product is more important, not necessarily its producibility;
- The *provider's view* shows the as-is profile as proposed or realised by the provider, detailed into the three fulfilment attributes Safety, Reliability, and Quality, for a similar period, for the requested market or for that market where the customer is located. This distinction is necessary especially for consumer goods, if the product is available in different markets with different usage environment conditions. For the provider, the producibility of the product is of more importance than its availability;
- The *overlapping of profiles* puts on top of each other the two profiles and thus allows a direct comparison of the targeted and the as-is performance. In this example the overall performance of the as-is attributes profile fulfils the target profile except of Maintainability.

There are different attribute profiles depending on the product and its application area. Figure 5 shows the profiles of a capital good and a consumer good, both from the provider's view.

Capital goods allow a customer himself to produce products that are sold either in the capital goods industry or as consumer goods. The expected period of use of capital goods is long. The expected period of use of a machine tool, as shown on the left side of Figure 5, should not cover less than 25 years. The machine tool must dispose of both high safety and reliability. It must provide the required functions at the highest quality level and the machine must be usable in reasonable and consistent way. Producibility must ensure that the fulfilment of the respective customer requirements is guaranteed. In order to keep downtimes as short as possible, maintainability must be very distinct. In this case, Product design and Sustainability are of less

importance. Since capital goods are usually designed and manufactured for a specific customer, the actual as-is profile offered by the provider will be largely identical with the target profile of the customer.

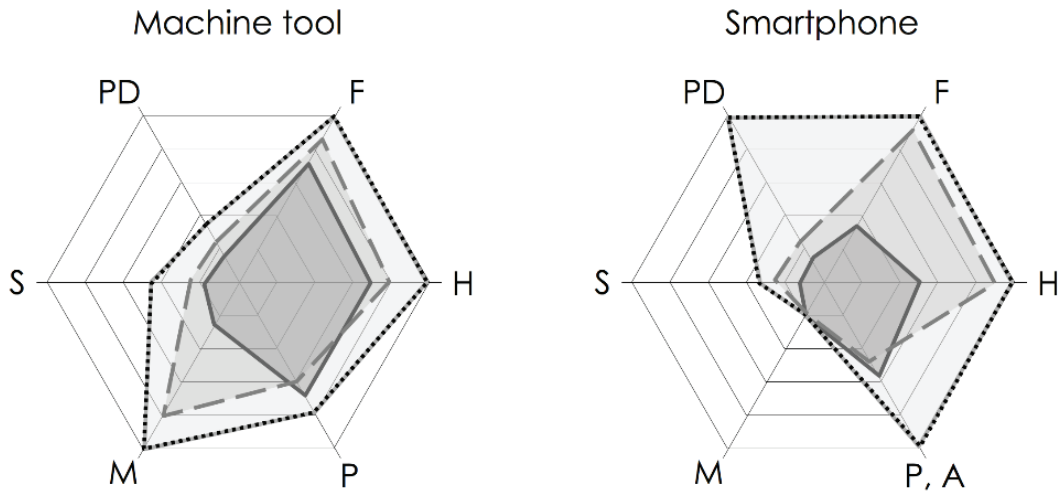

Figure 5: Attribute profiles of a customer good (left) and a consumer good (right), both from provider's view (legend as in Figure 4)

On the right side of Figure 5, the as-is profile of a smartphone is shown, a typical consumer product of today. At this product class, it can be shown that the statement "form follows function" is not necessarily true any more. Smartphones are design-driven and optimized for maximum usability. Actual product design does not reflect the functionality of the smartphone. Main reasons for this are, on the one hand, the increasing miniaturization of components today, on the other hand, the increasing replacement of mechanical functions by electrical, electronic, and software functions, etc. The typical customer of a smartphone is interested in an appealing product design, in a smooth, safe, and powerful functionality, in a simple and intuitive handling and in a high and continuous availability during the lifetime of the device. For the provider, a good producibility is added to this in order to achieve maximum profitability. However, Availability plays a certain role as well (not as dominant as Producibility), as in the consumer goods market a product, to be successful, has to be available at the right time on the market. Maintainability and sustainability of smartphones (and generally of products of consumer electronics) are not, however, in the focus, although, since June 2013, a Dutch company produces and sells sustainable smartphones [Fair-2013].

In the consumer goods sector, the provider offers a product to a target market. In order to gain a higher buying incentive for his own product, the as-is profile of the offered product must be better than the minimum target attribute profile required for this market (Figure 6, Provider's view). Such minimum attribute profiles are usually identified by the marketing department of the provider.

- For a new product, this profile describes the need situation in the market;

- For an existing product in this market, the profile reflects the experience gained so far from the success of the product or a class of similar products, i.e. sales, distribution, application, customer satisfaction, recommendation, etc.

A customer will decide to buy an offered product if it promises an added value to him and if its as-is profile of the attributes provides a better fulfilment than his own subjective target profile regarding type, degree, and quality, in short, if the product meets his (partly vague) expectations to his subjective estimation. This estimation is the result of own experience with the same or similar products and from external knowledge sources such as test and experience reports from various sources (magazines, friends, internet, etc.). This can lead to the following decision alternatives:

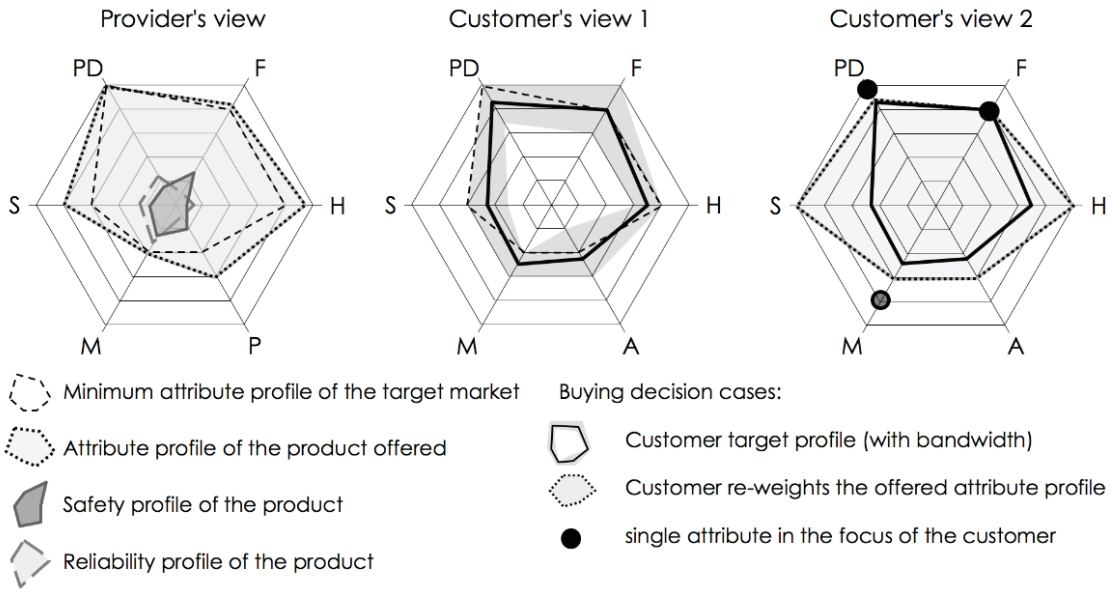

Figure 6: Decision alternatives when buying a product

- At the beginning of the decision-making process, a customer commonly has notions of the desired attribute profile. However, due to his mostly vague expectations, this profile comes along with a certain bandwidth (grey band in 'customer view 1' in Figure 6). Such a target profile fits into various as-is profiles, so the customer may investigate products of several providers. During the selection process (and with increasing knowledge of both the product and its application), the bandwidth is decreasing and the target profile becomes clearer (black profile). If this target profile fits into an offered as-is profile, the corresponding product is purchased. If there are several suitable as-is profiles (i.e. product alternatives), then the decision is in favour of the product with the highest expected added value;
- During the decision phase it may happen that a customer, based on the knowledge acquired during selection, individually re-weights and rebalances both the presence of single attributes and their respective levels of fulfilment in the as-is profile of the product.

This results in a changed as-is profile in which the target profile of the customer may now fit better ('Customer's view 2'). It is also possible that a customer compensates the (subjectively) not adequate fulfilment of an attribute with the fulfilments of another attribute or more other attributes;

- The customer is only interested in the performance of individual attributes with a certain level of fulfilment that he expects at least (black circles in 'Customer view 2'). The other attributes and their fulfilments do not matter in this case.

It is often the case that a product provides the customer a high emotional satisfaction due to e.g. a preference for a certain company or a product, to expected prestige, or to desired status. Although the customer has not a concrete idea yet, if and how he wants to use the product, he "has to" buy it - a so-called "must-have" product. In this case, the fulfilments of the individual attributes do not play a significant role. The offered as-is profile should, however, not fall below a minimum profile, which is either a generally accepted one or one recognized subjectively by the customer to be sufficient.

4 Conclusion and Outlook

The utilization of attributes to describe both the capability and the behaviour of the product performance provides a much more diverse and multi-objective form of creating and capturing (expected) characteristics and properties of a product as well as evaluating this product in relation to the requirements and the different application environments. The different groups (product attributes, fulfilment attributes, economic attributes) and different views (customer's view with target profile, provider's view with as is profile, overlapping view) allow simple and easy traceable comparisons of the differences between the requirements of customers and the offer of the provider.

Current and future research in IDE is performed on the mapping of requirements to the attributes, on the measurability of fulfilments and on the modelling of interdependencies between the attributes. One of the goals of this effort is to find out the attribute(s) in the as-is profile with which changes of requirements and / or application environments can be realised at the most sustainable and the most efficient means.

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Integrated Design Engineering

A Multidisciplinary and Holistic Approach for Product Development

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Univ. Prof. Dr.-Ing. Dr. h.c. Sándor Vajna
Chair of Information Technologies in Mechanical Engineering
Otto von Guericke University of Magdeburg

OTTO VON GUERICKE UNIVERSITÄT MAGDEBURG
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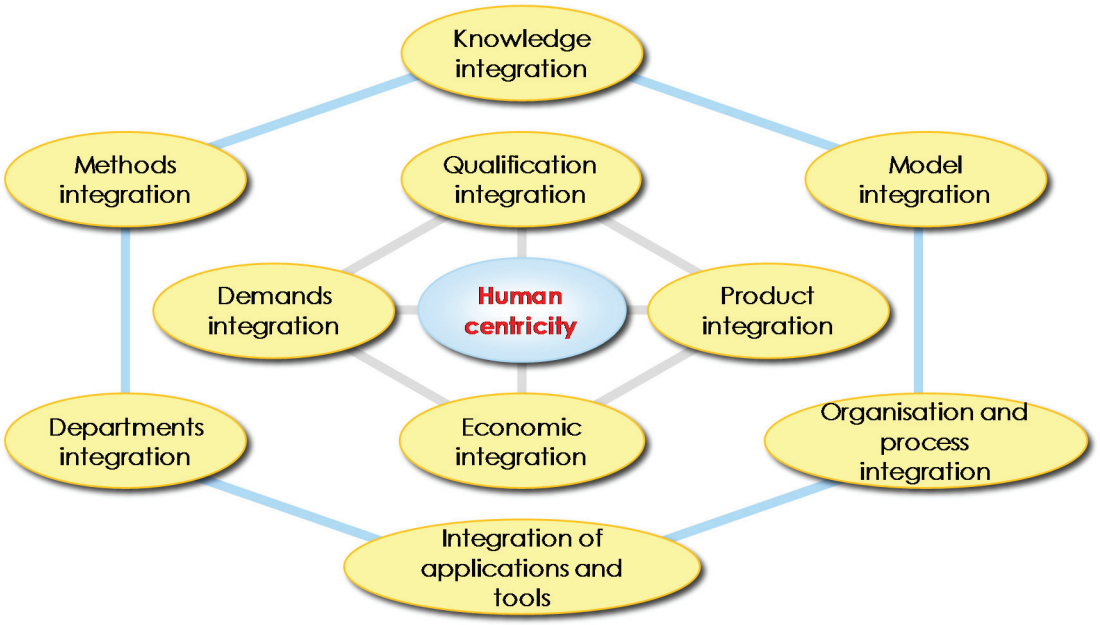
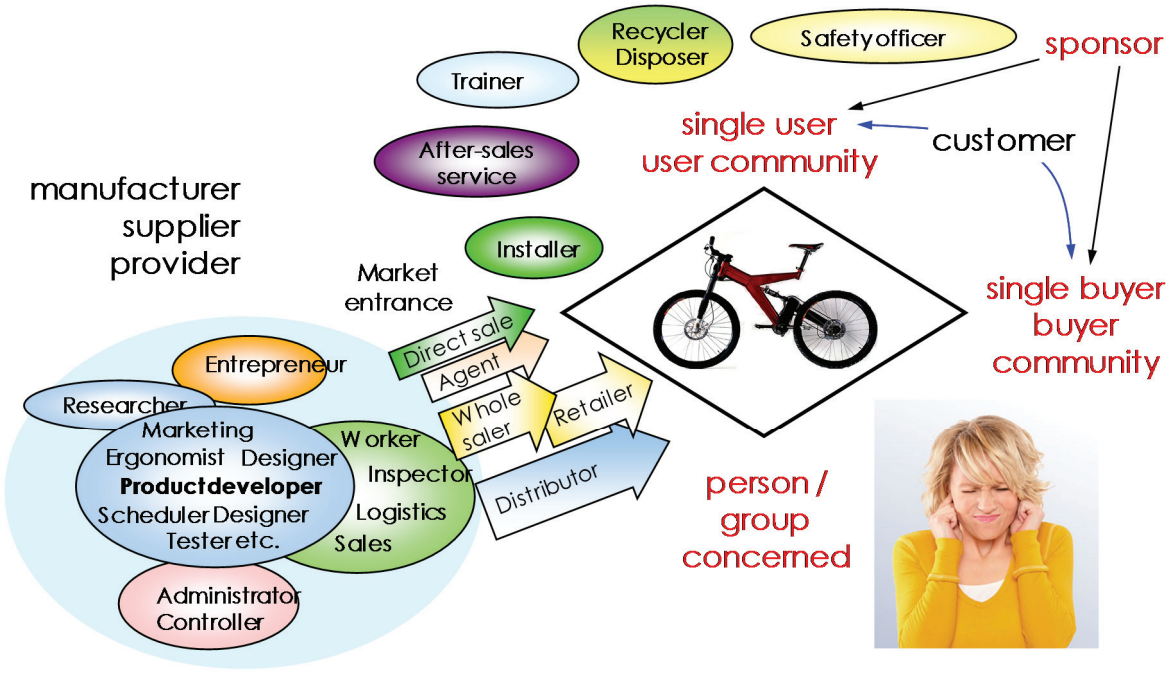
Foundation
Two Circles of Integration



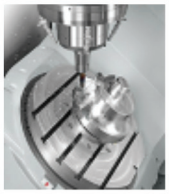
Foundation
Stakeholders and Their Roles in the Context of the Product



The Term „Product“
Definition and Contents (1)

A product is
- a result, achievement of human efforts (artefact)
- owner of its life cyle

It can be
- a physical object
- a non-physical / notional accomplishment:
  - Research result
  - Teaching performance
  - Manufacturing process
  - Care / help
  - (med.) treatment
  - Consultancy
  - Service
- Software



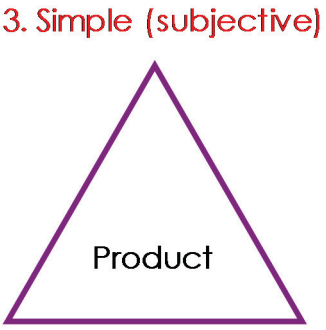
The Term „Product“
Definition and Contents (2)

Combinations of different domains, for example,

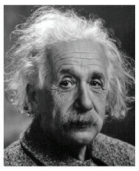
- Mechatronic products
- Product Service System (PSS): Product with related services, for example, Car sharing
- Communication between humans, machines and products via Internet technologies (Industry 4.0)
  - Self-regulating logistical and technological processes, e.g. adjustment of inventories by using RFID monitored and recorded sales movements
  - Cyber Physical Systems: Increasing replacement of physical components by software, e.g. regulation of household appliances via Apps
  - Internet of Things: Products with embedded computing power, as Smart Watches for acquiring, processing, and forwarding of body functions to exercise and control systems

The Term „Product“
Product Content

In respect to usability, behaviour, producibility, maintainability, and sustainability, a product has to be always:

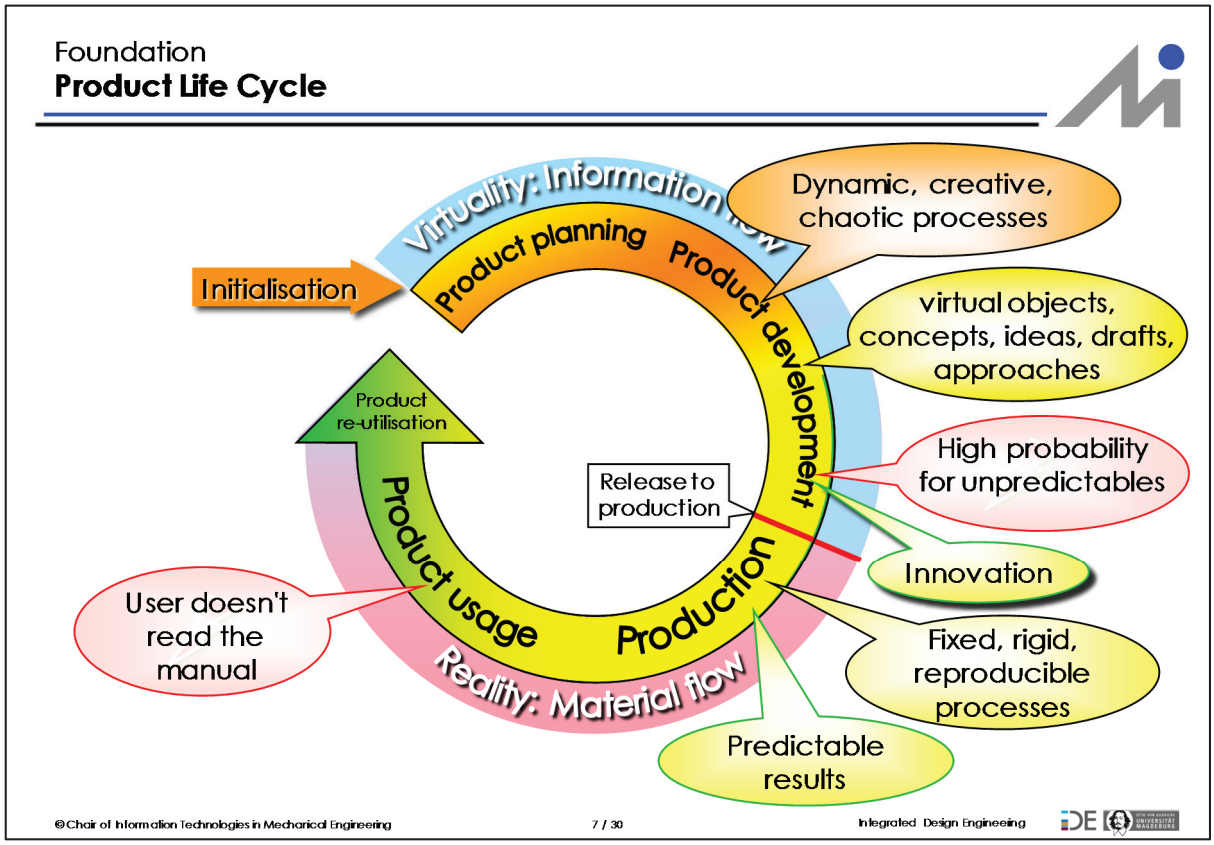


"From complexity via ingenuity to simplicity"
(Antoine de Saint-Exupéry)



"A solution has to be as simple as possible, but not simpler"
(Albert Einstein)

"The ingenuity of a product is based on its simplicity"
(Sergej Koroljov, soviet rocket designer


Foundation
Product Life Cycle
Virtuality: Information flow
Product planning
Product development
Initialisation
Dynamic, creative, chaotic processes
virtual objects, concepts, ideas, drafts, approaches
High probability for unpredictables
Release to production
Innovation
Fixed, rigid, reproducible processes
Predictable results
Production
Reality: Material flow
Product usage
Product re-utilisation
User doesn't read the manual
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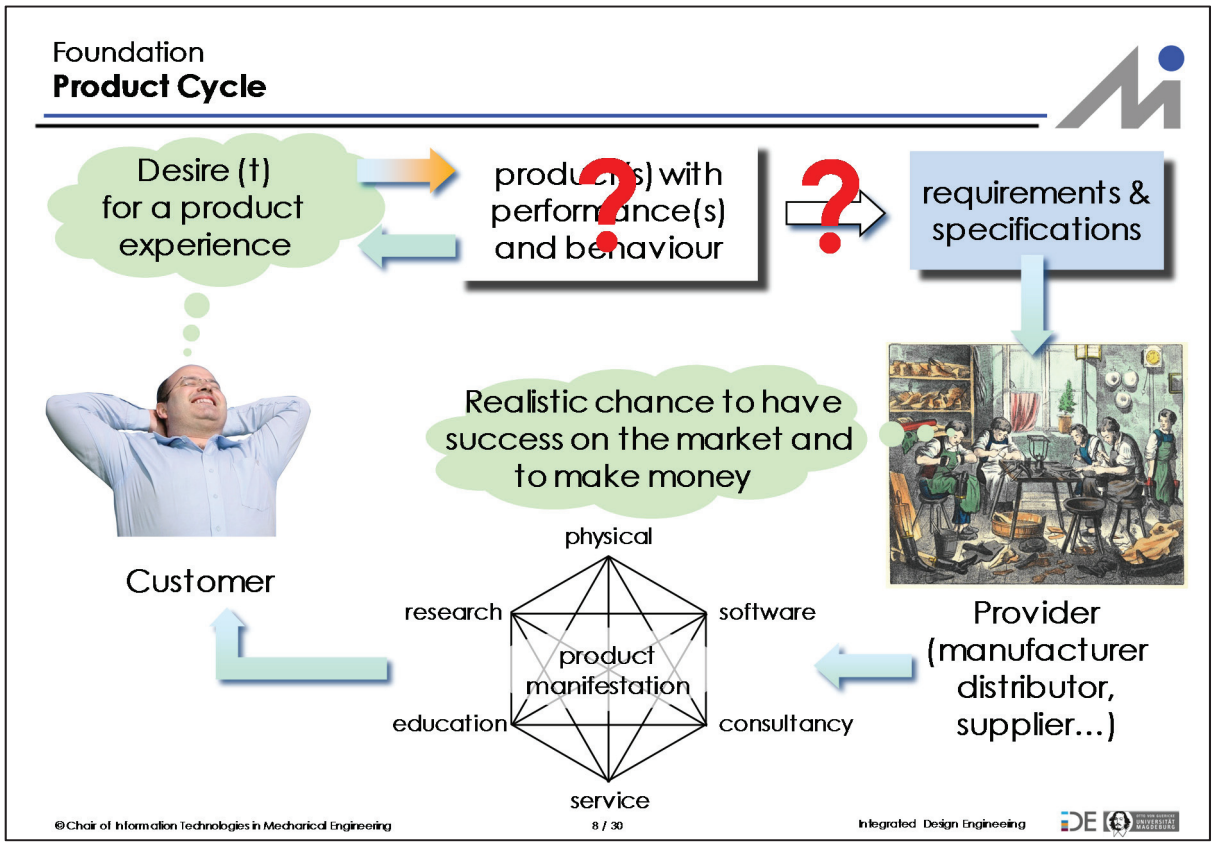
Integrated Design Engineering


Foundation
Product Cycle
Desire (t) for a product experience
product(s) with performance(s) and behaviour
requirements & specifications
Realistic chance to have success on the market and to make money
Customer
Provider (manufacturer distributor, supplier...)
physical
research
software
product manifestation
education
consultancy
service
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Integrated Design Engineering

Foundation
Product Attributes (Customer View)

Desire (t)
for a product
experience

product(s) with
performance(s)
and behaviour

Product appearance
and descriptions promise
- usability
- harmless
- usable at any time
- excellence
- benefits of use

Main Characteristic
- No presettings of realisation strategies and means

Product Attributes (1)
- Product Design
- Functionality
- Handling

Fulfilment Attributes
- Safety
- Reliability
- Quality

Benefit Attributes (1)
- Added Value

Foundation
Product Cycle (Provider View)

requirements &
specifications

Product Attributes (2)
- Producibility
- Availability

Fulfilment Attributes
- Safety
- Reliability
- Quality

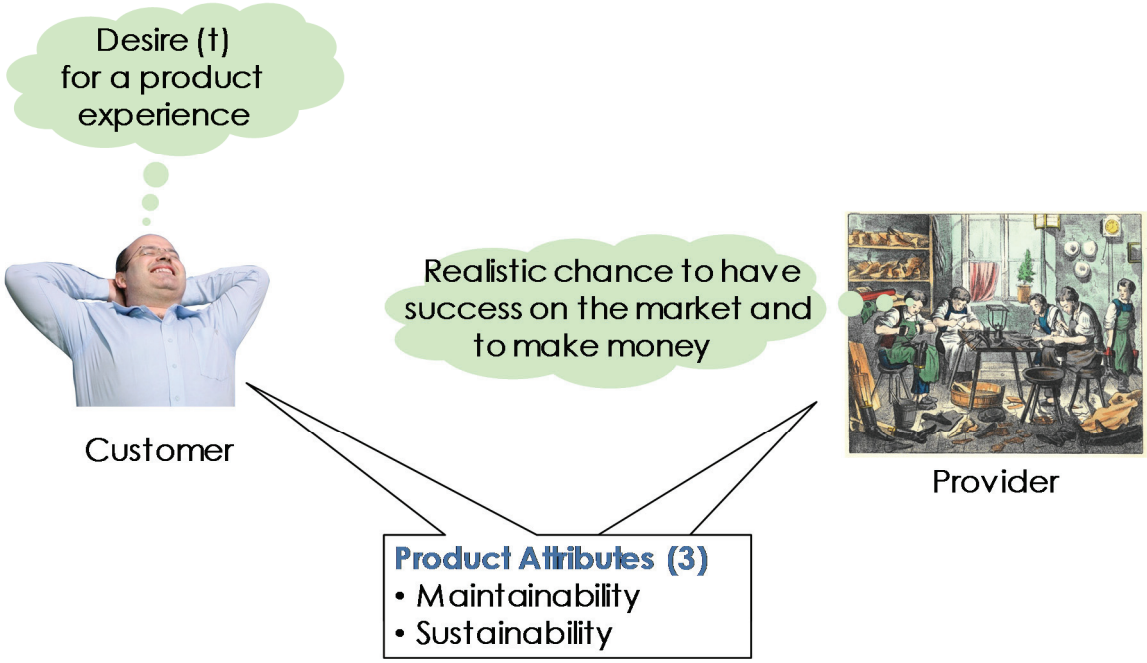
Benefit Attributes (2)
- Profitability

Customer

Provider
(manufacturer
distributor,
supplier...)

manifestation
education
consultancy
service

Foundation
Product Attributes (Common View)



Foundation
Attributes

- Design
- Functionality
- Handling / Usability
- Producibility / Availability
- Maintainability
- Sustainability

Product life cycle

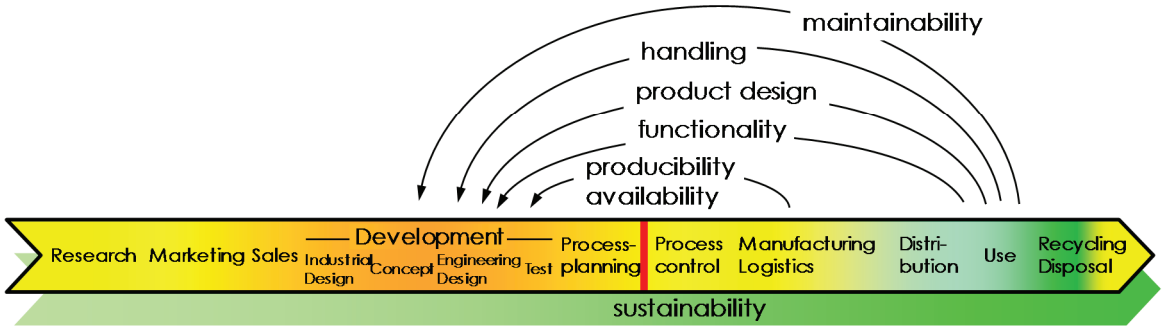
- Safety
- Reliability
- Quality

Type, degree, and excellence of fulfilment of requirements & specifications resulting in product behaviour & performance

- Added value (for the customer)
- Profitability (for the provider)

Material and ideal aspects of a product

Foundation
Product Attributes Origin from the Product Life Cycle



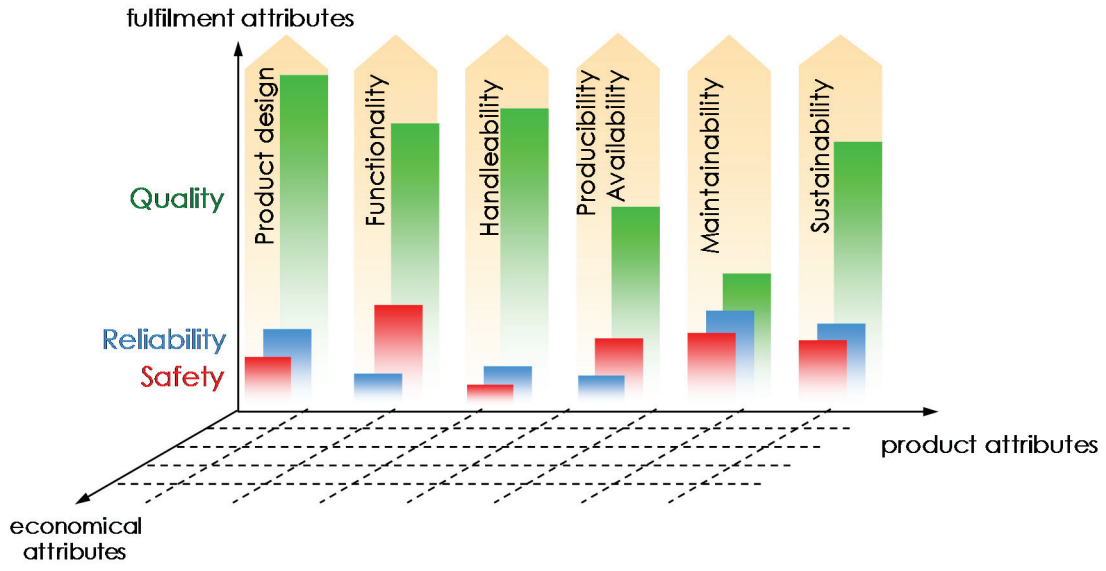
Attributes model
- product performance,
- product behaviour

Attributes don't preset product realisation strategies and means

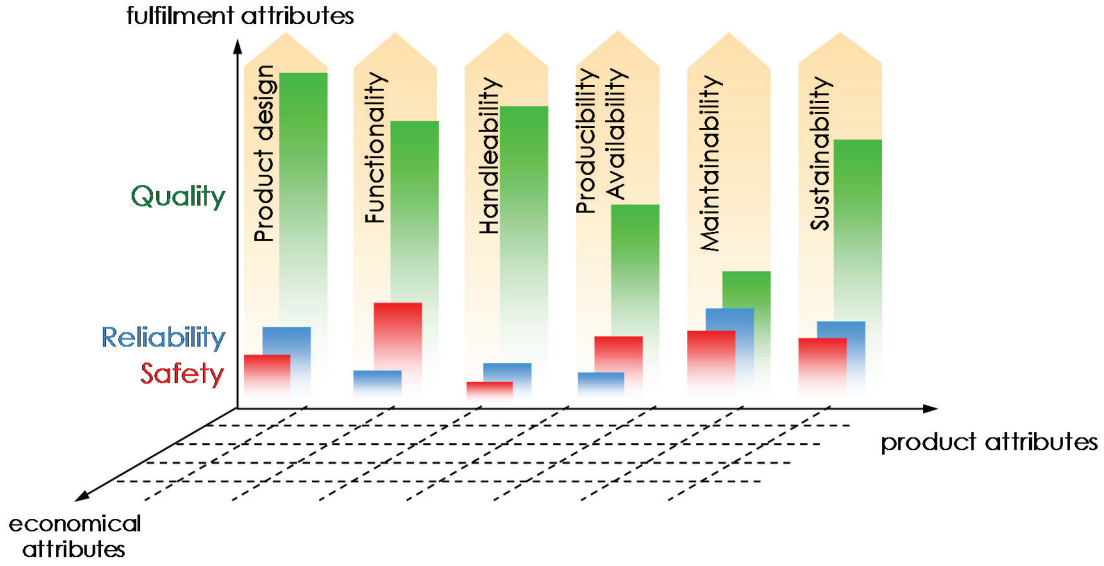
Attributes have in each case
- same meaning,
- same importance, and
- same value for the product

Attributes influence each other

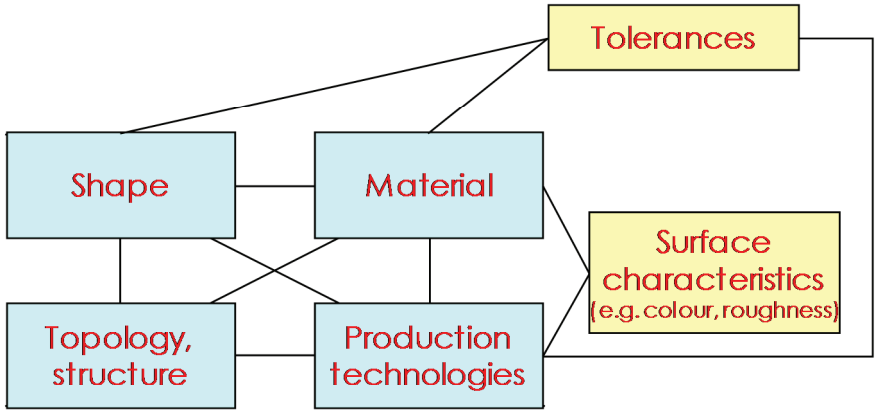
Working with Attributes in IDE
Attribute Groups Interaction



Working with Attributes in IDE
Attribute Groups Interaction



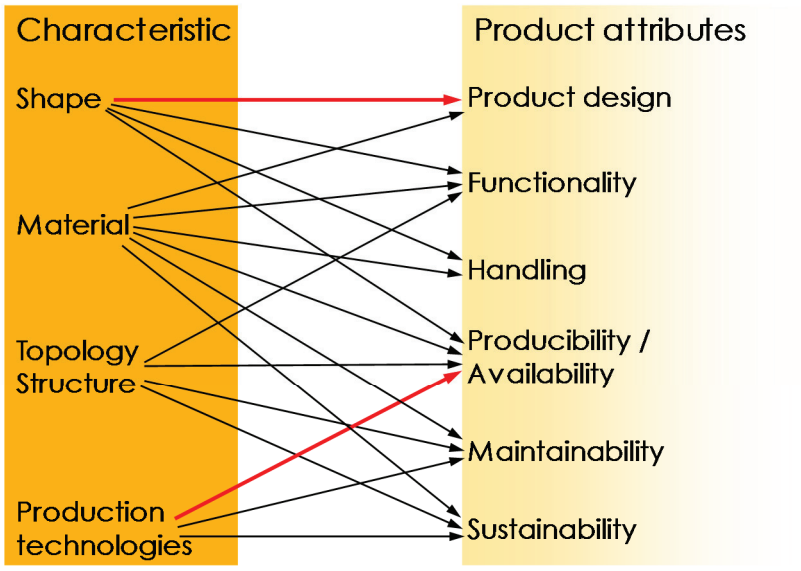
Working with Attributes in IDE
Product Characteristics (can be influenced directly)



yellow boxes: Theory of product characteristics by E. Tjalve (1976)

Working with Attributes in IDE

Relations between Characteristics and Attributes



Working with Attributes

Economical Attribute Added Value (Customer View)

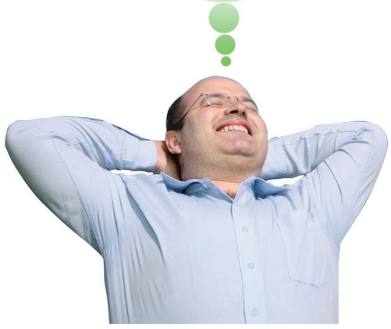
Difference of increased value (financial, ideational) and the expenditures for product procurement, usage, maintenance, and liquidation

Fulfilment of primary needs / given demands

Monetarily rateable benefits

Additional (and partly unexpected) application benefits

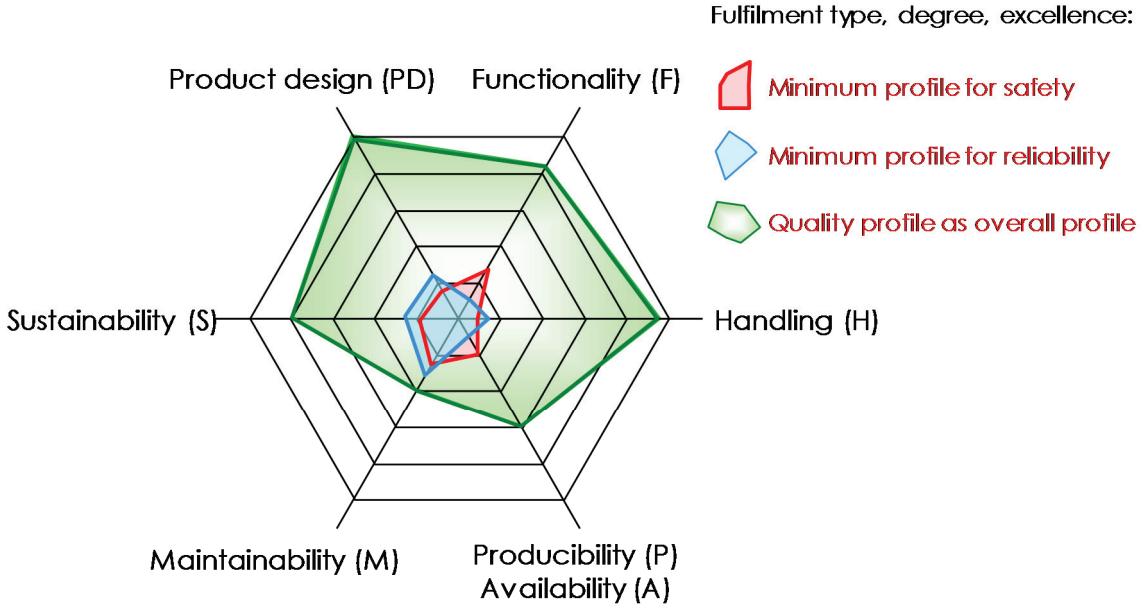
Increased well-being by performance and behaviour of the product



Changes of state:
- Unique feature
- "entrance ticket" into particular circles
- Reaction to public pressure
- Increase of prestige
- Envy factor

Good conscience towards fellow human beings and institutions

Working with Attributes
General Attribute Profile as Spider Diagram



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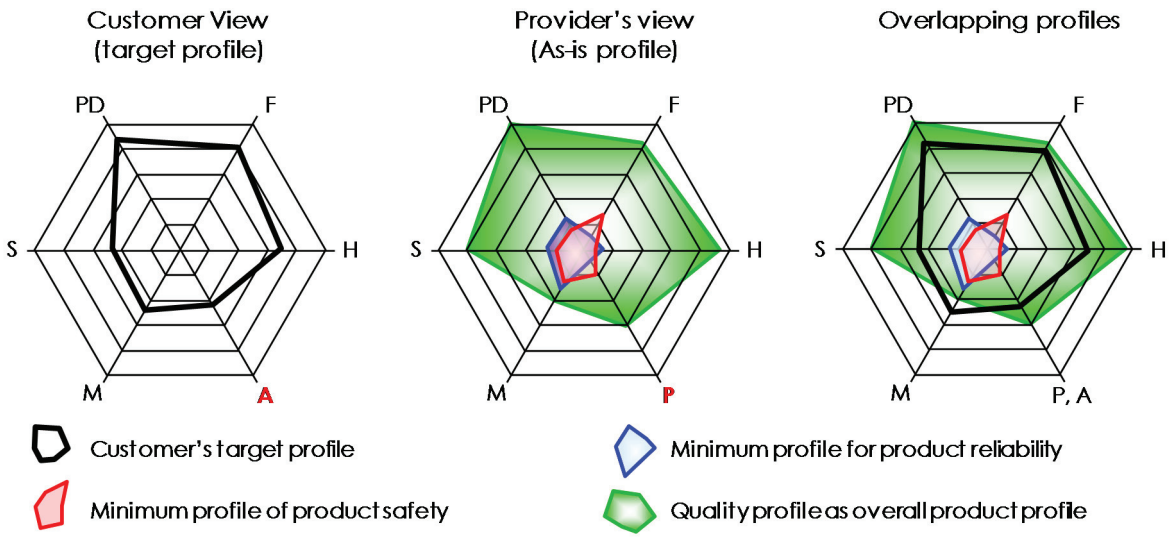
Working with Attributes
Customer View, Provider's View, Overlapping Profiles



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Foundation
Product Cycle

Desire (t) for a product experience

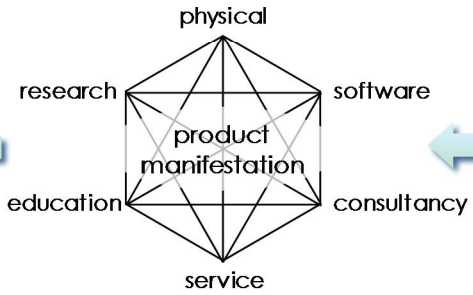
product(s) with performance(s) and behaviour

requirements & specifications

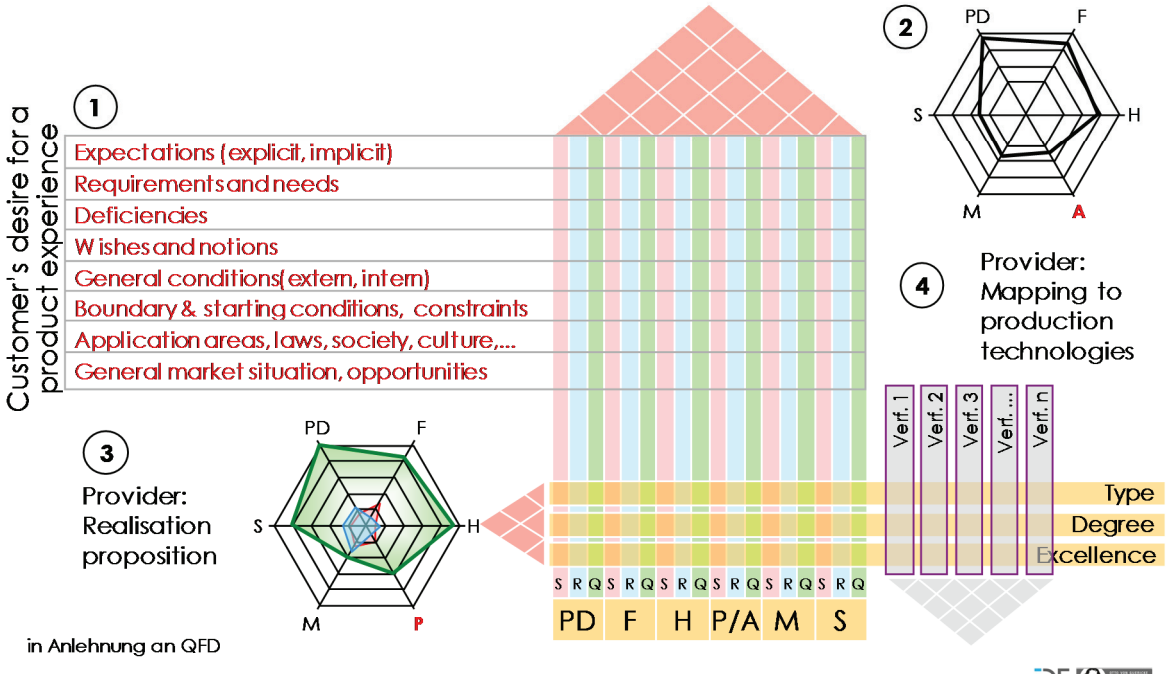
Customer

Realistic chance to have success on the market and to make money

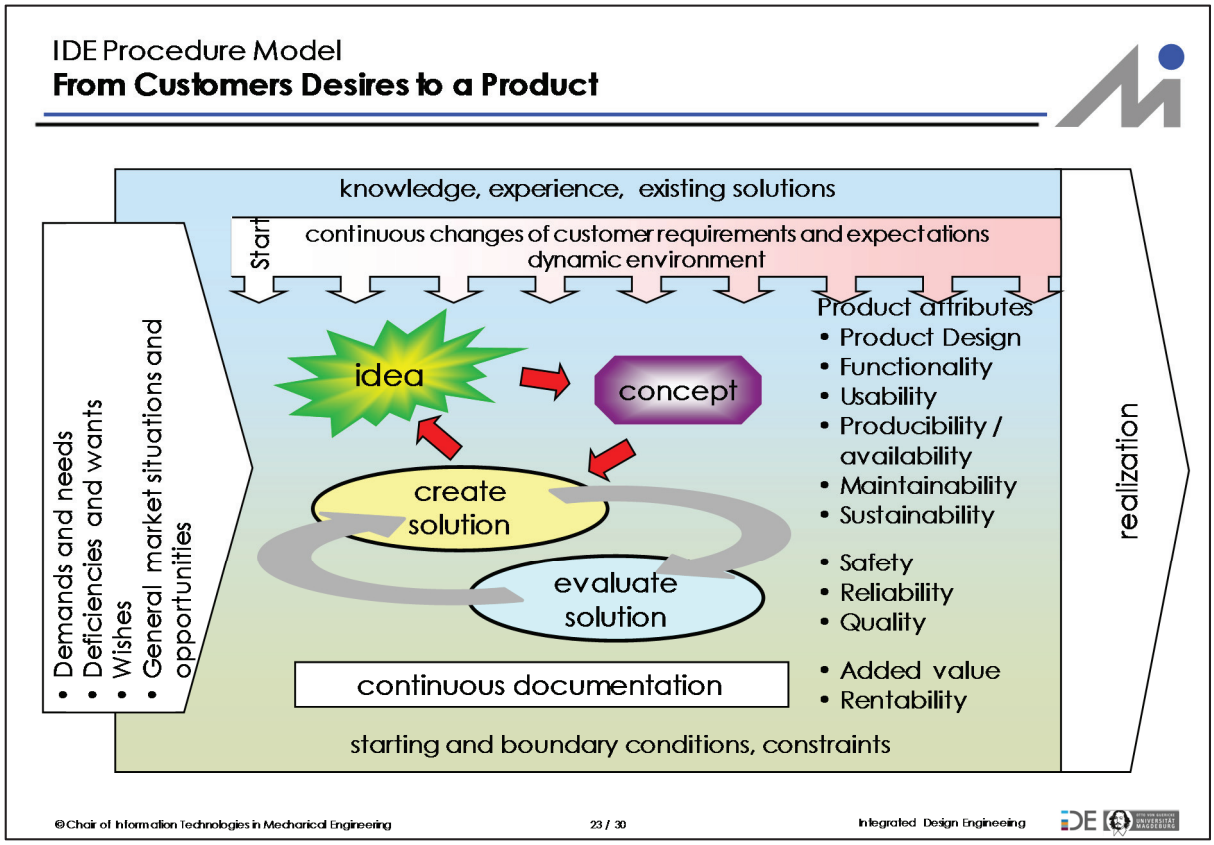
Provider (manufacturer distributor, supplier...)



Working with Attributes
Matching of Attributes and Production Technologies



in Anlehnung an QFD


IDE Procedure Model
From Customers Desires to a Product
knowledge, experience, existing solutions
start
continuous changes of customer requirements and expectations
dynamic environment
Demands and needs
Deficiencies and wants
Wishes
General market situations and opportunities
idea
concept
create solution
evaluate solution
continuous documentation
Product attributes
• Product Design
• Functionality
• Usability
• Producibility / availability
• Maintainability
• Sustainability
• Safety
• Reliability
• Quality
• Added value
• Rentability
starting and boundary conditions, constraints
realization
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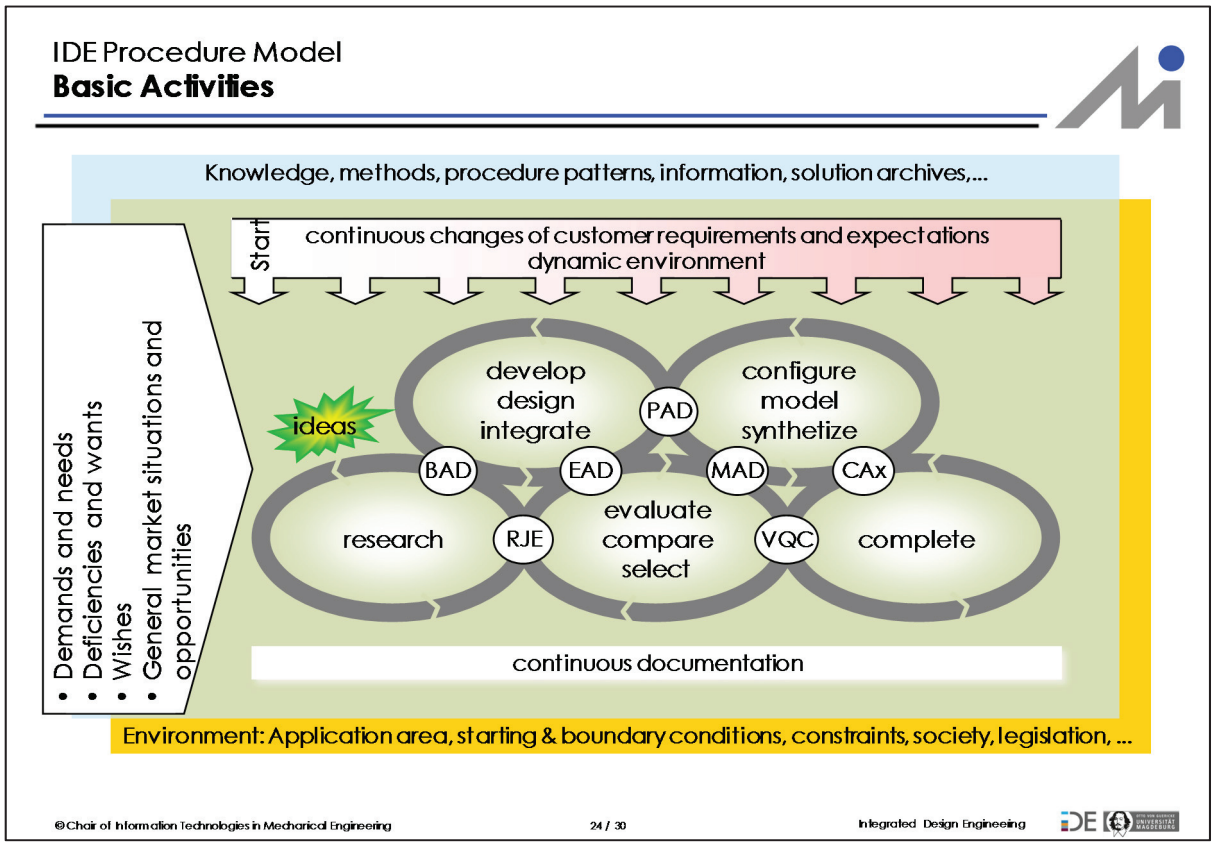
Integrated Design Engineering


IDE Procedure Model
Basic Activities
Knowledge, methods, procedure patterns, information, solution archives,...
start
continuous changes of customer requirements and expectations
dynamic environment
Demands and needs
Deficiencies and wants
Wishes
General market situations and opportunities
ideas
develop design integrate
configure model synthetize
PAD
BAD
EAD
MAD
CAx
research
RJE
evaluate compare select
VQC
complete
continuous documentation
Environment: Application area, starting & boundary conditions, constraints, society, legislation, ...
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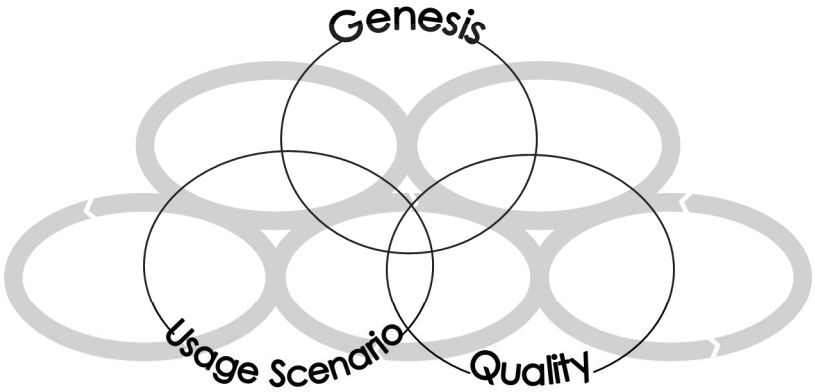
Integrated Design Engineering

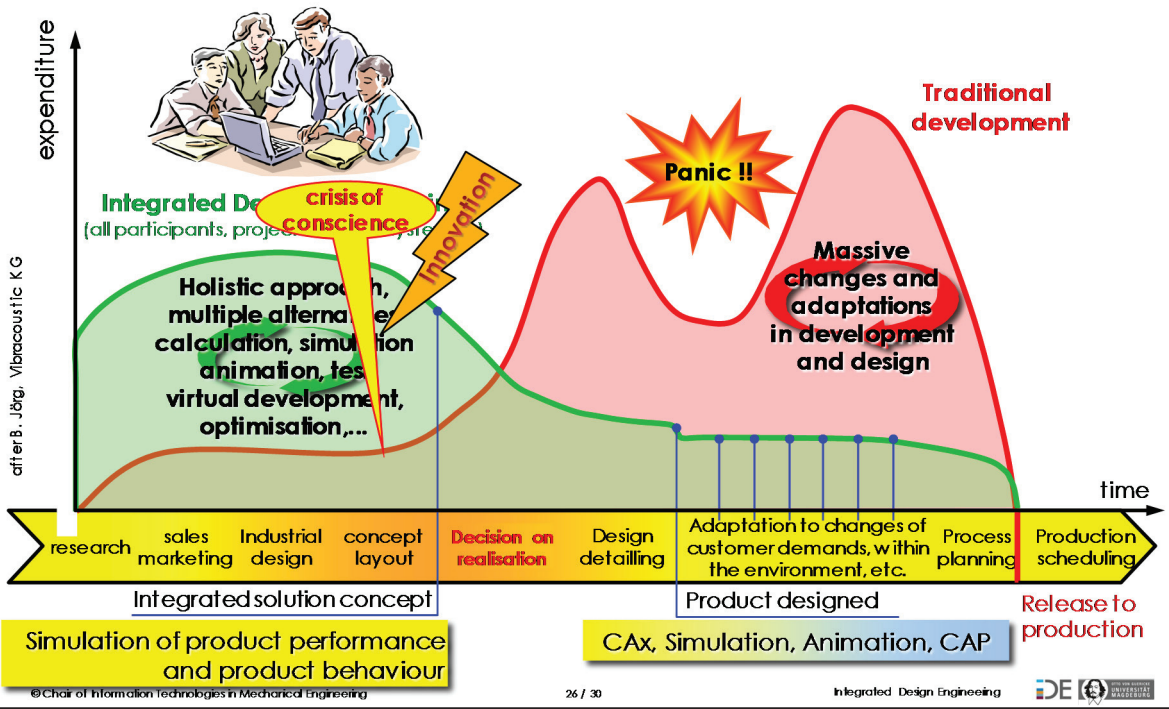
IDE Procedure Model

Usage Scenario, Genesis, Quality

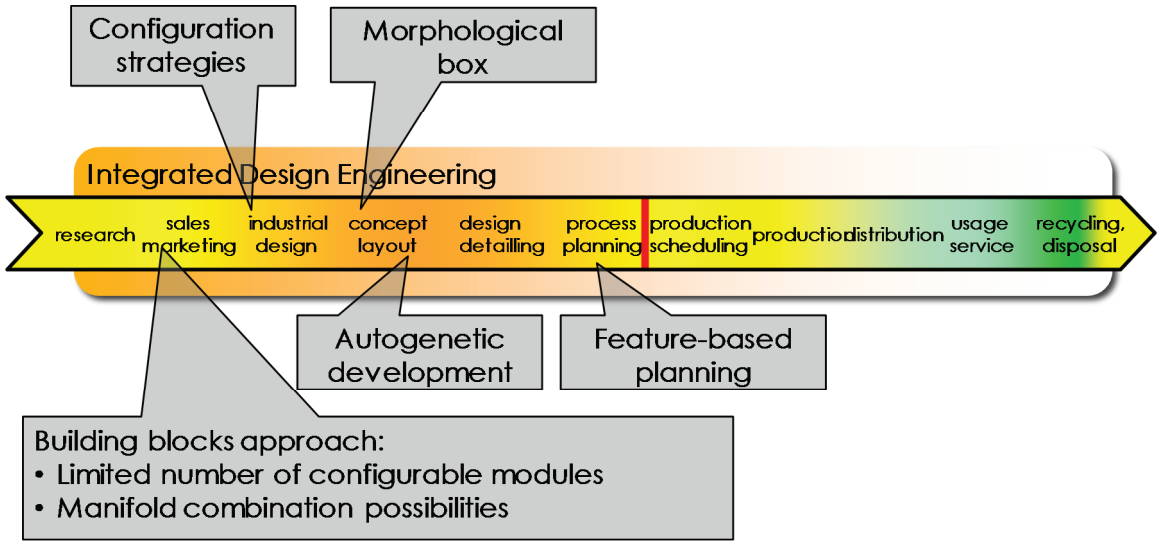


Conclusion

Improved Practices within Integrated Design Engineering



Conclusion
IDE and Further Strategic Approaches



Conclusion
Integrated Design Engineering

- is product life cycle oriented
- is applicable for any kind of products
- defines and describes a product by its performance and its behaviour in a neutral format using different groups of attributes
- integrates all phases of the product life and relocates corresponding decisions forward into product development phases
- takes into account the demands of a sustainable and an economic product development on the basis of the human-centred model of Integrated Product Development (IPD)

The End

Thank you for listening and your patience!

I will be pleased to answer your questions

More Information...

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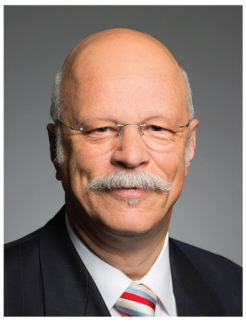

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Possui graduação em Engenharia Mecânica pela Universidade Federal de Santa Catarina - UFSC (1994), mestrado em Engenharia Mecânica pela Universidade Federal de Santa Catarina - UFSC (1995) e doutorado pela UFSC em cooperação com a RWTH-*Aachen* - Alemanha (2001). Desde janeiro de 2004 atua como professor da Divisão de Engenharia Mecânica-Aeronáutica do Instituto Tecnológico de Aeronáutica - ITA. É também Coordenador do Centro de Competência em Manufatura (CCM-ITA). Orienta pesquisas na pós-graduação (doutorado e mestrado) e na graduação, sendo pesquisador bolsista Produtividade em Pesquisa pelo CNPq. Tem experiência industrial e acadêmica na área de Engenharia Mecânica e Produção, atuando principalmente nos seguintes temas: análise de desempenho de processos de fabricação, análise de desempenho organizacional e tecnológico de plantas industriais, auxílio à tomada de decisões industriais, sustentabilidade em processos de fabricação e gestão da inovação. Entre agosto de 2011 e dezembro de 2014 atuou como Gerente Executivo do Departamento Nacional do SENAI para Tecnologia e Inovação. Desde fevereiro de 2015 é também Diretor Regional do SENAI do Estado de Santa Catarina. Consultor Unesco para o grupo de trabalho sobre Manufatura Avançada – MDIC / MCTI / CNI / ANPEI.

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Manufatura Avançada Verde e Amarela

Resumo

Este artigo e palestra apresenta uma inflexão sobre os impactos da Indústria Avançada sobre recursos humanos, combinação tecnológica, desenvolvimento de cadeia suprimentos, aspectos de regulação e infraestrutura necessária. A Manufatura Avançada Verde e Amarela utiliza de tecnologias avançadas para gerar vantagem competitiva. Os principais fabricantes do século 21 têm convergido totalmente os mundos digital e físico (sistemas ciber-físicos) em que se espera um hardware avançado combinado com um software avançado, sensoreamento, grandes quantidades de dados (big data), robótica colaborativa, manufatura híbrida e análises que resultem em produtos mais inteligentes (inteligência artificial), além de processos, clientes, cadeia de suprimentos, infraestrutura e regulação mais estreitamente conectados. A análise preditiva, a Internet of Things (Internet das coisas), os produtos inteligentes e fábricas inteligentes via Indústria 4.0, bem como o desenvolvimento e uso de materiais avançados serão fundamentais para a competitividade futura. Somado a todos estes fatores o talento (recursos humanos) é considerado o motor da competitividade.

Palavras - Chave

Manufatura Avançada Verde Amarela; Ciber-físicos; Cadeia de Suprimentos; Infraestrutura e Regulação; Recursos Humanos.

Dipl.-Inf. Rainer Glatz

Rainer Glatz was born in 1955 and studied at the University Karlsruhe, Germany, where he received his Diploma of Informatics in 1980. From 1981 to 1986 he worked as a scientific assistant in the "Institute for applied Computer Science in Mechanical Engineering" at the University Karlsruhe. In 1987 he moved to the "*Verband Deutscher Maschinen- und Anlagen e.V.* (VDMA)" in Frankfurt, Germany. Since 1990 he is Head Manager of Department of Informatics. Within VDMA he founded in 1999 the Software Association, in 2000 the Electrical Automation Association and in 2010 the Working Group Product and Know-how Protection. He is leading these groups as Managing Director. Between 2013 and 2015 he was also Leader of the project office *Plattform Industrie 4.0*.

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VDMA (*Verband Deutscher Maschinen- und Anlagenbau - Mechanical Engineering Industry Association*)

VDMA represents over 3,100 mostly medium-sized companies in the capital goods industry, making it the largest industry association in Europe. The association represents the shared financial, technical and scientific interests of the mechanical engineering industry, especially with respect to national and international authorities and business groups. For the purposes of safeguarding of their interests, members are entitled to instruction, advice and assistance. VDMA is divided into 37 trade associations and labour groups, cross-sector departments, branch offices in Berlin and Brussels, liaison offices in Brazil, China, India, Japan and Russia, international committees and forums, six state associations and several service organisations.

Development and Practice of *Industrie 4.0* in German Industry

Abstract

Industrie 4.0 is currently a hype topic not only in Germany, but also all over the World. The goal is the integration of the real world of production with the virtual world of IT to realize smart products and smart production. Research institutes, consultancies, vendors and politics announce the great perspective and possibilities of Industrie 4.0. Current surveys claim that more and more companies are on the way to digital transformation. The big challenge for the industry is however, how to develop, implement and test these new products, systems and/or business models in real practice. On one hand, worldwide efforts have been established to solve basis questions in the area of standardization, security, education and working environment. On the other hand, initiatives have been started to show practical experience via testbeds, pilot implementations or adapted use cases. VDMA concentrates the efforts to the support of small and medium sized companies. Concrete examples are two very successful practical guidelines or so-called "Lab-Tours" to universities. Besides the growing number of supporting activities – each company has to find his own way to Industrie 4.0.

Keyword

Industrie 4.0; Revolution; Platform; Germany; Smart Factories; Industry; High-Tech-Strategy; Guidelines; Readiness; Implementation; Standardization; Security; SME; Association; VDMA.

1 Introduction

The German economy is more focused on research, development and manufacturing of production technologies than any other. In this context, mechanical and plant engineering with turnover of EUR 218 billion and more than one million people employed, is of particular importance for the economy as an integrator and enabler. With 7.3 million directly employed and a trade surplus of more than EUR 100 billion, the production industry forms the backbone of the German economy. While there was a recognizable trend of deindustrialization in most of the classic industrialized countries, Germany continues to put its faith in the country's industrial production strength and innovative production technologies. This enabled Germany to successful maintain the number of people employed in the production industry for the most part and assert its leading role as the “factory outfitter of the world”. The German model of success is now being used by other countries, be it in counteracting their own deindustrialization or in making up for technology deficits.

The German plant engineering sector is currently a driver of innovations in production technology and equipment. However, mechanical engineering and the associated partner sectors (suppliers and buyers) are always under a great deal of pressure. Due to the appearance of new competitors from South-East Asia, global competition has risen sharply in the meantime. The industry will have to produce increasingly individualized and more efficient products for the same prices in the future, in order to meet the changing demands of the market. In addition to these economic and social challenges, German industrial production also faces a technical milestone. A fourth industrial revolution is looming, launched by the Internet of Things and services. Germany recognized this challenge early on and created a now internationally recognized example under the label “*Industrie 4.0*”.

2 *Industrie 4.0* as part of the German High-Tech Strategy 2020

Industrie 4.0 was first mentioned in 2011 as one of ten future-oriented projects within the German federal government's High-Tech Strategy 2020 (Figure 1). The future-oriented project *Industrie 4.0* addressed the evolutionary technological transition of modern technologies in information technology merging with classic industrial processes to Smart Factories and their revolutionary effects on the industry. The German federal government took advantage of the rapid social and technological development in this area and prepared the structures for the cooperation of all players in innovations in Germany.

The working group *Industrie 4.0* appointed by the “*Forschungsunion Wirtschaft – Wissenschaft*” (Economic research union – science) of BMBF (the Federal Ministry of Education and Research) highlighted the conditions for successfully starting the fourth industrial age. It became clear very quickly that the path to *Industrie 4.0* in Germany would

require some effort in research and development and that the following characteristics of *Industrie 4.0* are to be kept in mind:

- Horizontal Integration through value networks;
- End-to-end engineering across the entire value chain;
- Vertical integration and networked manufacturing systems.

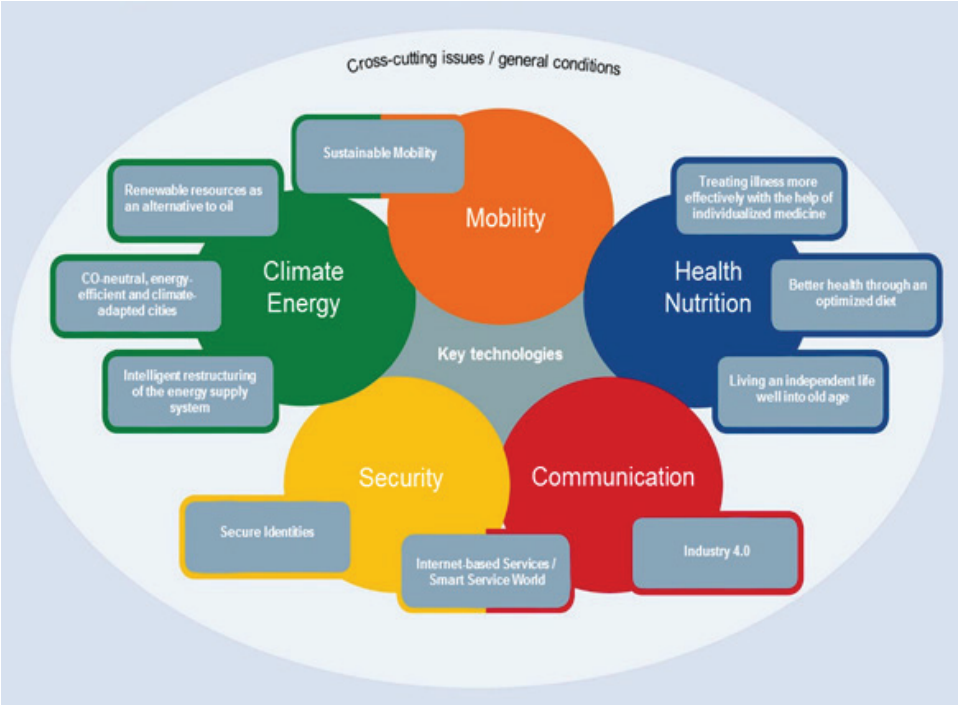

Figure 1: High-Tech-Strategie: Forward-looking projects and fields of action

In April 2013, the working group submitted its final report with the title “Recommendations for implementing the strategic initiative *INDUSTRIE 4.0*” [1]. The federal government first provided around EUR 200 million for research projects. The many projects, some still ongoing, are important for focusing the picture of *Industrie 4.0* and driving prototypical implementations forward.

3 Interdisciplinary platforms for *Industrie 4.0*

3.1 The technological association *Plattform Industrie 4.0*

Discussions in the working groups at Acatech (National Academy for Science and Engineering) make it clear that *Industrie 4.0* is more than just a pure research initiative. Together, the BITKOM (Federal Association for Information Technology, Telecommunications and New Media), ZVEI (Central Association of Electrical Engineering and Electronics Industry) and VDMA (Mechanical Engineering Industry Association) established the joint Association

Plattform Industrie 4.0 for driving and developing the *Industrie 4.0* project and ensuring a coordinated approach across sectors. The main goal of the platform was to drive the vision of *Industrie 4.0* towards the industry and create the proper conditions for the economic implementation of *Industrie 4.0.*

Renowned industrial companies and stakeholders in the *Industrie 4.0* environment took over the strategic and thematic management of the platform. The following working groups were set up for the professional discussion of important problem areas:

- Strategy & Framework;
- Standardization;
- Research;
- Security.

The strategic and professional work was additionally accompanied by a scientific advisory board.

The complexity of the topics and the necessary interdisciplinary cooperation proved to be difficult at first and was sometimes characterized by losses of efficiency. Despite this, it was possible to achieve important results (Figure 2):

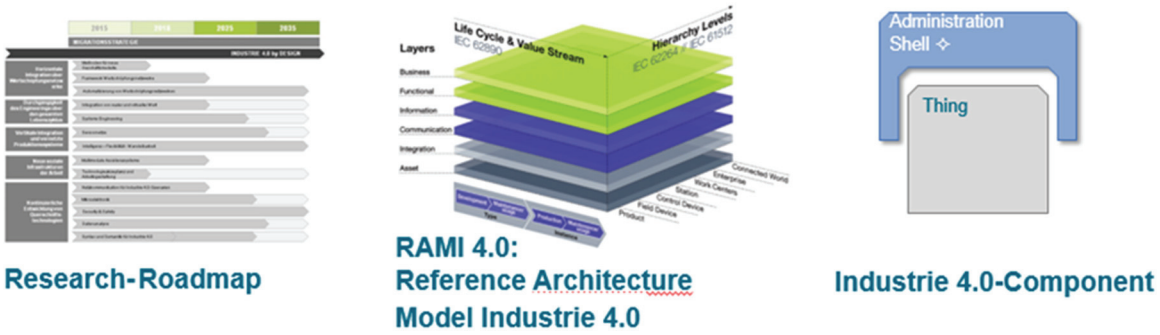

Figure 2: Results of the Association Plattform Industrie 4.0

- Research roadmap: 14 different research topics were identified by the Research working group (until 2035) and described in fact sheets. Milestones and dependencies of topics are presented in the fact sheets. The roadmap shows research topics with their time classification. It provides solid orientation for further developing the topics of *Industrie 4.0* using suitable measures and funding instruments via policy and companies;
- Reference architectural model *Industrie 4.0* (RAMI 4.0): RAMI 4.0 is a framework where the existing standards can be found, which allows the need for expansion or processing to be ascertained. The objective is to provide a clear structure for the complex environment of *Industrie 4.0*, thus fostering targeted discussion;

- *Industrie 4.0* component: The *Industrie 4.0* component connects "objects" (physical objects) with one another. The respective physical object is supplemented by an administration shell (a virtual representation) to connect it to the virtual world.

The platform published the findings and results it compiled in April 2015 with the title "Implementation Strategy *Industrie 4.0*: Report on the results of the *Industrie 4.0* Platform" [2].

Together, the three associations represent more than 6,000 industrial member companies. Correspondingly, there was another important task here: informing their members and the general public about *Industrie 4.0*. A high level of awareness about Industrie 4.0 was attained amongst members through internal workshops, public conferences and trade fairs. Additionally, a wave of further events, studies and publications was kicked off, where *Industrie 4.0* really experience a hype – and not just in Germany but worldwide.

3.2 The political *Plattform Industrie 4.0*

A purely technological discussion isn't enough for implementing *Industrie 4.0* strategically and comprehensively. Economic and socio-political issues also need to be discussed and clarified. This requires discourse and the approval of further industrial sectors and associations, unions, policy makers and workforces in companies. Based on the preparatory work of the association platform, an expanded, politically-oriented *Plattform Industrie 4.0* was thus established in April 2015.

Germany's Federal Minister for Economic Affairs, Sigmar Gabriel and the Federal Minister for Research Prof. Johanna Wanka jointly manage and head the platform with top-class representation from the economy, science and unions. Experts from companies, science, associations and unions develop operative solutions together with representatives from different federal ministries in the thematically expanded working groups (Figure 3).

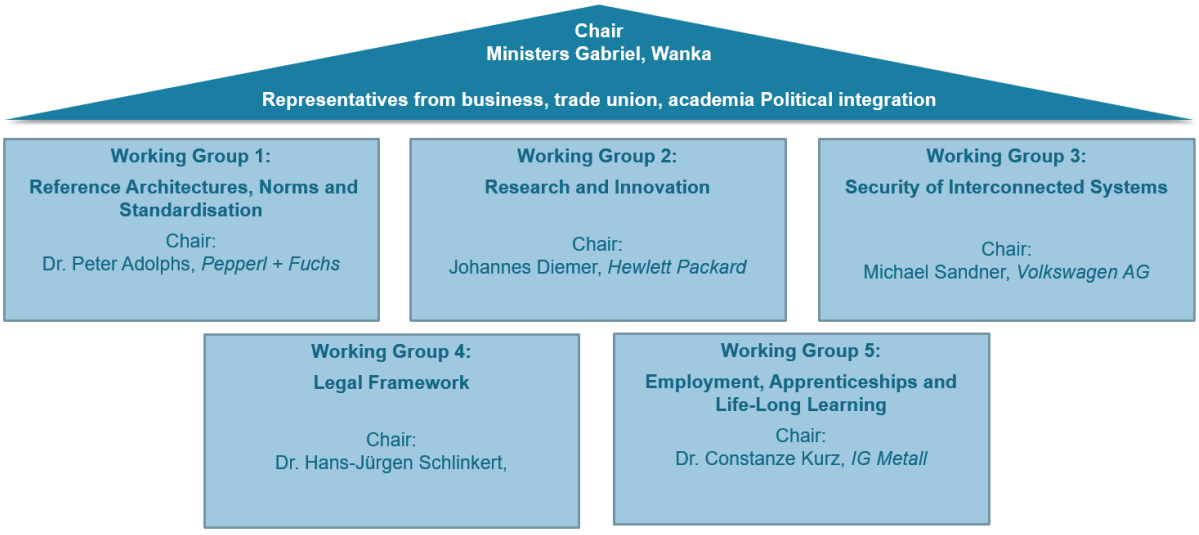

Figure 3: The working groups of the Plattform Industrie 4.0

The new platform also wants to develop joint recommendations for action for all players, which are to be the basis for harmonized and reliable conditions. It wants to initiate alliances and networks at a pre-competitive level, which are to support the entrepreneurial competence and energy already found in Germany. The platform aspires to identify all relevant trends and developments in the field of the production industry and to bring about a harmonized global understanding of *Industrie 4.0*.

Detailed information and news about the platform can be found on the website www.plattform-I40.de.

3.3 International platforms

Industrie 4.0 is not relevant to Germany alone. Though the title *Industrie 4.0* is German, the ideas can also be found in platforms and initiatives such as “Advanced Manufacturing”, “Industrial Internet” or “Made in China 2025” (Figure 4). Even if these initiatives are in competition globally, there are increasing efforts to cooperate more closely with one another and to coordinate in fundamental questions, such as standardization and security. This led the *Plattform Industrie 4.0* and the Industrial Internet Consortium (IIC) to agreeing on closer cooperation at the beginning of the year. The cooperation comprises future interoperability of the systems and the use of joint testing environments. There are further cooperations with China and within Europe.

Figure 4: Industrie 4.0 in international competition

An overview from the European Commission (EU) found 17 national initiatives in Europe alone with four at the EU level. The EU Commission understands *Industrie 4.0* as more than just a chance to produce high-value products but also as an opportunity to support environmentally-friendly and socially sustainable production. Thus, new technologies should help in developing

economically and ecologically sustainable value chains, especially with competitive companies in Europe. The long-term goal is to achieve a “Digital Single Market” in Europe – even for *Industrie 4.0*.

4 Implementing *Industrie 4.0* in the industry

Right now, *Industrie 4.0* is discussed everywhere in politics, the media, science and the economy. More intelligent, more personalized, more efficient, faster, more connected – these are just a few of the new industrial age's promises, for both vendors and users of technologies having to do with *Industrie 4.0*.

4.1 The potential of *Industrie 4.0*

Based on a study carried out by Fraunhofer IAO and Bitkom [3], growth possibilities to the amount of around EUR 78 billion could be achieved by 2025 in six economy-relevant sectors with *Industrie 4.0* (Figure 5). An average of 1.7 percent per year and sector could be targeted in addition for gross added value. The main beneficiaries are the ITC sector and mechanical and plant engineering.

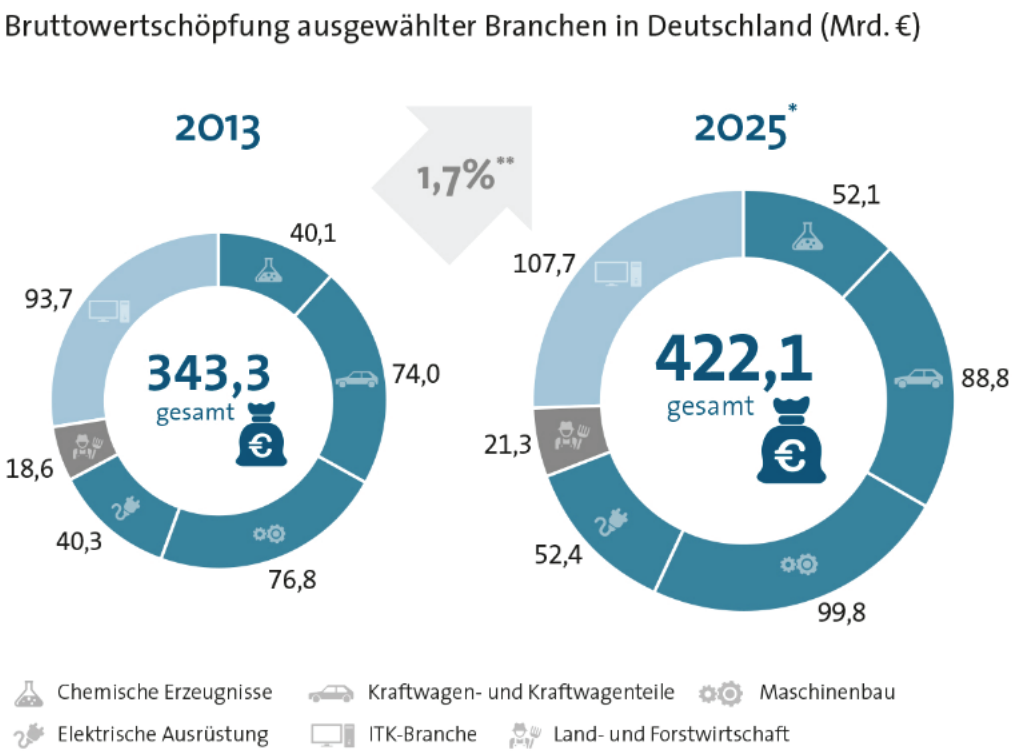

Figure 5: Growth possibilities with Industrie 4.0

A study supported by the VDMA and carried out by PricewaterhouseCoopers (PwC) found that 235 surveyed industrial companies want to invest an average of 3.3 percent of their annual turnover into *Industrie 4.0* solutions by 2020, so approx. EUR 8.5 million per year. This

corresponds to just under half of the planned new equipment investments. Other studies also paint a predominantly positive picture of *Industrie 4.0*.

4.2 *Industrie 4.0* readiness

Despite the potential and positive projections, it is not clear where companies really stand and how far along they are in implementing *Industrie 4.0*. The readiness study conducted by the "VDMA Impuls Foundation" addressed these and other questions and came to the following core messages:

- Nine out of ten mechanical engineering companies see significant opportunities in differentiating themselves on the market through connected production (*Industrie 4.0*);
- Many companies have already taken successful steps on the path to *Industrie 4.0*;
- Nearly 60 percent of mechanical engineering companies are involved in *Industrie 4.0*, around a third of them intensively – about twice as many as in the entire processing industry.

The study was based on a "readiness model" with six significant dimensions of *Industrie 4.0*:

- Strategy and organization;
- Smart factory;
- Smart operations;
- Smart products;
- Data-driven services and;
- Employees.

These allow companies to be classified as "newcomers", "learners" or "leaders". According to the study, nearly six percent of mechanical and plant engineering companies can be classified as "*Industrie 4.0* leaders", while as many as 18 percent have already taken some initial systematic measures and are thus considered "learners".

The readiness model of the study was validated and analyzed by means of a representative survey conducted among German companies in the mechanical and plant engineering sector. It also serves as a basis for an online self-assessment which companies in the mechanical and plant engineering sector can carry out on their own terms.

An interesting result of the study was that the companies assess the basic challenges of *Industrie 4.0* differently based on the maturity level (Figure 6). While the leaders are convinced of the economic benefit, the beginners and advanced companies are not aware that significant financial resources are needed in order to implement *Industrie 4.0*.

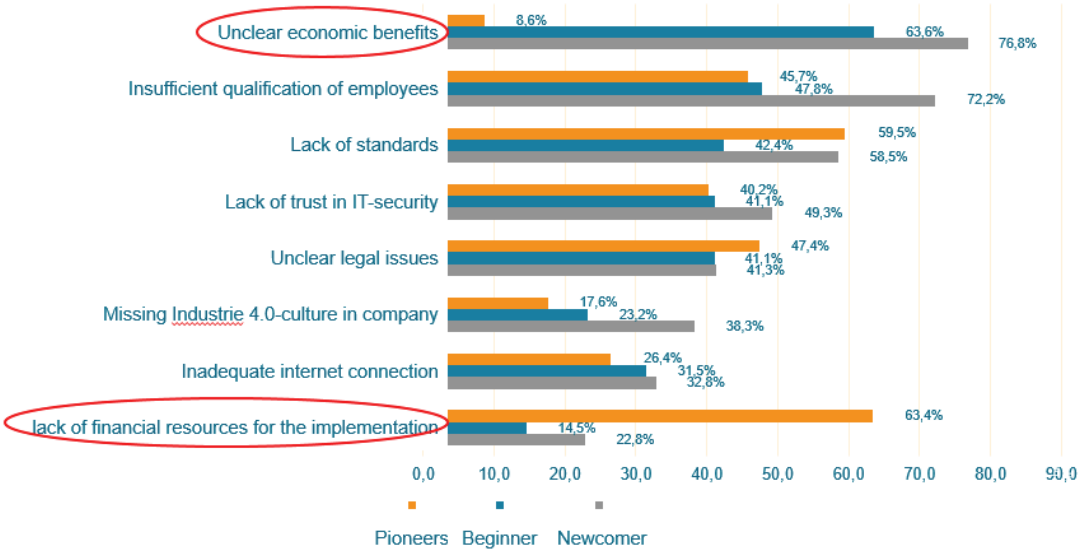

Figure 6: Challenges depend on the degree of maturity

4.3 Virtual Map *Industrie 4.0*

Federal Minister Sigmar Gabriel isn't the only one who sees Germany as the current leader in the implementation of *Industrie 4.0*. The many diverse application examples and testing environments on the online map of the *Plattform Industrie 4.0* demonstrate as much. The map shows practical examples of where *Industrie 4.0* is already being used in Germany with a “pin” for each example (Figure 7). It is encouraging that 28% of the application examples already come from SMEs.

Figure 7: Virtual Map Industrie 4.0

The number of application examples and the testing environments or consulting services listed is constantly growing. You can discover interesting information at the click of a mouse (http://www.plattform-i40.de/I40/Navigation/Karte/SiteGlobals/Forms/Formulare/karte-anwendungsbeispiele-formular.html). The search is made easier with filter functions.

In addition to this map, there are numerous other activities of the *Plattform Industrie 4.0*, which especially strive for the goal of inspiring SMEs for *Industrie 4.0*.

5 VDMA's activities

VDMA has been involved in the discussions about *Industrie 4.0* right from the beginning and brought the particular requirements and constraints of medium-sized German mechanical and plant engineering companies to the table. Additionally, VDMA headed the project office of the Association *Plattform Industrie 4.0* from 2012 to 2015. VDMA is represented in all relevant committees on *Industrie 4.0* to this day.

In order to ensure the direct support of the many SME member companies, VDMA established the "VDMA Forum *Industrie 4.0*" in 2015. Six key topics are addressed in this forum (Figure 8).

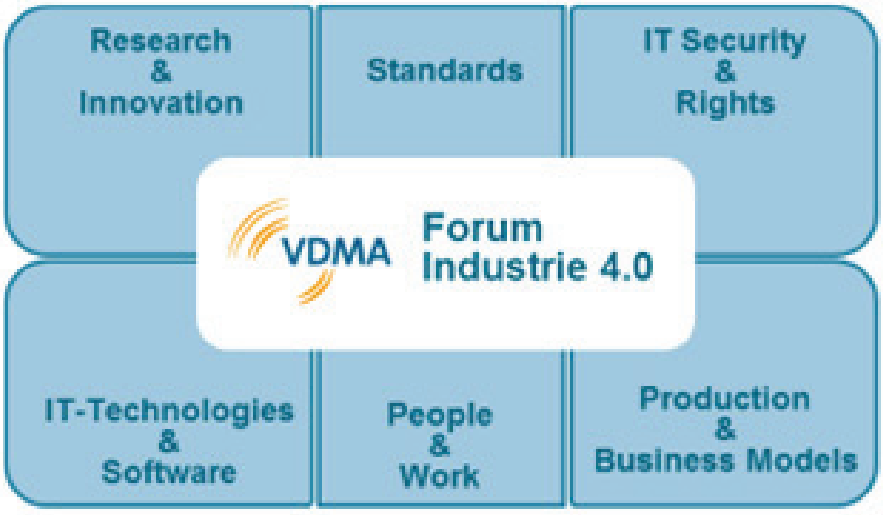

Figure 8: VDMA-Forum Industrie 4.0 - Spheres of action

Even the VDMA Forum has its own *Industrie 4.0* map. In this case, it refers to contact points for the "Lab Tour I40". Supporting mechanical engineering SMEs in implementing the topic of *Industrie 4.0* is taken into account with Lab Tours I40. SMEs can experience the cream of the crop first hand in demonstrations at universities and research institutes. The number of lab tours will grow to a total of 15 with nearly 500 participants by the end of 2016.

Another important activity of the forum is the development and publication of practical support, such as studies, guidelines and information material. In the meantime, there are already 10 publications available to VDMA members, some of which are publicly available for download or are available in English (industrie40.vdma.org/article/-/articleview/13933597).

The VDMA *Industrie 4.0* guideline is especially popular, since it managed to present the complex topic of Industrie I40 clearly and comprehensibly. The guideline is intended as support for German mechanical and plant engineering SMEs for the fast implementation of business

models for *Industrie 4.0*. It provides a procedural model which addresses the visions of *Industrie 4.0* and breaks them down into realistic development stages. Applying these development stages helps a company with brainstorming new business models, innovative products and improved production.

The conceptual design of business models is carried out in company-internal workshop. The guideline presents the structure and procedure of such a workshop. As such, the guideline offers orientation for SMEs in finding their own definition of *Industrie 4.0*, understanding the benefit for their company and estimating the costs.

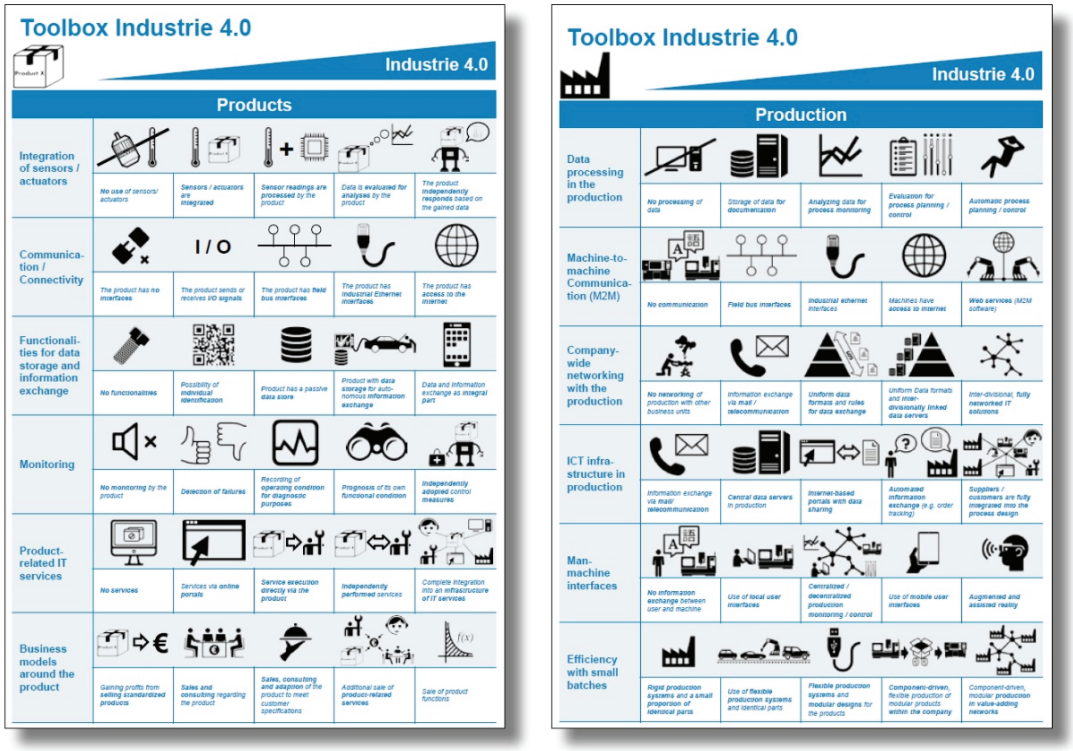

Figure 9: Toolboxes: One for the Products, one for the Production

6 Outlook

Following the initial ideas and visions from 2011, *Industrie 4.0* is becoming more and more defined. *Industrie 4.0* has already made its way from research to practice. Based on the diverse initiatives and research projects, many of today's challenges will be solved in the near future.

However, *Industrie 4.0* will only be possible when a broad range of industrial penetration has been achieved, not just for SMEs but also for customers and suppliers around the world, e.g. in Brazil. *Industrie 4.0* can't be bought off the shelf, so each company has to find its own way to *Industrie 4.0*. To make sure not too many companies are left by the wayside with this development, the undecided also have to be motivated to start pilot projects and gain practical experience with *Industrie 4.0*.

Whether *Industrie 4.0* is more revolution or evolution is mostly meaningless. We are convinced that *Industrie 4.0* will create huge opportunities and changes. Ultimately, *Industrie 4.0* will only become a reality when it is no longer just a buzzword but when *Industrie 4.0* technologies and concepts are practiced and used in companies as a matter of course.

7 References

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Forum Industrie 4.0
VDMA
Development and Practice of Industrie 4.0 in German Industry
Rainer Glatz, VDMA
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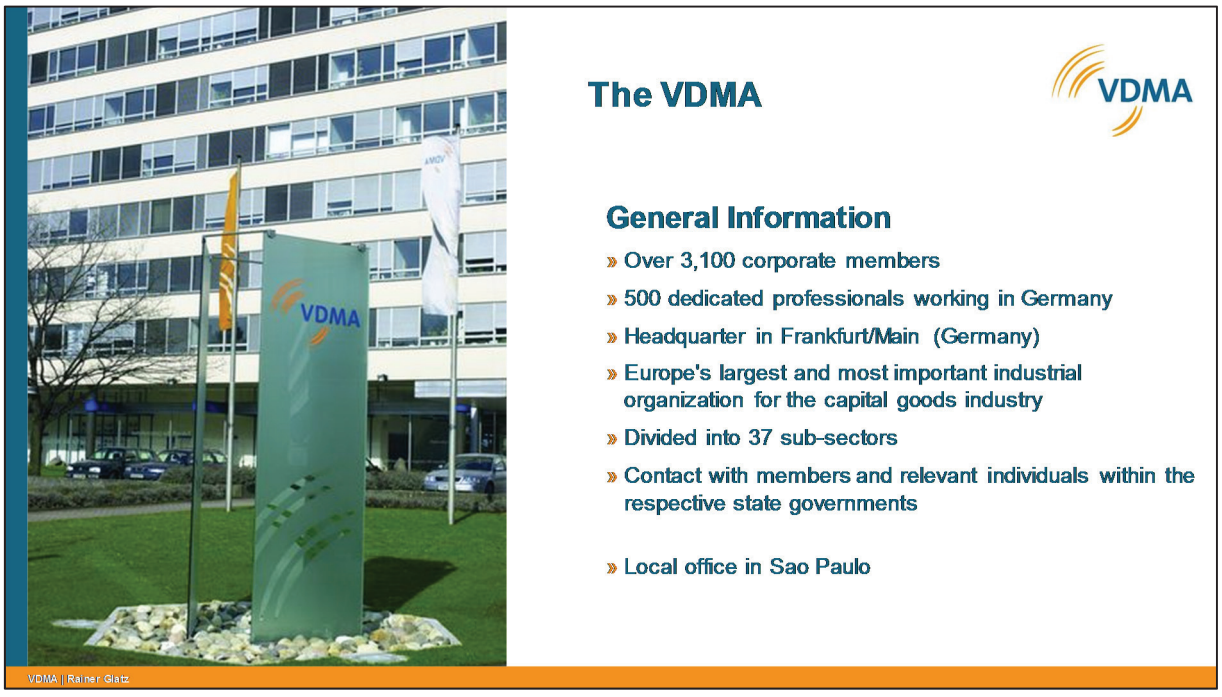
VDMA
The VDMA
VDMA
General Information
» Over 3,100 corporate members
» 500 dedicated professionals working in Germany
» Headquarter in Frankfurt/Main (Germany)
» Europe's largest and most important industrial organization for the capital goods industry
» Divided into 37 sub-sectors
» Contact with members and relevant individuals within the respective state governments
» Local office in Sao Paulo
VDMA | Rainer Glatz

VDMA Brazil Office

- **opened in Mai 2013**
- **Executive Director: Thomas Junqueira Ayres Ulbrich**
- **300 VDMA members in Brasil**
- **Important sectors are:**
  - Construction Equipment and Building Mateiral
  - Material Handling and Intralogistics
  - Plastic and Rubber Machines
  - Textile Machinery
  - Food Processing Machinery and
  - Packing Machinery
  - Woodworking Machinery
- **http://brazil.vdma.org**

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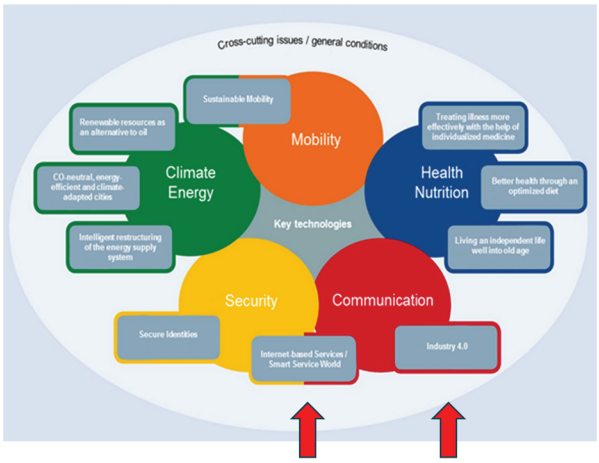
German High-Tech-Strategie 2020

Focus: Key Technologies

MKR1

5 Main Areas :
- Health, Nutrition
- Communication
- Safety
- Climate, Energy
- Mobility

10 Forward-looking Projects, including:
- Industrie 4.0
- Smart Service World



Source (adapted): BMBF

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Forschungsunion
Wirtschaft und Wissenschaft begleiten die Hightech-Strategie

acatech
NATIONAL ACADEMY OF SCIENCE AND ENGINEERING

Securing the future of German manufacturing industry

Recommendations for implementing the strategic initiative INDUSTRIE 4.0

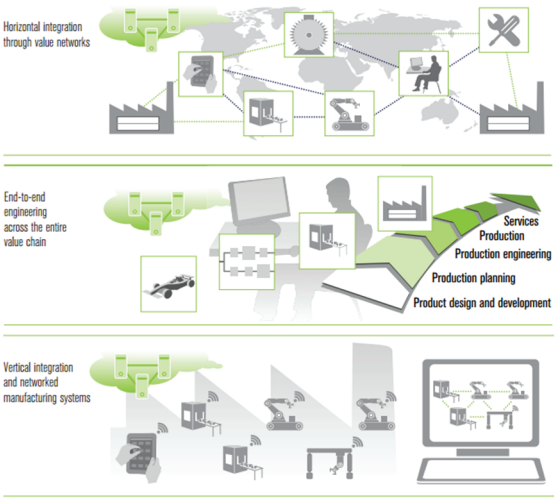
Final report of the Industrie 4.0 Working Group

April 2013

Federal Ministry of Education and Research

Recommendations for implementing Industrie 4.0

VDMA



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Association Plattform Industrie 4.0

VDMA

Plattform INDUSTRIE 4.0

Common project of the associations in functional, subject oriented cooperation

BITKOM · VDMA · ZVEI: Die Elektroindustrie

Secretariat (Sec.)

Governing Board (GB)

Steering Committee (SC)

Strategy & Framework | Standardi-zation | Research | Security

acatech
DEUTSCHE AKADEMIE DER TECHNIKWISSENSCHAFTEN
Scientific Advisory Committee (SAC)

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BITKOM VDMA ZVEI

Umsetzungsstrategie Industrie 4.0

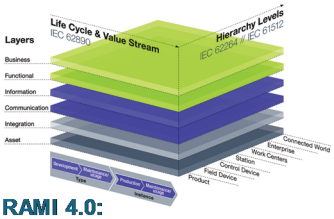
Ergebnisbericht der Plattform Industrie 4.0

April 2015

Results of the Plattform Industrie 4.0

VDMA

Research-Roadmap



RAMI 4.0: Reference Architecture Model Industrie 4.0

Industrie 4.0-Component

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The Working Groups of the PLATTFORM INDUSTRIE 4.0

VDMA

Chair
Ministers Gabriel, Wanka

Representatives from business, trade union, academia Political integration

Working Group 1:
Reference Architectures, Norms and Standardisation
Chair:
Dr. Peter Adolphs, *Pepperl+Fuchs*

Working Group 2:
Research and Innovation
Chair:
Johannes Diemer, *Hewlett Packard*

Working Group 3:
Security of Interconnected Systems
Chair:
Michael Sandner, *Volkswagen AG*

Working Group 4:
Legal Framework
Chair:
Dr. Hans-Jürgen Schlinkert,

Working Group 5:
Employment, Apprenticeships and Life-Long Learning
Chair:
Dr. Constanze Kurz, *IG Metall*

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Industrie 4.0 in international competition

Image based on Piot Ardel, Specialist acat DiK, TU Darmstadt,

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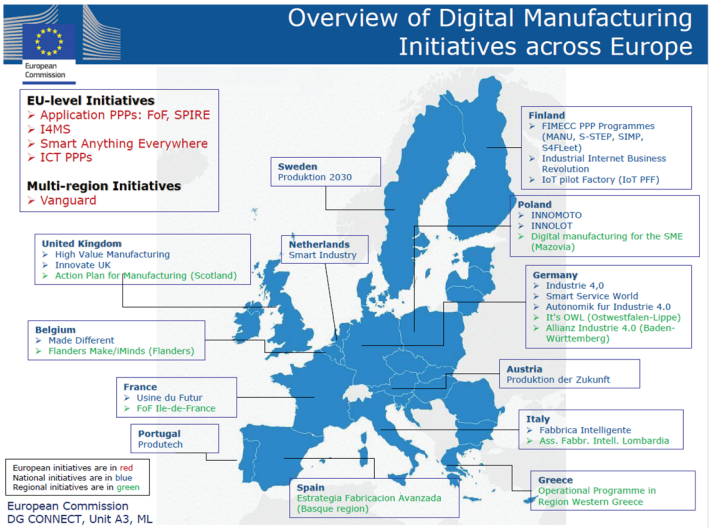
Industrie 4.0 in Europe



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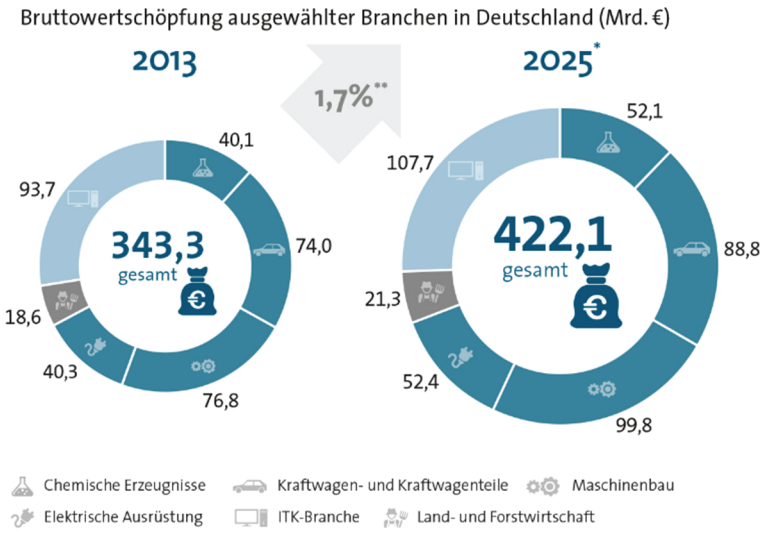
Growth possibilities with Industrie 4.0



Quelle: BMWi/VDMA

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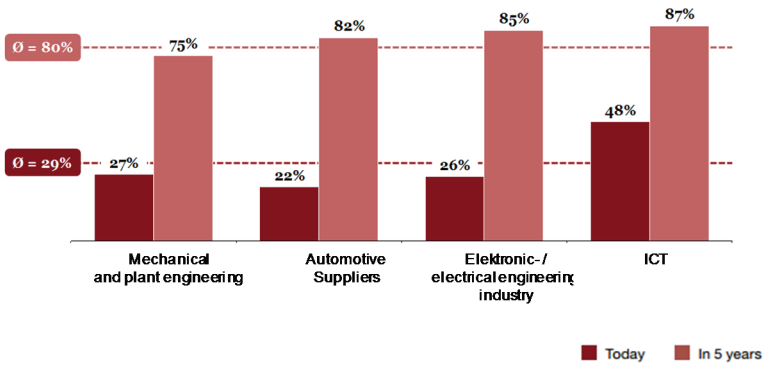
PwC-study supported by VDMA and Siemens - Degree of digitization of production



235 German companies interviewed by TNS Emnid from June to September 2014

- Investment in the next 5 years for digitization: 3,3 % of sales / 8,5 bill. Euro p.a.
- Expected sales by digitization: +13,2% / 6,4 Mrd. Euro p.a.

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IMPULS
START CHECK
ABOUT THE MODEL
ABOUT US
CONTACT
Industry 4.0 Readiness
Online Self-Check for Businesses
Where does your business stand? Check your readiness for Industry 4.0!
This self-check lets you calculate your very own Industry 4.0 scorecard. Find out wh
you are already well prepared for Industry 4.0 and where you still have room for
improvement.
Level 5
Level 4
Level 3
Level 2
Level 1
Level 0
Top performer
Expert
Experienced
Intermediate
Beginner
Outsider
Leaders
The Readiness Model is the foundation for a self-assessment and comparison. The O
Self-Check developed for this purpose gives companies the ability to check their ov
Industry 4.0 readiness.
IMPULS-Study
„Industrie 4.0-Readiness“
VDMA
Determining the individual industry 4.0 – maturity
classification into the types of companies
» Newcomer
» Beginner
» Pioneers
Online-Self-Check
www.industrie40-readiness.de
Results of the Study:
www.impuls-stiftung.de
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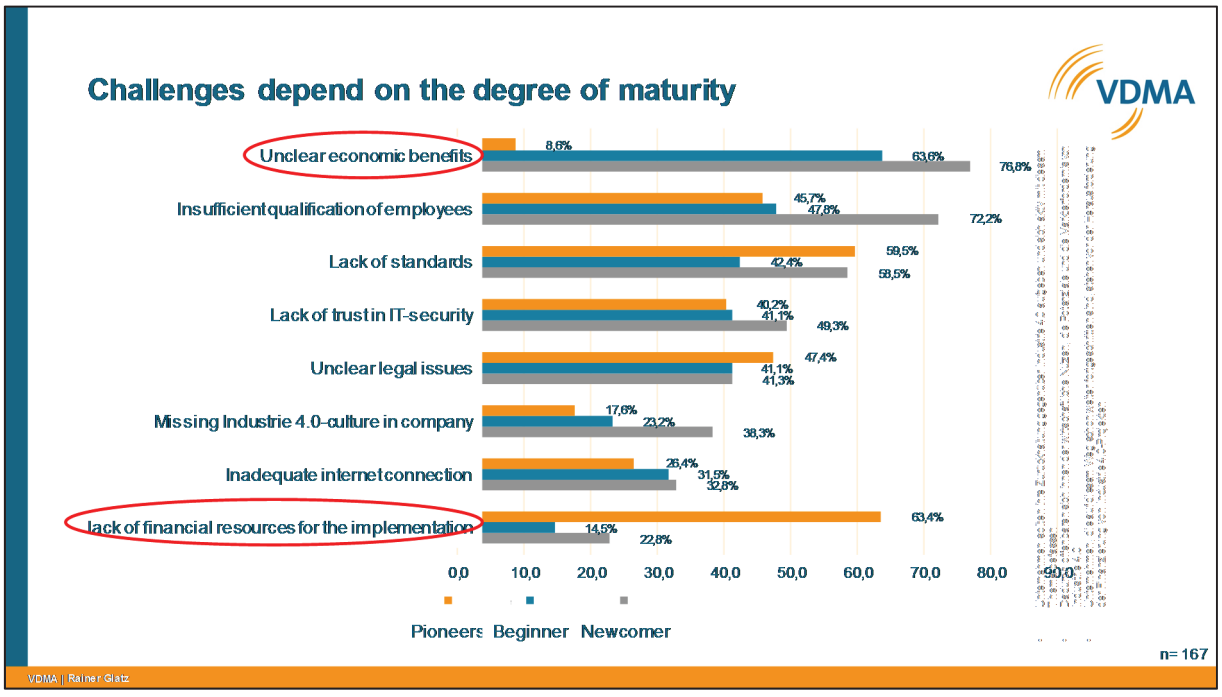
Challenges depend on the degree of maturity
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Unclear economic benefits
8,6%
63,6%
76,8%
Insufficient qualification of employees
45,7%
47,8%
72,2%
Lack of standards
59,5%
42,4%
58,5%
Lack of trust in IT-security
40,2%
41,1%
49,3%
Unclear legal issues
47,4%
41,1%
41,3%
Missing Industrie 4.0-culture in company
17,6%
23,2%
38,3%
Inadequate internet connection
26,4%
31,5%
32,8%
lack of financial resources for the implementation
63,4%
14,5%
22,8%
0,0
10,0
20,0
30,0
40,0
50,0
60,0
70,0
80,0
90,0
Pioneers
Beginner
Newcomer
n= 167
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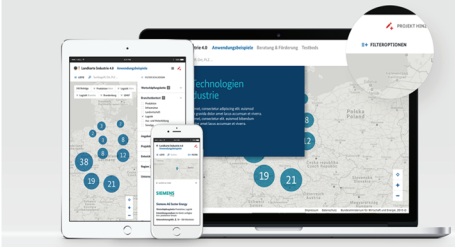
Virtual Map Industrie 4.0
Where Industrie 4.0 is put into practice already

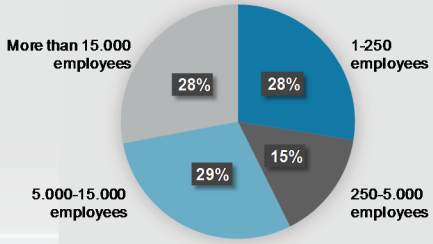
VDMA

Over 207 examples of application of Industrie 4.0...

...within small, medium and large sized enterprises from various branches.



Number of employees within the enterprises



http://www.plattform-i40.de/I40/Landkarte

Source: Plattform Industrie 4.0

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Forum Industrie 4.0
Spheres of action

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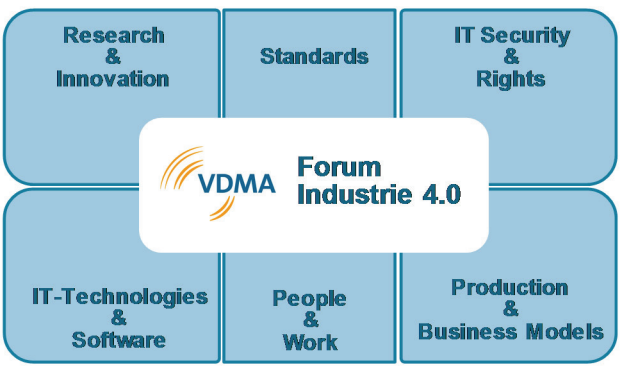

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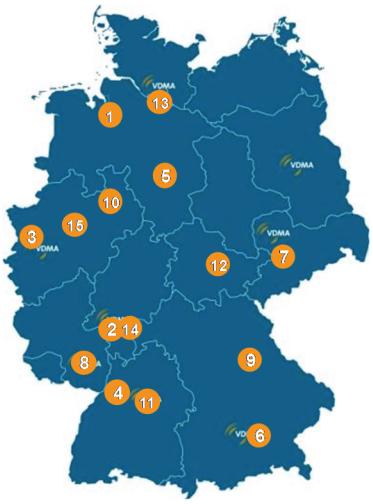
Lab Tour I40



1. Bremen, Kompetenz- und Transferzentrum für Cyber-Physische Logistik (BIBA), 24.06.2014
2. Darmstadt, Effiziente Fabrik 4.0, TU Darmstadt (DiK, PTW), 23.09.2014
3. Aachen, Demonstrationsfabrik, RWTH Aachen (WZL), 02.12.2014
4. Karlsruher Institut für Technologie (KIT) und Fraunhofer IOSB, 24.02.2015
5. Hannover, Institut für Integrierte Produktion (IPH), 29.04.2015
6. München, Institut für Werkzeugmaschinen und Betriebs-wissenschaften (iwb), TU München, 12.05.2015
7. Chemnitz, Fraunhofer-Institut für Werkzeugmaschinen und Umformtechnik (IWU), 14.07.2015
8. Kaiserslautern, SmartFactory^{KL}, 05.11.2015
9. Nürnberg, Lehrstuhl für Fertigungsautomatisierung und Produktionssystematik (FAPS), FAU Nürnberg, 12.04.2016
10. Lemgo, SmartFactoryOWL, Hochschule OWL und Fraunhofer IOSB, 23.05.2016
11. Stuttgart, Fraunhofer IAO und Fraunhofer IPA, 14.07.2016
12. Ilmenau, Institut für Mikroelektronik- und Mechatroniksysteme, 23.08.2016
13. Hamburg, Automatisierungstechnisches Institut der Helmut-Schmidt-Universität Hamburg, 20.09.2016
14. Darmstadt, Effiziente Fabrik 4.0, TU Darmstadt, 08.11.2016
15. Dortmund, Fraunhofer IML, 08.12.2016

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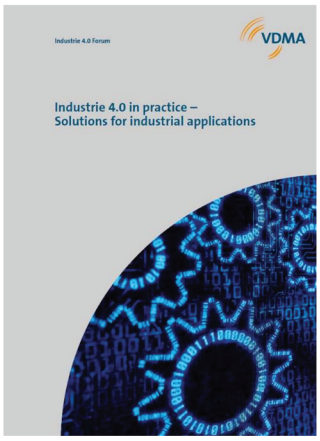
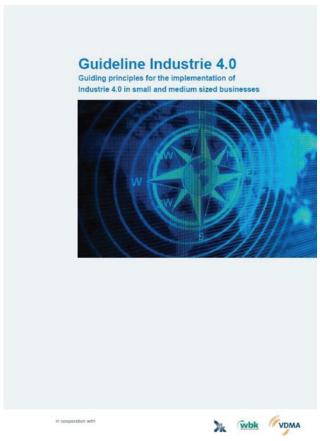
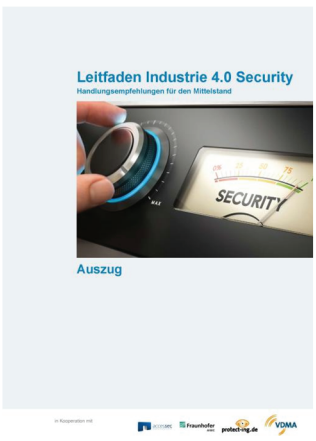
Publications of VDMA-Forum Industrie 4.0







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Complete list under: http://industrie40.vdma.org/article/-/articleview/13933597

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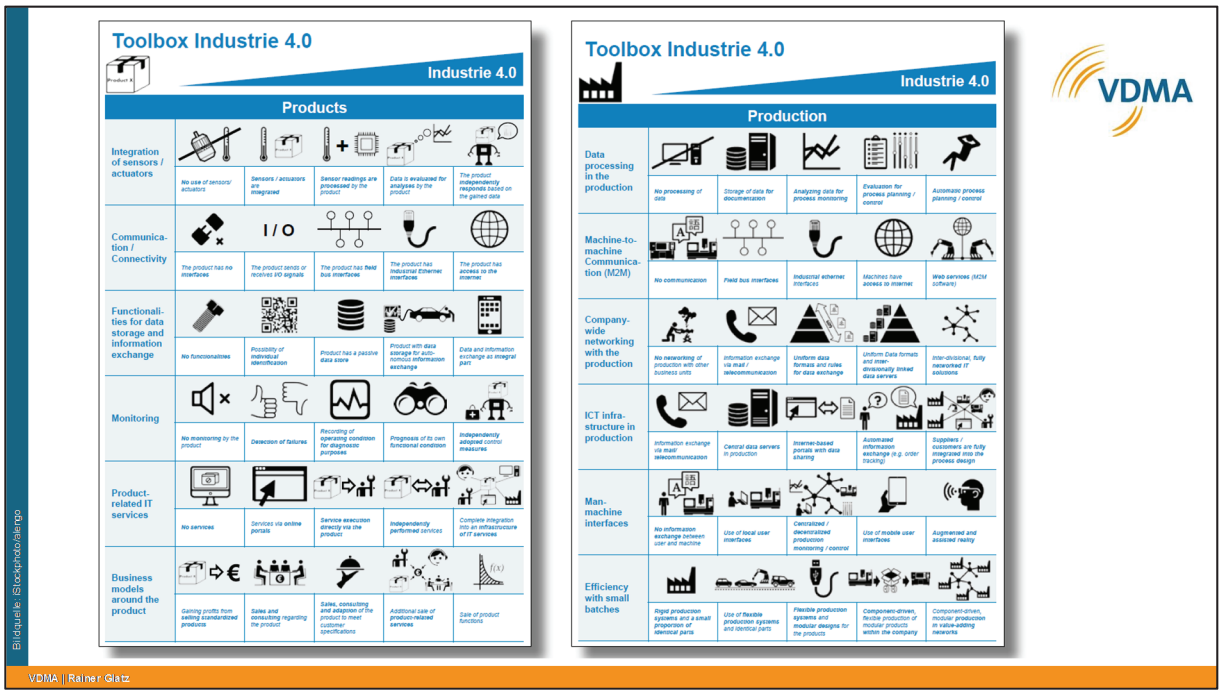
Toolbox Industrie 4.0
Industrie 4.0
Products
Integration of sensors / actuators
Communication / Connectivity
Functionalities for data storage and information exchange
Monitoring
Product-related IT services
Business models around the product
Toolbox Industrie 4.0
Industrie 4.0
Production
Data processing in the production
Machine-to-machine Communication (M2M)
Company-wide networking with the production
ICT infrastructure in production
Man-machine interfaces
Efficiency with small batches
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» Production Organisation & Business Models
Success Stories and basic informations
» Industry Best Practice
» I40-Research at German Research Institutions
» Serveral Movies explaining Industrie 4.0
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VDMA
Thank you
Thank you
for your attention!
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Dipl.-Ing. Rolf Neumann

After Graduation at the FH Ulm as Electrical Engineer in 1996, Mr. Neumann started as Quality and Process Engineer at an elevator company. From 1999 he worked for several years in SAP Consulting, to join the Bosch Group in 2004. There he worked in different functions like Coordination/Consulting and Management in IT Projects in Germany. After 3 Years in Japan (2012-2015) with his family, leading one of the biggest SAP Projects within Bosch, he returned one year ago back to Germany to take over the Connected Industry Project management for the CC (Chassis System Control) Division within the Bosch Group. He is married and has two kids.

✉ rolf.neumann@de.bosch.com

The Bosch Group

The Bosch Group is a leading global supplier of technology and services. The company employs roughly 375,000 associates worldwide (as of December 31, 2015), and generated of 70.6 billion euros in 2015. Its operations are divided into four business sectors: Mobility Solutions, Industrial Technology, Consumer Goods, and Energy and Building Technology. The Bosch Group comprises Robert Bosch GmbH and its roughly 440 subsidiaries and regional companies in some 60 countries. Including its sales and service partners, Bosch is represented in roughly 150 countries. This worldwide development, manufacturing, and sales network is the foundation for further growth. The Bosch Group's strategic objective is to deliver innovations for a connected life. Bosch improves quality of life worldwide with products and services that are innovative and spark enthusiasm. In short, Bosch creates technology that is "Invented for life." More information: www.bosch.com, www.bosch-press.com, http://twitter.com/BoschPresse.

BOSCH
Tecnologia para a vida

Connected Industry at Bosch

Abstract

Award-winning success: in less than one year, Bosch improved its productivity in the manufacture of ABS/ESP braking systems by nearly one-quarter by deploying Industrie 4.0 solutions throughout its international manufacturing network. In recognition of this achievement, the Blaichach plant, which spearheaded the initiative, received the prestigious Industrie 4.0 Award in 2015. One reason for this productivity increase is that Bosch collects data from the thousands of sensors that are installed along the plant's production lines. Sensors record the movement of cylinders, the cycle times of grippers, and the temperature and pressure levels in the manufacturing process. This wealth of information is entered into massive databases, with a clear structure. Thanks to RFID (radio frequency identification) technology, Blaichach can also digitally map its internal flows of goods. The result is a computer-generated virtual representation, or "digital twin," of the actual factory. This digital representation facilitates transparency across the entire value stream. In turn, this transparency makes many more I4.0 solutions possible. Bosch is making its manufacturing connected, with more than 100 projects already successfully running worldwide. Among other benefits, this increases the availability of its machinery – and hence also its productivity and competitiveness. Connected industry is now becoming an international reality at Bosch!

Keywords

Innovative; Lead Provider; Worldwide Connected.

1 *Industrie 4.0* live at Bosch Blaichach is an object lesson in connectivity

Its shopfloor features huge touchscreens. Where production experts used to have to go to the machines to inspect and check parts, the commercially available tablet computer has now become a commonplace workday tool, used to track production processes and help the expert intervene, if necessary. This is the new working world, the world of the fourth industrial revolution: *Industrie 4.0*. Blaichach, a major Bosch plant in the south of Germany, has made the switch. By thoroughly connecting its manufacturing operations with the latest in IT, plus digitalizing and visualizing all its processes in line with the Bosch Production System, the Bosch location has begun to blaze a path to the future.

As the lead plant for an international manufacturing network of eleven locations, Blaichach is the perfect choice for this pioneering role. Each year its 3,300-strong workforce produces some 6.7 million units of the widely selling ABS/ESP® safety systems alone. Departments for production planning, special-purpose machinery, software and system operations all work side by side, constantly sharing information and driving forward further improvements. *Industrie 4.0*, also called connected manufacturing, offers plenty of new opportunities for making production even more efficient. The wealth of information and data generated by connectivity is something that companies need to exploit to their advantage. Super-fast computers are used to analyze this data. If this analysis is done properly, quality can be assured and the process of monitoring workpieces speeded up – saving time and money. There is also the advantage of a global database to reveal error patterns in production. Blaichach has combined these patterns with experience gained from resolving the errors successfully, and developed what it calls its operator support system.

This system not only displays error messages themselves, but also tried-and-tested recommendations for dealing with them. Another digital tool, known as the performance tracker, allows experts to keep a close watch on cycle times and to intervene early on, even when deviations are in the millisecond range. In recent years, these advances have made it possible for Bosch to increase productivity at its ABS/ESP® manufacturing facilities worldwide by almost 24%. One further advantage is that product quality has been given a new dimension. Data gathered directly from customers during product use can be analyzed and transmitted automatically to manufacturers.

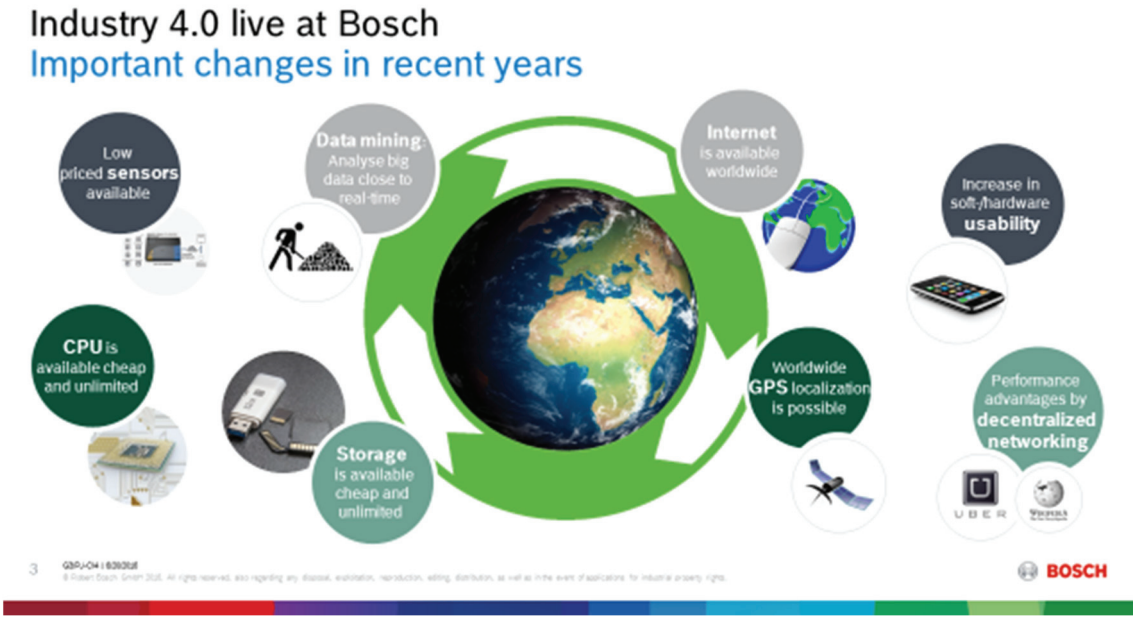
Yet the success of the technology depends on people. Their work has changed. They have to work with digital connectivity, understand the technology and tap the opportunities it offers. People have to interpret the information and make the right decisions. That’s why Blaichach highlights “soft factors” as well. Factors like “rethinking” and “culture change”, or working with technology – an activity that should be as simple as it is effective.

2 Technological Fundament

Low priced sensors are now available (e. g. MEMS by Bosch) and the internet is available worldwide, via LAN, WLAN or GSM/LTE.

The usability of soft-and hardware has significantly increased. A worldwide localization via GPS is possible with a few meters accuracy. Computing power (CPU) is cheap and available nearly unlimited (cloud).

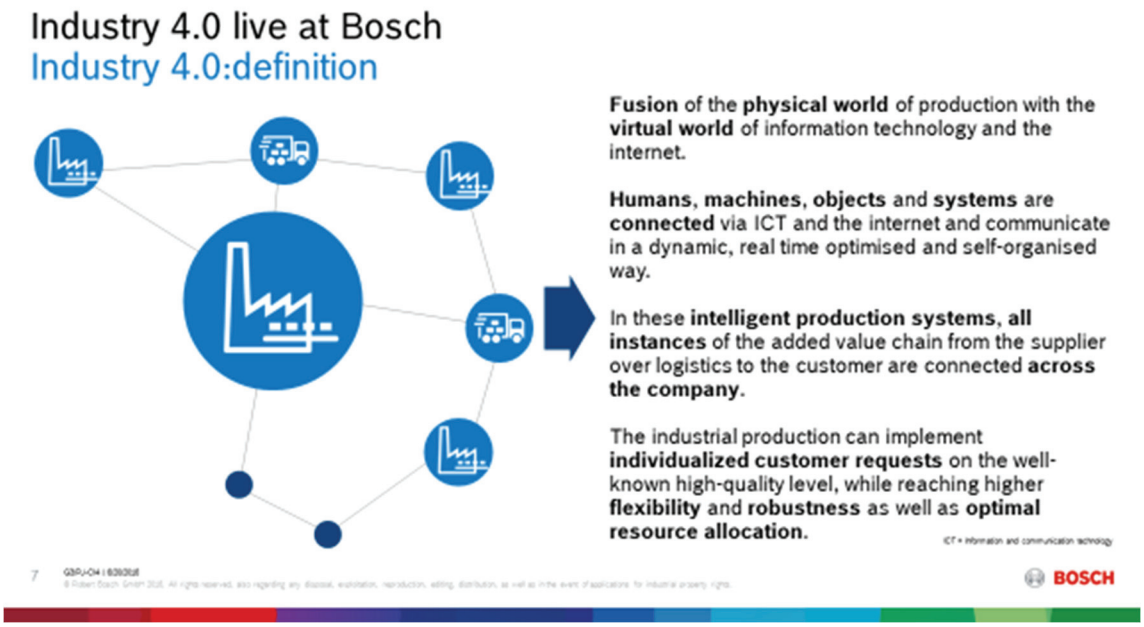
Data storage is cheap and available nearly unlimited (cloud based or in production location for faster accessibility). Data Mining gives new possibilities to analyze big data close to real time and the principle of “decentralized networking” has proven its performance and advantages in many cases.



3 Definition of *Industrie 4.0* at Bosch

The name *Industrie 4.0* describes the networked manufacturing of the future. After the weaving loom, assembly line and usage of electrical engineering in the production the fourth industrial revolution starts: The internet with its unlimited possibilities of information exchange will be included in the production. The result is the “smart factory”, which is characterized by versatility, resource efficiency and ergonomic design as well as its direct integration of business partners.

In the “smart factory” (semi-) autonomous machines move and work without direct human control and make decisions independently. This shall evoke a productivity increase to maintain and improve competitiveness. The human will play a new role as designer, user and decision-maker. Technology supports him in doing so better than ever before.



4 Seven features of *industrie 4.0* at Bosch

Fast integration and flexible configuration are indispensable for an efficient data exchange in all kinds of production systems and for enhancing efficiency for individual customer requirements in small and medium batch productions. Therefore, it requires open standards in software and hardware architecture, especially at production networks across all plants.

Distributed intelligence, which is the capability to recognize conditions of products, machines, etc., locally and derive effective measures, mandatorily requires a real-time virtual representation of the event, which allows a model-based description of the current production systems, and therefore even an optimization in immediate future.

For secure value-creation networks, it is necessary to have elaborated systems for data security that ensure both the exchange of selected and the protection of sensitive data.

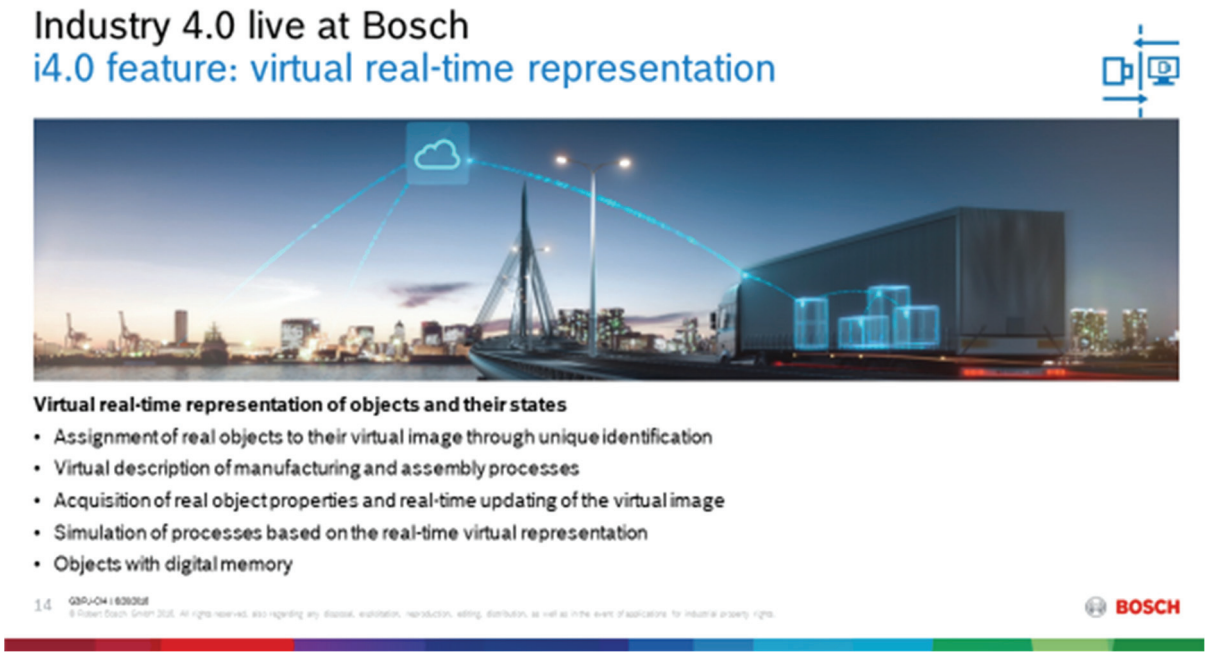
The digital life-cycle management allows to clearly assign individual data of a product, or of the part in production, up to the field operation and analyze with the help of “Big Data Analytics”. So it is possible to receive information about so far not recognized interdependency – “there is something, take a look” – transform this information into knowledge with help of the human – “this is how it works” – and eventually implement it for benefit increase – “this is how we increase quality, effectiveness and efficiency”.

We are firmly convinced that the human as a key player is going to stand in the focus of this industrial event.

5 *Industrie 4.0* Live at Bosch

Virtual real-time representations of objects interact with each other and with software systems.

All products and components are represented as virtual real-time representations in various software environments. These virtual real-time representations are closely linked to their physical counterparts. Sensors monitor their location, environmental conditions, and operating parameters.

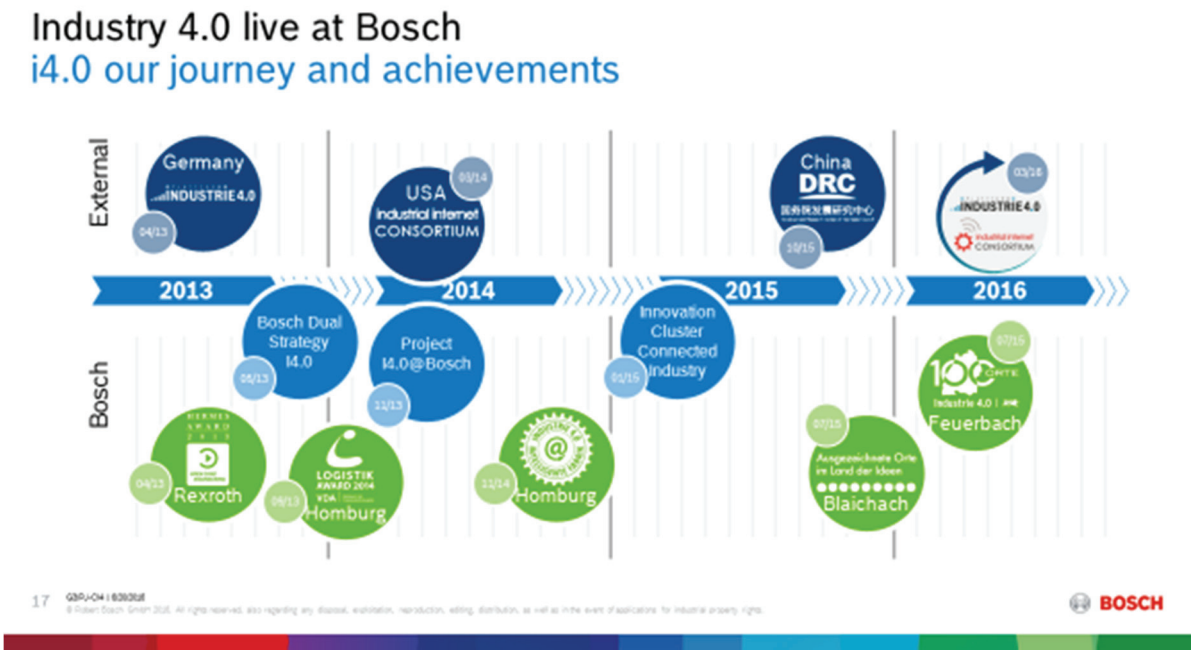


Where do we stand today with *industrie 4.0* and what have we already achieved at Bosch?

For us at Bosch it was clear from the beginning that *industrie 4.0* will neither be a new nor a second product strategy. We have focused our authorities through interdisciplinary cooperation across domains in an innovation cluster called “Connected Industry”. First successes like the Hermes Award 2013 for our open software solution Open Core Engineering of Bosch Rexroth and the VDA Logistic Award 2014 as well as the 2015 I4.0 Award for our multi product line encourage us in our line-up and strategic orientation.

Since 2013 Bosch also participates in the German *Plattform Industrie 4.0*, where numerous well-known companies and associations of industrial manufacturing, plant construction and IT industry come together.

The *Plattform Industrie 4.0* serves the implementation of the high-tech strategy of the German Government. Aim is the stronger networking of products and machines, higher efficiency in Germany producing companies as well as success in competition. The Industrial Internet Consortium (IIC) in the USA pursues a much broader approach. It reaches over the industrial production and the machine and plant construction to the internet of things and services in a wider sense. Bosch not only acts on the subject of Connected Industry, the main topic of I4.0, but also on the fields of Connected Mobility, Connected Home and Connected Energy. Therefore, since 2014, we are also active in the IIC over our subsidiary company Bosch Software Innovations, the software and system house of the Bosch Group. Both initiatives – I4.0 and IIC – have a range of similar topics for example the data security and open standards.

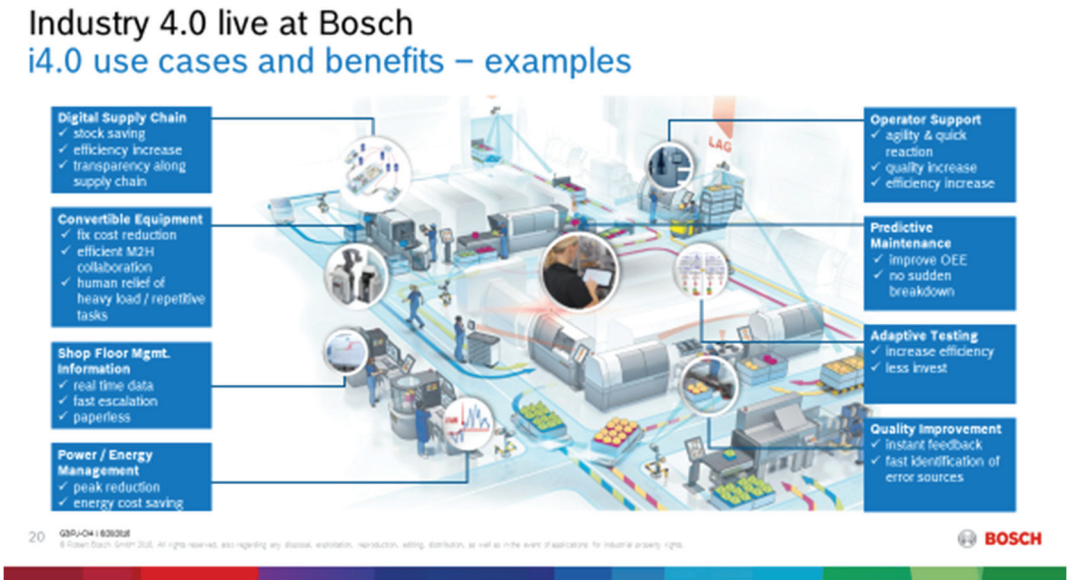


6 I4.0 use cases and benefits

Two streams are leading us to the networked production. In the so-called pilot stream we are working in pilot projects on fast knowledge production and new strategies. In the so-called main stream we are working on consistent development of our present product base.

The pilot stream is our vanguard for the networked production environment, its projects are the pioneers. In a first step our divisions developed potential pilot projects. Which of these projects are really good and create value? How to separate the wheat from the chaff? Our projects were valued and classified based on criteria such as “innovation hub” and “widespread impact”. More than 100 projects are currently in the process of implementation, of which you will get to know a few examples in this presentation. Our Innovation Cluster Connected Industry provides rapid knowledge transfer from pilots to the main stream. Thus, we ensure that new insights can be shared and used promptly and globally. The main stream uses the newly obtained knowledge for further development and optimization of consisting machines or on planning and purchasing new machines.

In order to give you an overview about *Industrie 4.0*, the next figure shows many *Industrie 4.0* use cases and their benefits.

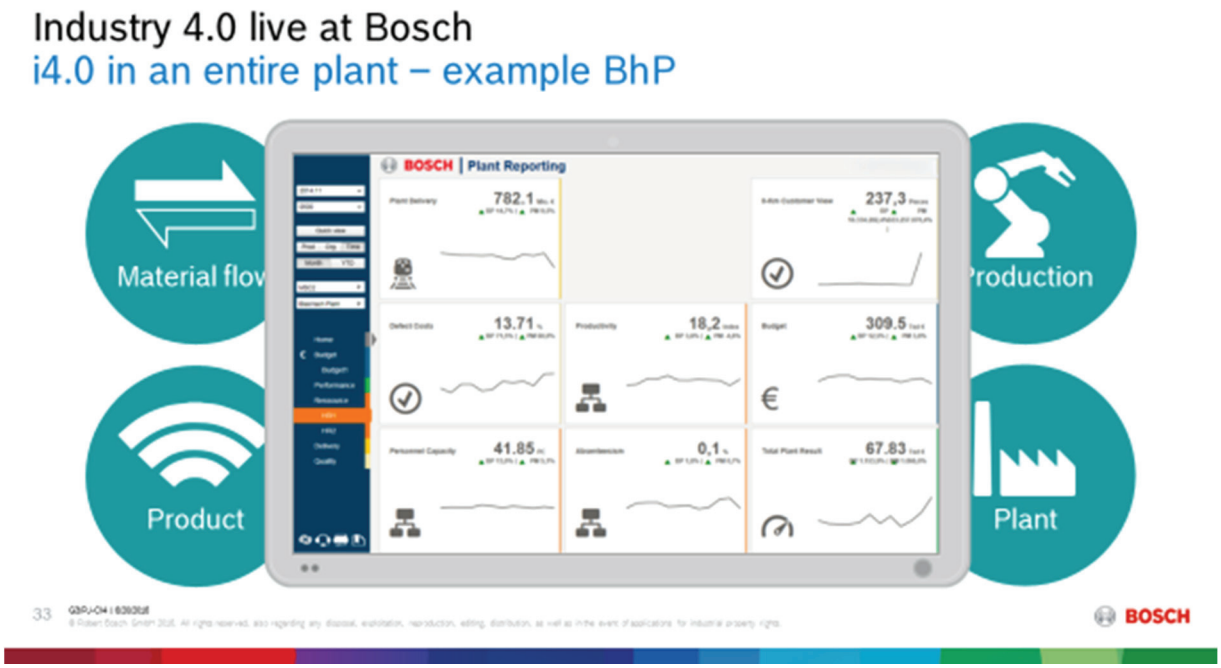


In the next examples we will have a closer look at the plant in Blaichach, where a holistic *Industrie 4.0* approach is pursued. The overall objective is to increase efficiency by the application of *Industrie 4.0* technology in all relevant areas.

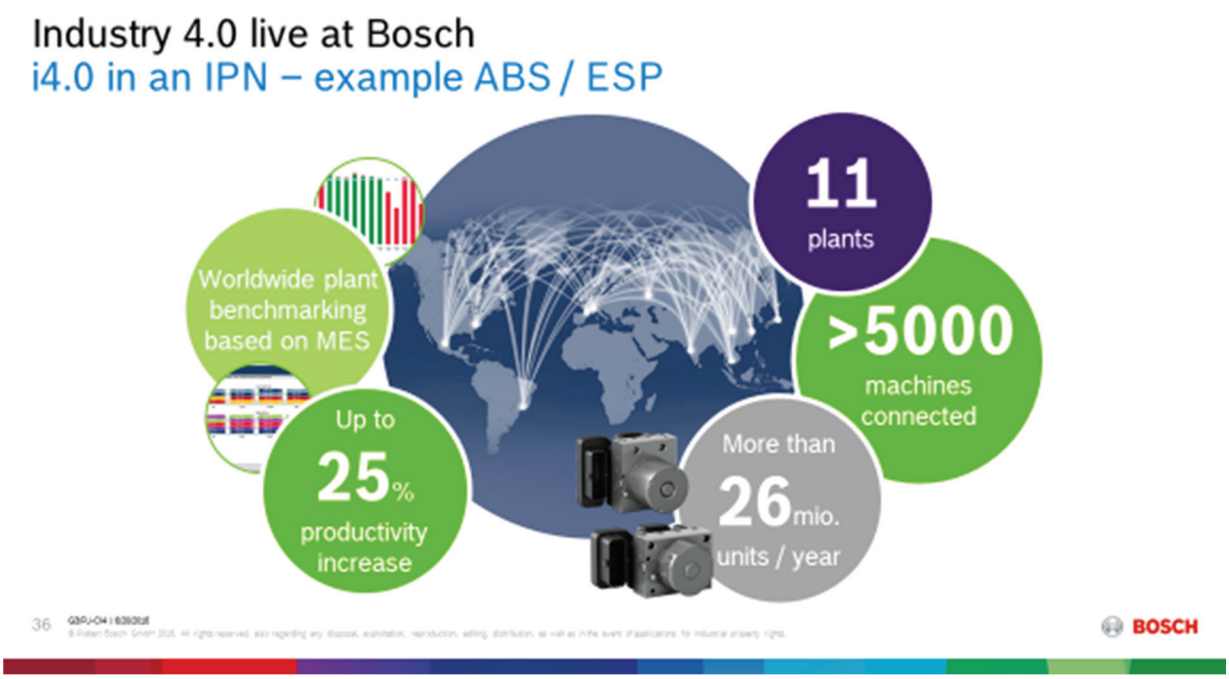
- **Plant:** To optimize the plant at BhP they implemented the Bosch Energy Management system as a central control technology for the overall energy consumption and were able to reduce their costs for compressed air by 40%. Additionally, they have their own hydro power station, which will be integrated into the MES system and connected to weather forecasts to increase its efficiency;

- **Product:** The iBooster, one of the main products produced in Blaichach, sends Field-Data and User-Profiles back to Bosch. Based on the analysis of this data, Bosch is able to develop customized Software and Updates that are provided to the iBooster again. So in this case *Industrie 4.0* enables an accelerated product development;
- **Material flow:** The already mentioned RFID technology guarantees a traceable and transparent material flow;
- **Production:**The production process is supported by *Industrie 4.0* technology as well. Deviations are detected with the help of real-time data. If needed, automatic alerts are triggered. On top of that, problems can be solved with the help of a Service Support System, which enables experts to analyze a problem directly via remote maintenance.

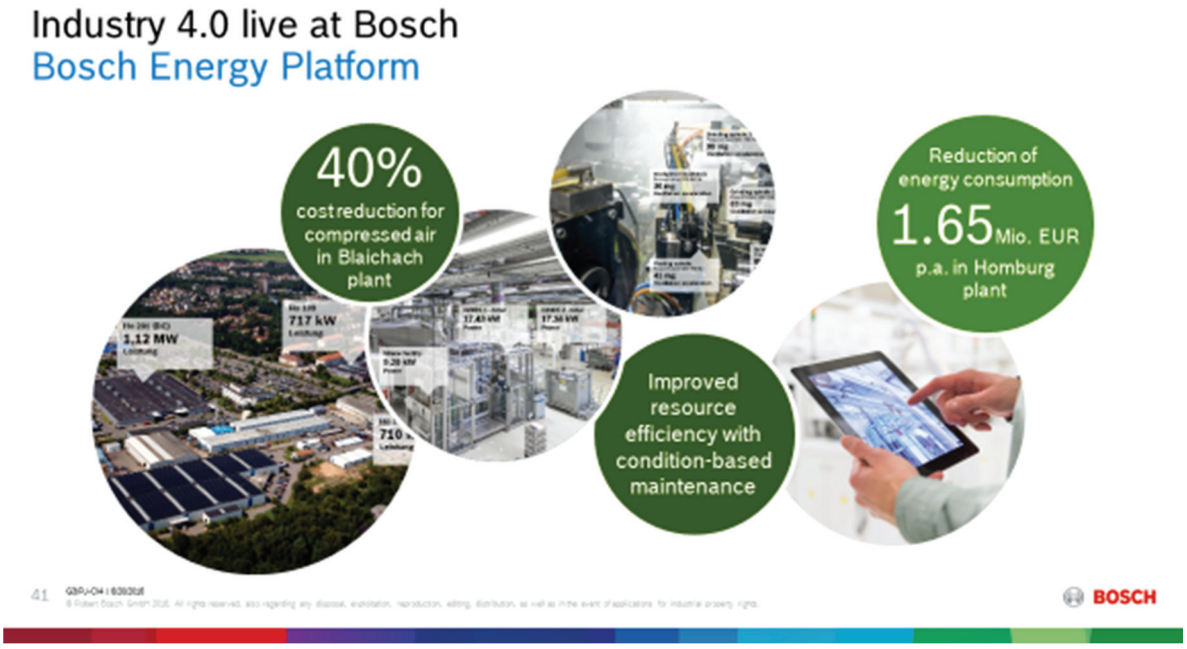
This are only a few opportunities that are already in use. However, at the end people are still the key players. In order to provide them the most efficient use of the countless new possibilities, professional education and individual trainings are offered as well as employee participation is required. Blaichach also implements a personalized plant reporting tool: Each manager gets the relevant KPI in real-time in a personalized dash board.



ABS/ESP production in Blaichach has already realized parts of such an IPN. In the eleven participating plants more than 5000 machines are connected. An online ranking of all lines in these plants is created. This gamification approach motivates employees and connects them. For example, if our plant in the USA is always on top of that list, employees will connect with them and exchange worthwhile tips to increase productivity. The worldwide plant benchmarking results in a 25 % productivity increase that enables a production of more than 26 mio. units per year.

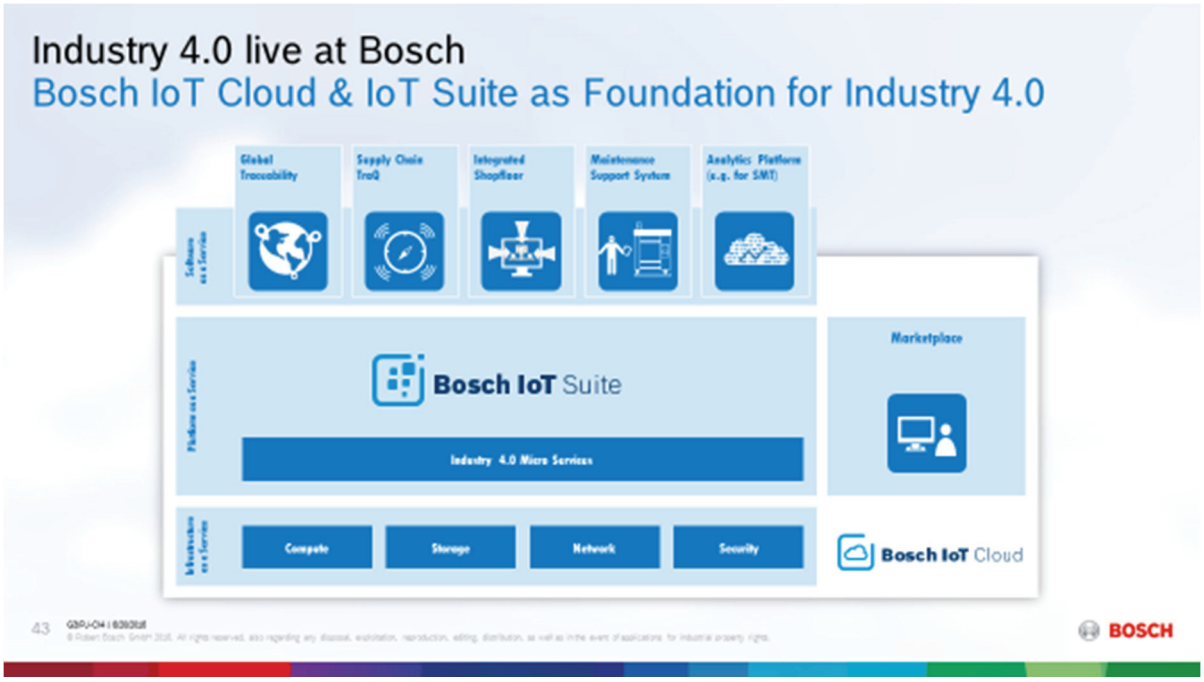


Energy costs are a major factor in manufacturing enterprises. The Energy Platform provides a full breakdown of energy consumption and costs for the whole facility or individual machines. The concept is as simple as it is effective: we first measure the precise consumption in all locations within production halls, where energy is converted or required. These values are then transferred via a secure connection to the Energy Platform, where they are analyzed. They are then converted into useful data that can be viewed online. Thanks to our software solution the user is always able to look at his current energy data, which can be easily accessed via any Internet Browser. The success is clearly underlined by numbers, which speak for themselves.



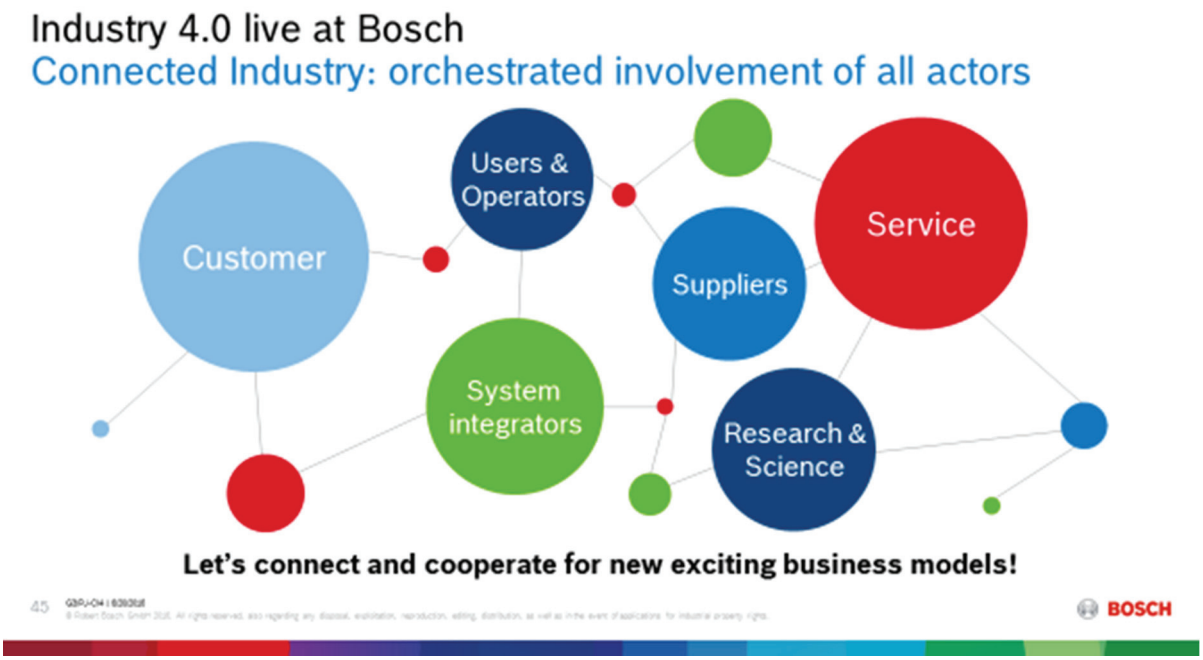
7 Bosch IoT Cloud & IoT Suite

As you have seen in numerous examples *Industrie 4.0* solutions require a sound IT infrastructure. Bosch has its own in-house solution: The Bosch IoT cloud. This cloud can provide infrastructure dynamically as a service e.g. storage capacity and computing power. Part of this holistic platform that is provided as a service are also *Industrie 4.0* micro services. Those provide basic building blocks for *Industrie 4.0* solutions and can easily be used across different software applications. The Industr 4.0 software solutions are provided as a service to the costumer. For time-critical applications *Industrie 4.0* solutions can also be provided on premise at your plant.



Connected industry, the fourth industrial revolution, will become a reality and a success only if all the actors involved open up and work together to implement it. “Connected” and “individualistic”, “connected” and “proprietary”: those are contradictions in terms, in the world of linguistics just as much as in the world of manufacturing. Only someone in an ivory tower could think otherwise.

All the individual actors in industry need to come together to form a giant orchestra. Everyone involved must be tied into the value-creation network. Where previously we have tended to optimize by looking within our own plants or perhaps within the confines of our own companies, what we need to do now is overcome the barriers between companies and think in terms of business ecosystems. We have already shown that we are capable of networking beyond corporate boundaries. We even created one of the major prerequisites for this capability: standardized data exchange. As well as getting connected within the “industry community,” we will also network with other sectors. It is precisely the interface between new partners where we are going to see interesting, exciting business models develop.


Industry 4.0 live at Bosch
Connected Industry: orchestrated involvement of all actors
Customer
Users & Operators
Suppliers
Service
System integrators
Research & Science
Let's connect and cooperate for new exciting business models!
45
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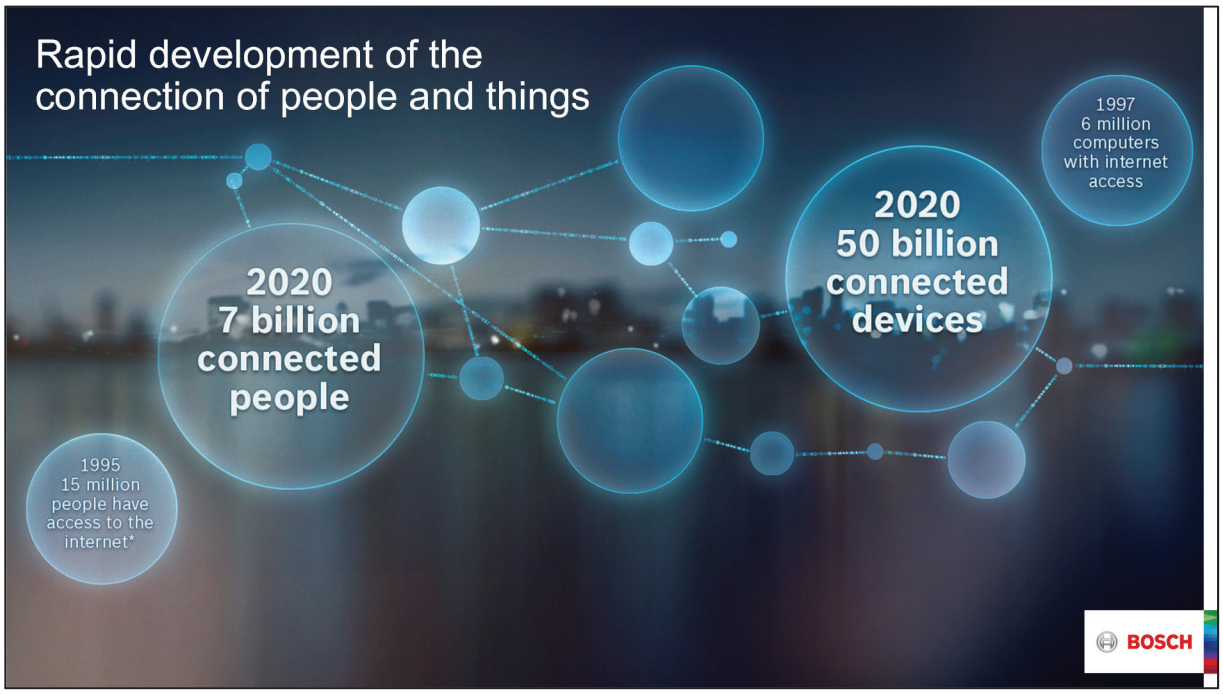
INDUSTRY 4.0 LIVE AT BOSCH
ROLF NEUMANN
RETRIEVING DATA ...
Simply.
Connected.
BOSCH


Rapid development of the
connection of people and things
1997
6 million
computers
with internet
access
2020
50 billion
connected
devices
2020
7 billion
connected
people
1995
15 million
people have
access to the
internet*
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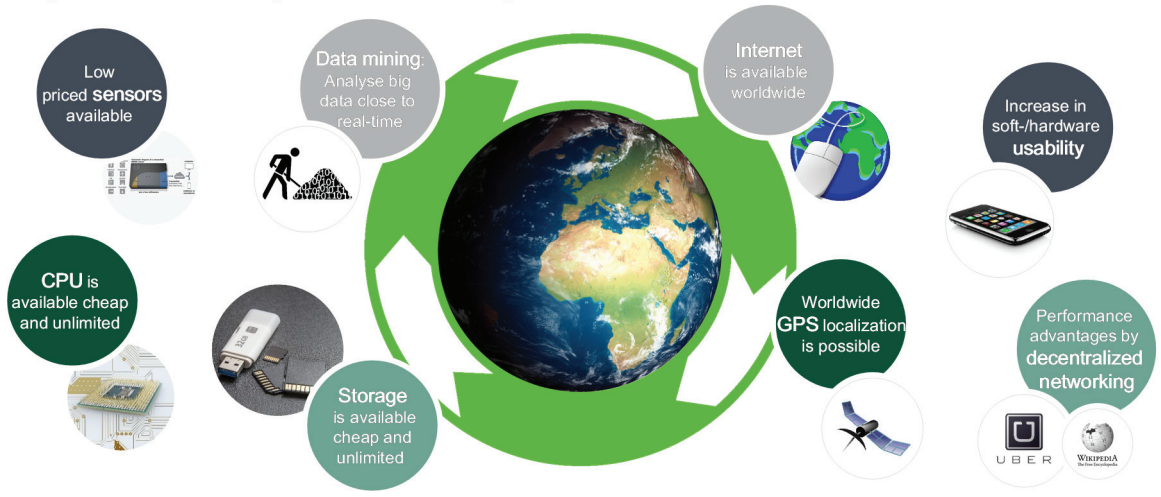
Industry 4.0 live at Bosch
Important changes in recent years



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Industry 4.0 live at Bosch
Industry 4.0: challenges & chances

- Volatile markets
- Individual customer requirements
- Shortened delivery times
- Shortened product life cycles
- 24/7 worldwide service
- Social behavior, new cooperation
- Disruptive business models

Added value potential for Germany ≈ 80 bn €[1]

there of:

- 15 bn €
- 23 bn €
- 12 bn €

390.000 additional workplaces[2]

there of:

- 50.000
- 95.000

automobile & -parts · machine building · electrical equipment

1) Added value potential of selected industries until 2025 by I4.0 in Germany; Source: Industrie 4.0 – Volkswirtschaftliches Potenzial für Deutschland; Studie BITKOM 2014
2) Added new workplaces until 2025 by I 4.0 in Germany; Source: BCG Study for Wirtschaftswoche

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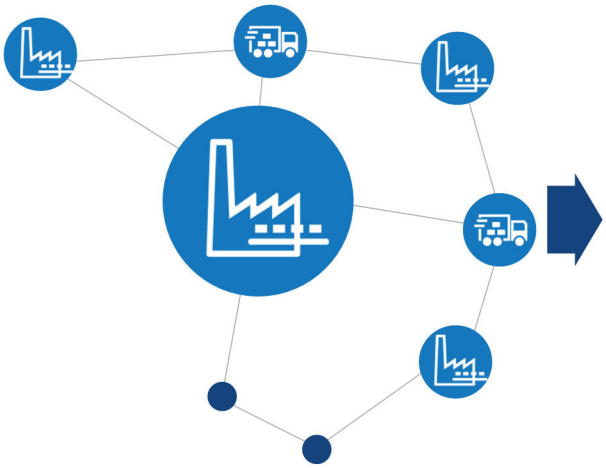
Industry 4.0 live at Bosch

Industry 4.0:definition



Fusion of the **physical world** of production with the **virtual world** of information technology and the internet.

Humans, **machines**, **objects** and **systems** are **connected** via ICT and the internet and communicate in a dynamic, real time optimised and self-organised way.

In these **intelligent production systems**, **all instances** of the added value chain from the supplier over logistics to the customer are connected **across the company**.

The industrial production can implement **individualized customer requests** on the well-known high-quality level, while reaching higher **flexibility** and **robustness** as well as **optimal resource allocation**.

ICT = Information and communication technology

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Industry 4.0: the next industrial revolution

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Features of Industry 4.0
Fast integration and flexible configuration
Open standards
People as key players
Distributed intelligence
Virtual real-time representation
Secure value-creation network
Digital life-cycle management
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Industry 4.0 live at Bosch
i4.0 feature: people as key players
People play the decisive role in the connected plant
• Decisions based on contextual digital information
• Mastering complexity through new ways of visualization and operation
New ways of learning
• Individual integration of the employee in the work process
• Assistance functions and ability amplifier for people
• Health and well-being through adaptive workplace ergonomics
8
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Industry 4.0 live at Bosch
i4.0 feature: virtual real-time representation

Virtual real-time representation of objects and their states

- Assignment of real objects to their virtual image through unique identification
- Virtual description of manufacturing and assembly processes
- Acquisition of real object properties and real-time updating of the virtual image
- Simulation of processes based on the real-time virtual representation
- Objects with digital memory

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Header of section

- MoVie CP/LOG Mannheim Process forum (Check with Andreas Müller NEUMANN)
- https://inside-ilm.bosch.com/irj/go/km/docs/room_extensions_rb_2/cm_stores/documents/workspaces/1148f411-4281-3310-a5b8-d538412ff29d/Logistics%20for%20I4.0/TraQ/Videos/TraQ_%20The%20Vision

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i4.0 feature: digital life-cycle management

Engineering on the basis of all relevant information relating to the life cycles of products, machinery, and plant

- Seamless integration and processing of all data along the value stream
- Automation, acceleration and protection of engineering and business processes
- Evaluation and optimization of simulated scenarios (workpiece-quantity, machinery, value-stream scenarios ...)

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i4.0 feature: secure value-creation network

Secure cross-company value-creation networks

- Secure infrastructure for people, processes, and data
- Protection of the means of production and the company's IT systems from attacks and disturbances (data security)
- Unique tamper-proof digital identity for each intelligent component, machine, and product
- Tight and secure collaboration between people and machines (safety)

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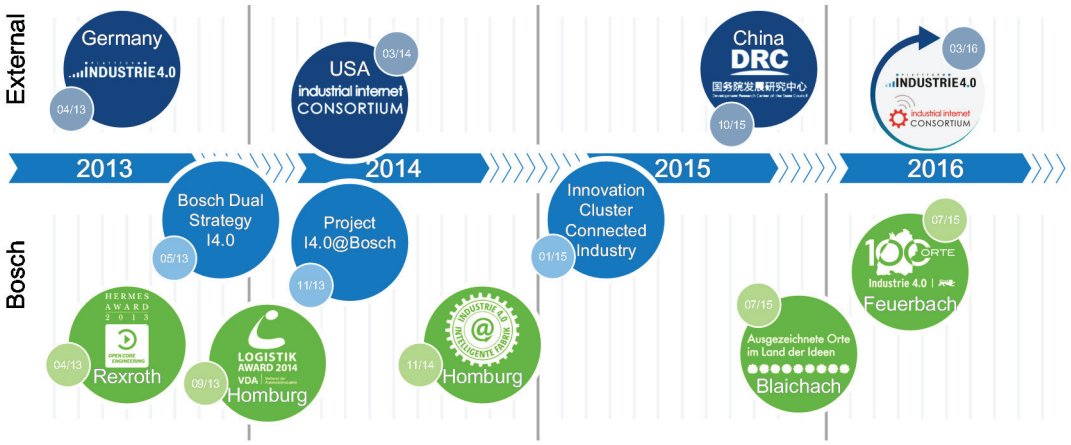
i4.0 our journey and achievements



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Dual strategy for Connected Industry

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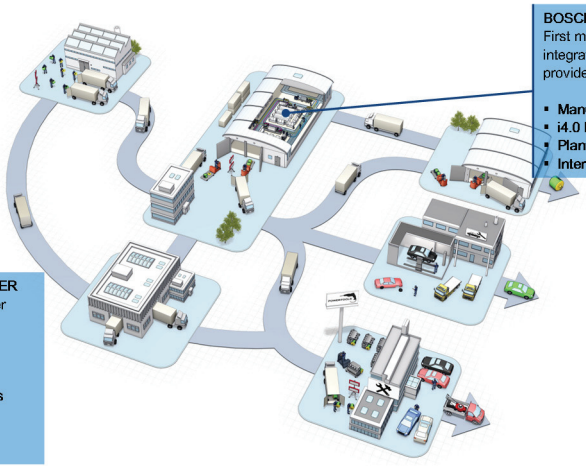
Industry 4.0: example plant



BOSCH AS LEADING USER
First mover in the realisation of integrated concepts with equipment providers

- Manufacturer of products with i4.0
- i4.0 Machine operator
- Plant operator
- Interface to customers/suppliers

BOSCH AS LEADING PROVIDER
Technology and solution supplier for OEMs and end users

- i4.0 software solutions
- i4.0 services
- i4.0 components and systems for automation
- Machines for Packaging Technology

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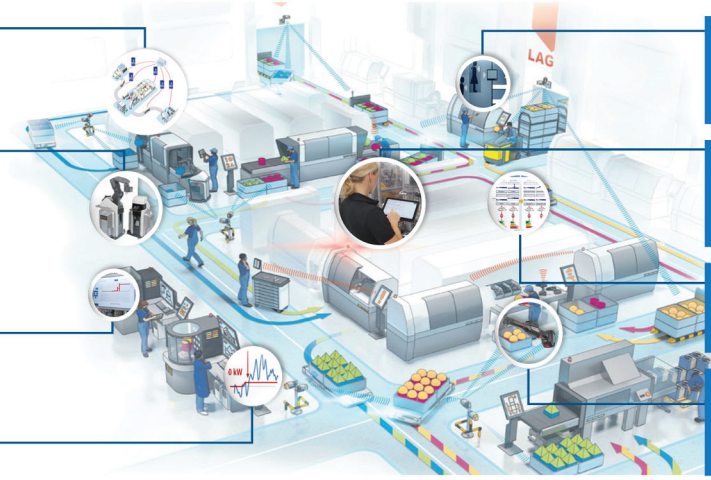
Industry 4.0 live at Bosch
i4.0 use cases and benefits – examples

Digital Supply Chain
- ✓ stock saving
- ✓ efficiency increase
- ✓ transparency along supply chain

Convertible Equipment
- ✓ fix cost reduction
- ✓ efficient M2H collaboration
- ✓ human relief of heavy load / repetitive tasks

Shop Floor Mgmt. Information
- ✓ real time data
- ✓ fast escalation
- ✓ paperless

Power / Energy Management
- ✓ peak reduction
- ✓ energy cost saving



Operator Support
- ✓ agility & quick reaction
- ✓ quality increase
- ✓ efficiency increase

Predictive Maintenance
- ✓ improve OEE
- ✓ no sudden breakdown

Adaptive Testing
- ✓ increase efficiency
- ✓ less invest

Quality Improvement
- ✓ instant feedback
- ✓ fast identification of error sources

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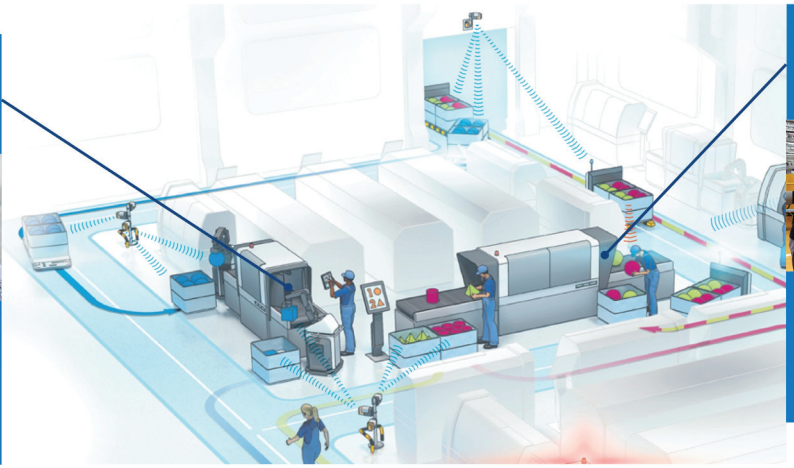
Robots share the load:
Handling of dangerous, strenuous, or monotonous tasks so associates don`t have to.

The APAS Family:
The mobile production assistants of the APAS family already work hand in hand with their human colleagues.

APAS: Automated production assistant



Round or angular?:
Components tell machines how they need to be shaped. The system then adjusts itself accordingly.

Bosch Rexroth in Homburg:
A manufacturing system with batch size of one already is in place producing many products on one line.

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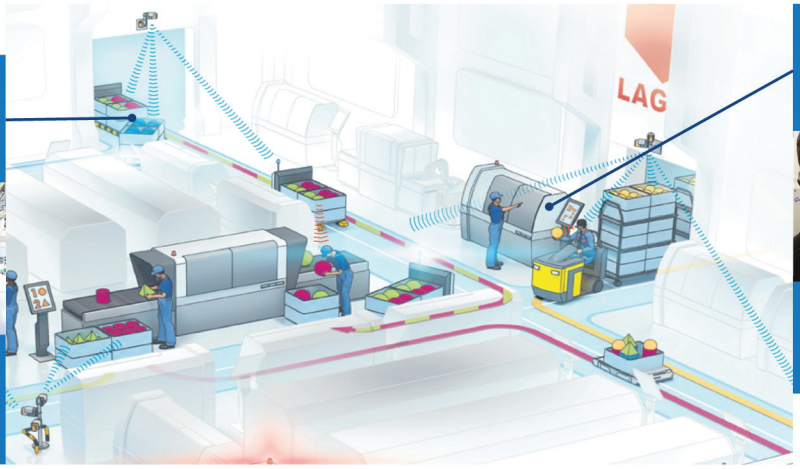
Flows of Goods, digitally recorded:
Due to automatic data capture the supply chain is virtually mapped and logistics are optimized.

RFID technology:
In pilot projects the plant is already aware of the condition of products and containers via RFID technology.



Faster Work with technical aids:
Warehouse associates receive their orders and operating instructions directly on displays.

Smart glasses:
Technical aids like smart glasses make work easier. Initial tests are being conducted in Bosch plants.

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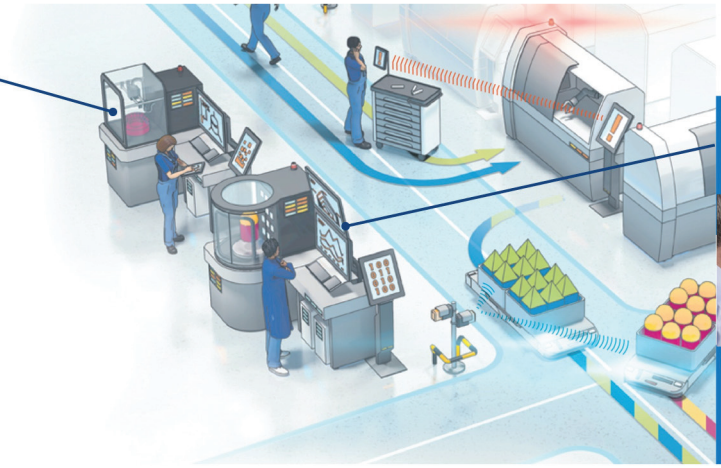
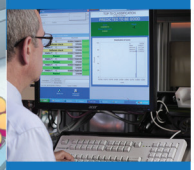
Models at top speed:
A component is drafted on the computer, sent to the device, and produced there from a base material.

Rapid prototyping:
3D- printers have a place in the smart production. One application at Bosch is prototype production.



Predictive quality:
Close examination of questionable parts based on millions of data points.



Data mining for quality:
At the Anderson plant in the U.S. "data mining" already gets used to improve quality.

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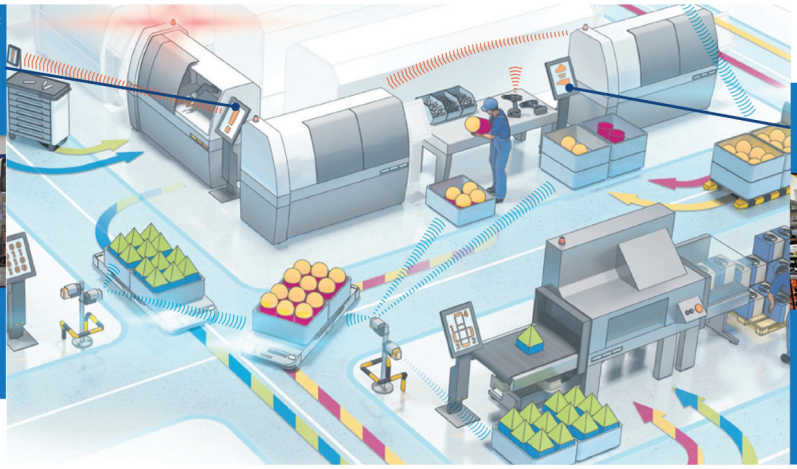
Facilities predict problems:
Smart lines analyze data and report problems directly to the service department.

Predictive Maintenance:
A pilot is up and running at Bosch. Bosch Software innovations offers this type of solution.



Data from Tools:
Tools are networked and send important data to server for quality proof.

"Nexo" Smart Tightening:
Screwdriver is able to measure and submit the tightening torque and screwing angle for quality prove.

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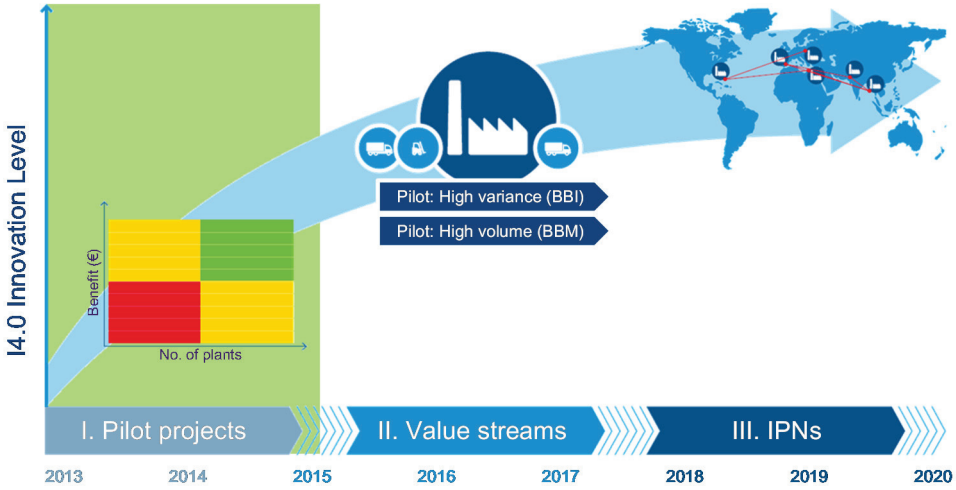
Industry 4.0 live at Bosch
Implementation roadmap



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Logistics with RFID

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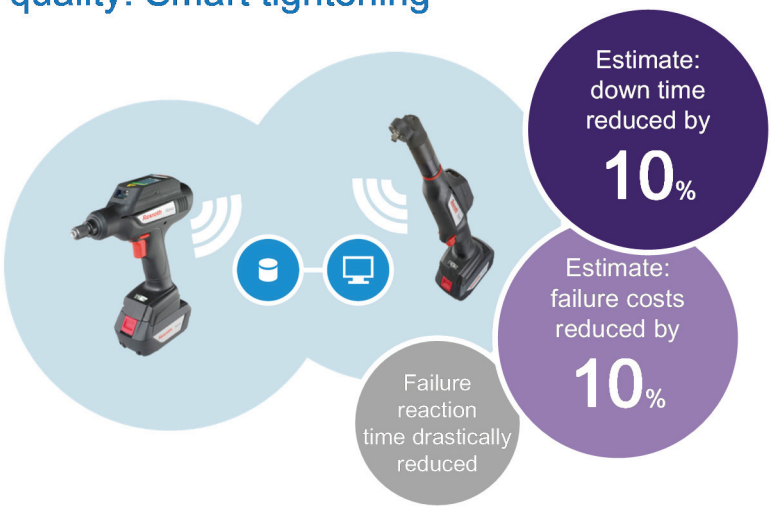
Production quality: Smart tightening



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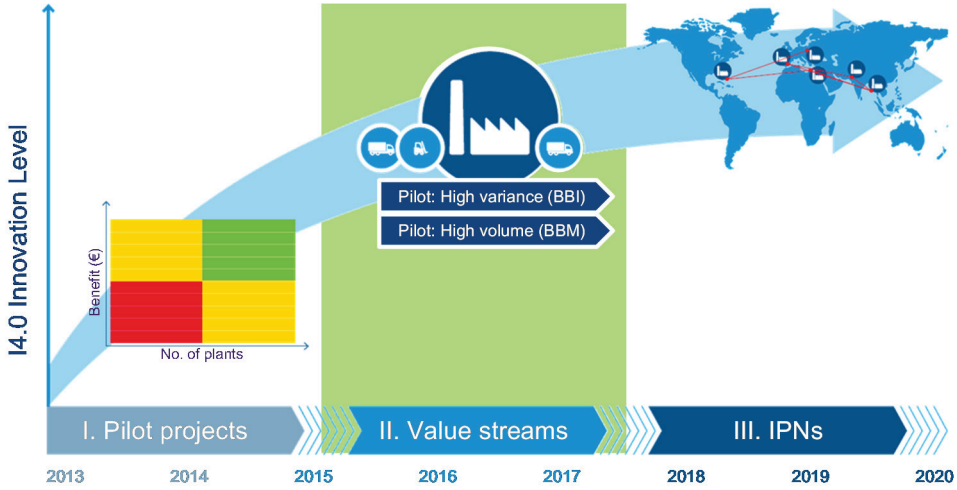
Industry 4.0 live at Bosch
Implementation roadmap



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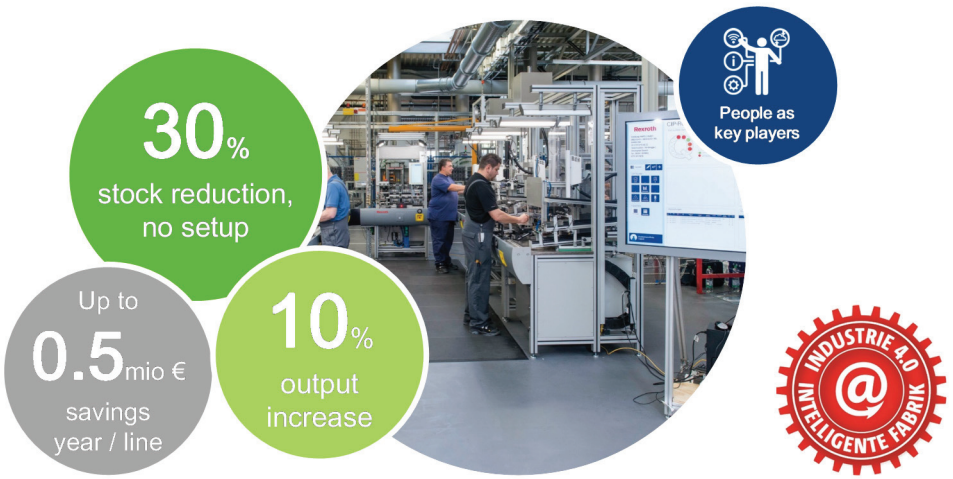
Industry 4.0 live at Bosch
i4.0 in an entire line – example Homburg



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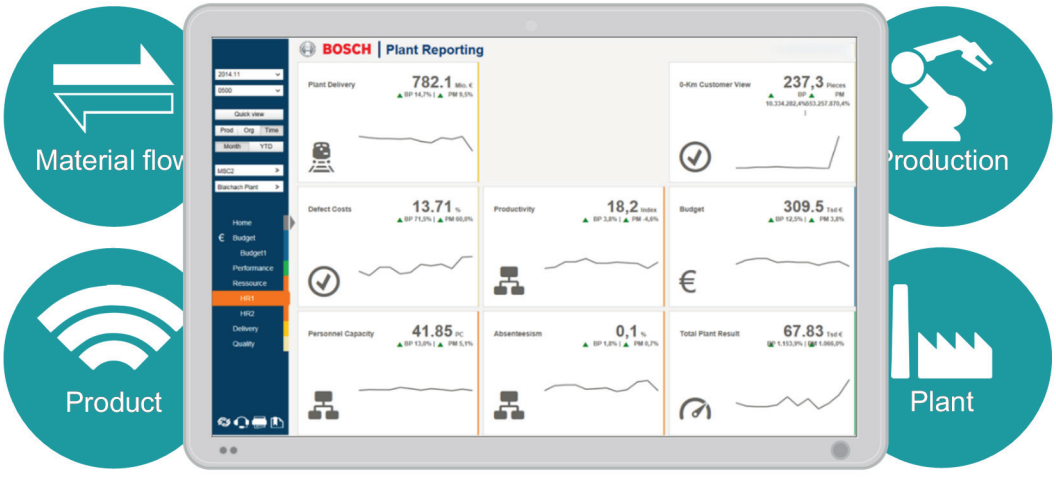
Industry 4.0 live at Bosch
i4.0 in an entire plant – example BhP



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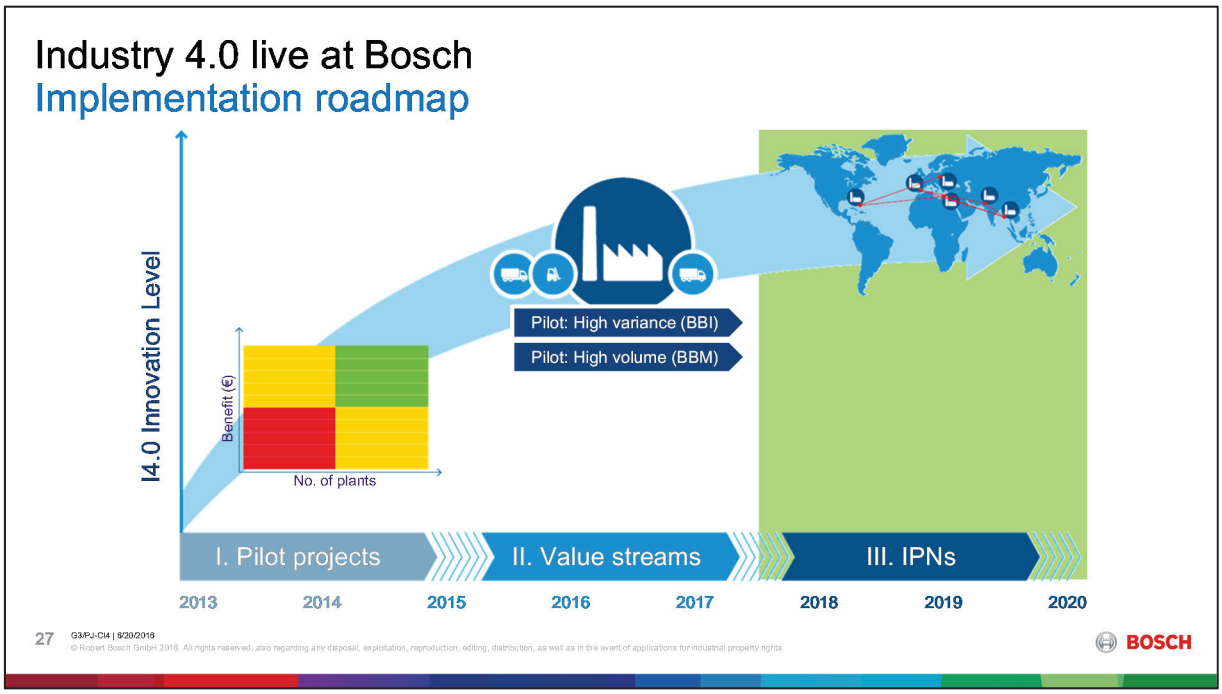
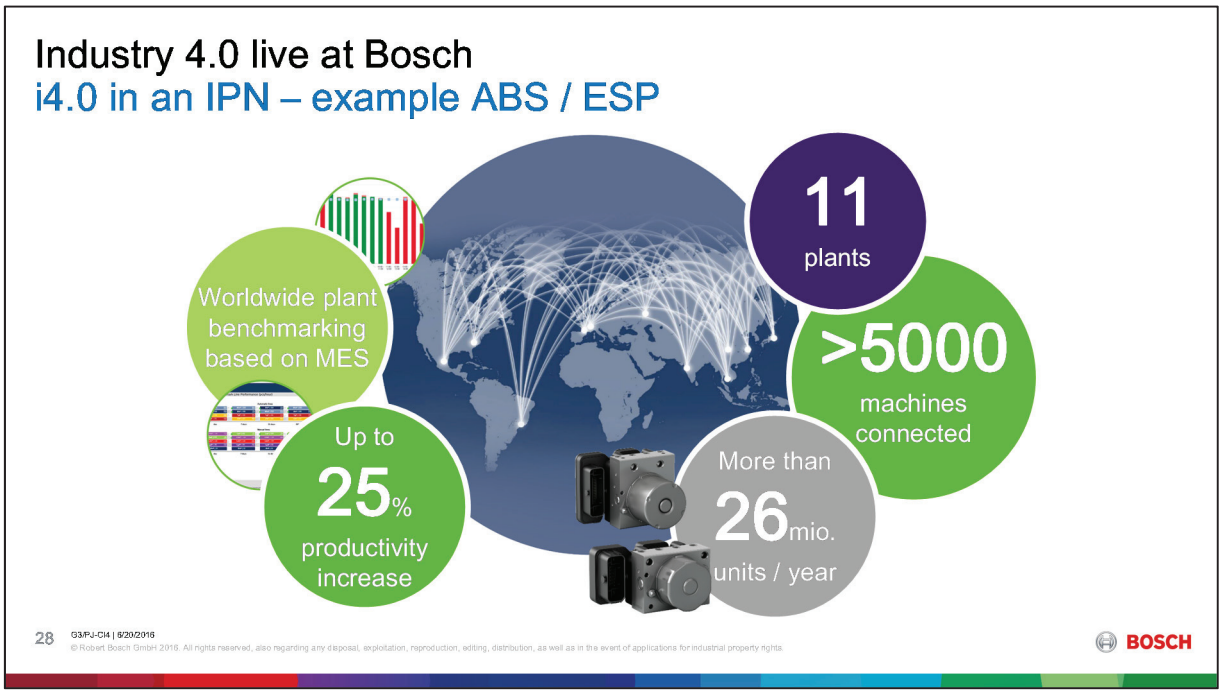
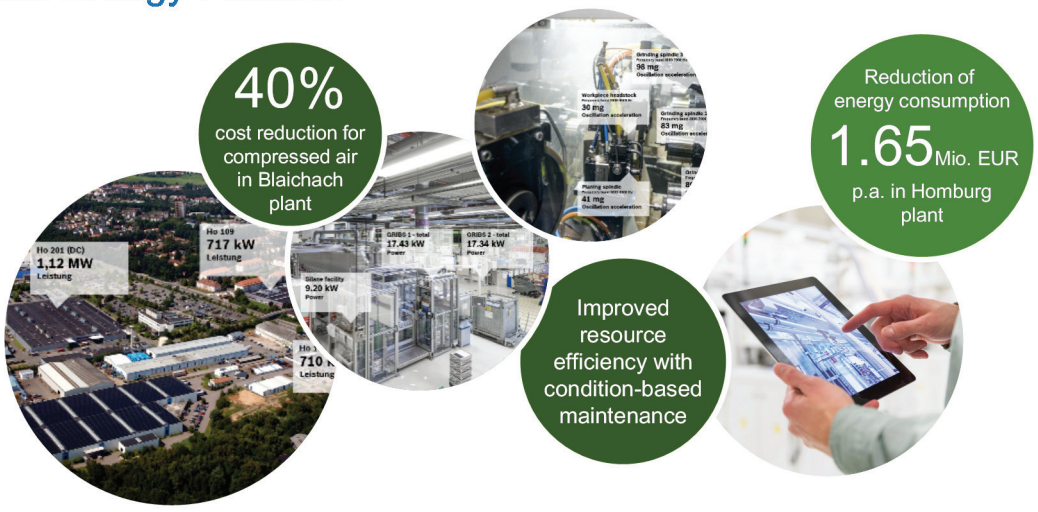

Industry 4.0 live at Bosch
Implementation roadmap
I4.0 Innovation Level
Benefit (€)
No. of plants
Pilot: High variance (BBI)
Pilot: High volume (BBM)
I. Pilot projects
II. Value streams
III. IPNs
2013
2014
2015
2016
2017
2018
2019
2020
27
BOSCH


Industry 4.0 live at Bosch
i4.0 in an IPN – example ABS / ESP
11
plants
>5000
machines
connected
Worldwide plant
benchmarking
based on MES
Up to
25%
productivity
increase
More than
26mio.
units / year
28
BOSCH

Industry 4.0 live at Bosch
Bosch Energy Platform



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Industry 4.0 live at Bosch
People as key players

- Extended space for decisions and participation
- Opportunities for stress regulation
- New challenges and opportunities for engineer´s and skilled worker´s knowledge

Criterion for success: i4.0 ≠ "CIM 2.0"

CIM: Computer Integrated Manufacturing

Physical assistance
by amplification of capability

Innovative forms of learning mobile, personalized, situative

Networked working
by multi-modal interaction human-machine and human-human

Maintenance and planning assistance
location-based, context-adaptive

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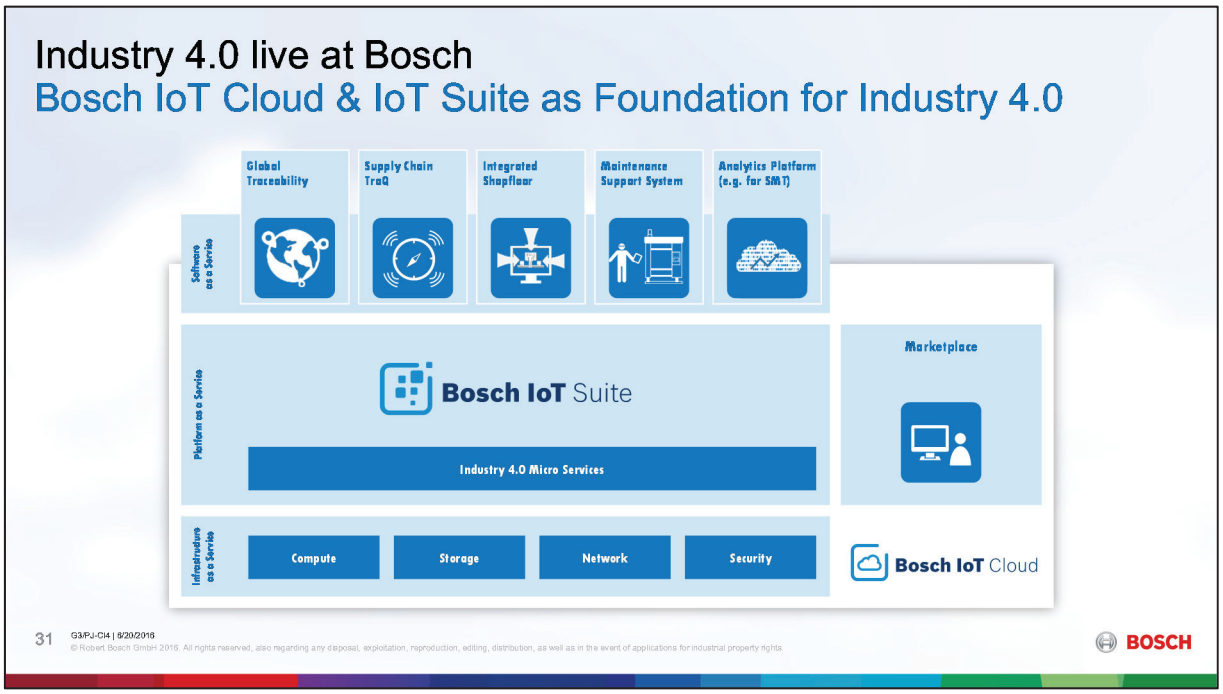
Industry 4.0 live at Bosch
Bosch IoT Cloud & IoT Suite as Foundation for Industry 4.0
Global Traceability
Supply Chain TraQ
Integrated Shopfloor
Maintenance Support System
Analytics Platform (e.g. for SMT)
Software as a Service
Platform as a Service
Bosch IoT Suite
Industry 4.0 Micro Services
Marketplace
Infrastructure as a Service
Compute
Storage
Network
Security
Bosch IoT Cloud
31
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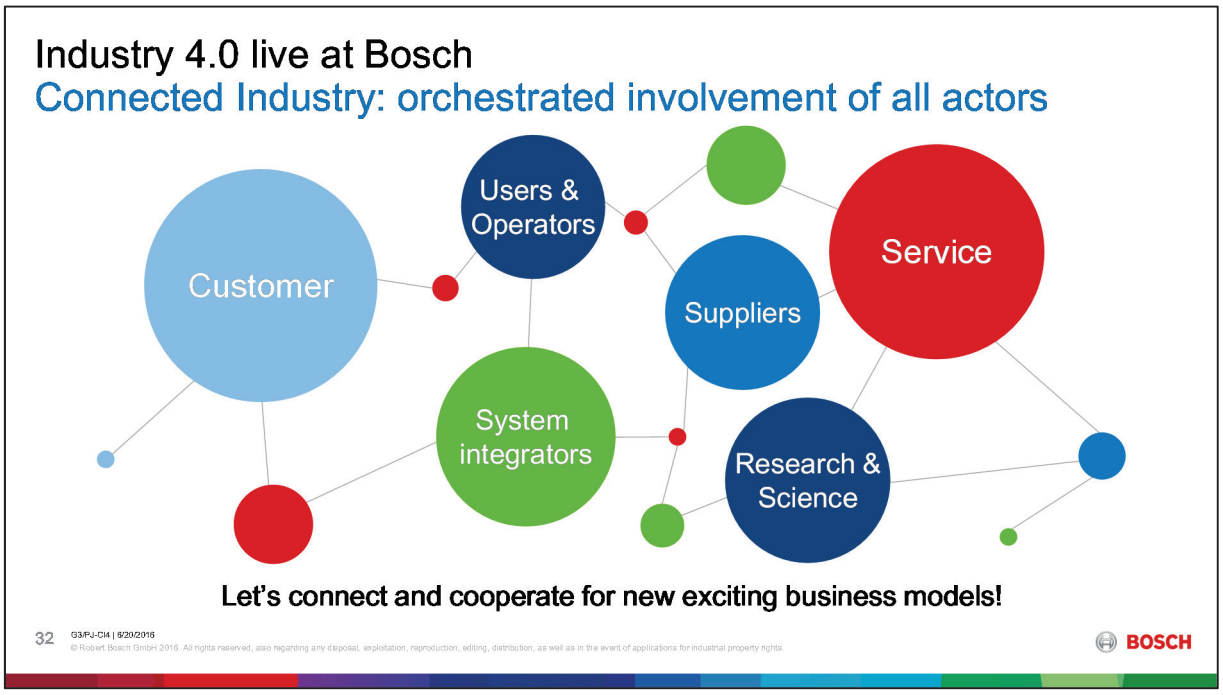
Industry 4.0 live at Bosch
Connected Industry: orchestrated involvement of all actors
Customer
Users & Operators
Suppliers
Service
System integrators
Research & Science
Let's connect and cooperate for new exciting business models!
32
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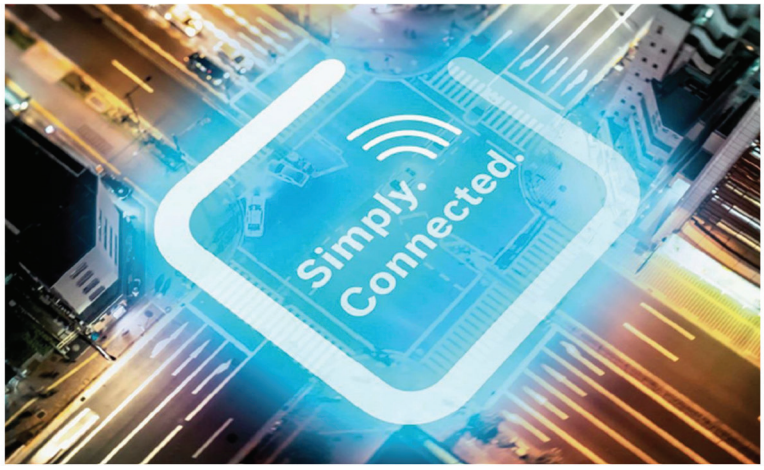
Thank You!



Bosch IoT Cloud will play a key role in industry

- Sensors, software, services and now Cloud enable new business models in industry

Industry 4.0 is a people`s business

- People and partnerships play the decisive role in the connected plant

Invented for Life

- The Bosch IoT Cloud together with Industry 4.0 will make life easier

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THANK YOU FOR YOUR ATTENTION!

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Celso Luis Placeres é Diretor da Engenharia de Manufatura da Volkswagen do Brasil desde 2011 e Vice-Presidente da VDI - Associação de Engenheiros Brasil-Alemanha, desde 2010. Graduado em Engenharia Mecânica pela FEI, com especialização em Visão Estratégica de Negócios na FGV – Fundação Getúlio Vargas e Gerenciamento de Projetos na *George Washington University* ("*in company*"), Placeres iniciou sua carreira na Volkswagen em 1985 como Engenheiro de Instalações Industriais. Em 2003 fez parte do programa "*Group Junior Executive*" da VW Alemanha e em 2007 do programa "*Skills, Tools and Competences* – STC", realizado pela FDC Brasil e pela *Kellogg University* de Chicago. Entre suas funções estratégicas, está o trabalho contínuo para a modernização dos processos produtivos das quatro fábricas da Volkswagen no Brasil, no sentido de possibilitar uma maior produtividade, eficiência e qualidade nas linhas de montagem, cada vez mais ergonômicas e que garantam a excelência operacional aos colaboradores.

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Volkswagen do Brasil

Instalada no Brasil desde 1953, a Volkswagen do Brasil é uma das maiores empresas privadas do País. A unidade de São Bernardo do Campo foi a primeira a fábrica construída pela Volkswagen fora da Alemanha. A empresa conta com a maior rede de distribuição, com aproximadamente 600 concessionárias no território nacional, e cerca de 18 mil empregados em suas quatro fábricas: São Bernardo do Campo, Taubaté e São Carlos, em São Paulo, e São José dos Pinhais, no Paraná. Ao longo de sua trajetória de mais de seis décadas no País, a Volkswagen do Brasil acumula marcas expressivas: mais de 22 milhões de veículos produzidos, mais de 3 milhões de veículos exportados e vendas internas que superam 18 milhões de unidades. A empresa conta com o maior portfólio de produtos do mercado nacional e foi pioneira em diversas tecnologias no País, como a TSI, que combina alto desempenho e baixo consumo, assim como o Total Flex e a injeção eletrônica.

Manufatura Avançada: A era das fábricas inteligentes

Resumo

A "Indústria 4.0" ou "Manufatura Avançada", como intitulam os americanos, está influenciando as indústrias a pesquisar formas de auto-gestão e interligação plena de informações, a procurar flexibilidade e rapidez nos processos, que viabilize a máxima customização e competitividade de seus produtos, bem como levar a indústria a total conectividade das informações de produção e logística. O que era antes apenas uma iniciativa pontual de automação, passou agora a ter uma visão muito mais abrangente e sistematizada da gestão da produção e fornecimento de indicadores de forma plena e automática. Um dos pilares importantes dessa nova era da Industria é a "Fábrica Digital", que compõe um conjunto de tecnologias de softwares que integram diversas informações em um ambiente virtual. A Digitalização visa dominar a complexidade de processos e sistemas em rede para uma tomada de decisão rápida, transparente e sistemática no processo operacional oferecendo economias em custos para o empreendimento, tais como, redução do desenvolvimento do Produto e processo, Comissionamento antecipado das instalações, aumento da disponibilidade do processo, redução de retrabalhos, antecipação da identificação das interferências do Produto no processo. Por esse motivo temos cada vez mais a necessidade de cooperação e intercambio com Universidades e parceria com fornecedores de máquinas e equipamentos para o desenvolvimento da auto-gestão.

Palavras - Chave

Indústria 4.0; Manufatura Avançada; Flexibilidade; Conectividade; Fábrica Digital.

1 Introdução

As empresas de manufatura estão constantemente diante de pressões competitivas, que podem ser traduzidas como a redução do tempo de entrega, as inúmeras ofertas dos concorrentes, a baixa de preços e os novos entrantes (MARTIN et al.,1994).

Novos patamares de produtividade são necessários para fazer frente a este ambiente ampliado da concorrência. A exigência do consumidor por variedade e personalização traz à tona a necessidade de flexibilidade, algo não tão simples de ser transferido para o processo produtivo. O uso da tecnologia já é uma realidade na produção e serve de base para a inovação em produto e processo, mas impõe desafios, como o volume de investimento necessário. As constantes alterações no mercado não permitem uma visualização mais clara do cenário competitivo, fazendo com que as indústrias sofram de uma incerteza crônica. Portanto é árdua a tarefa de elaborar estratégias de manufatura que coloquem a empresa em um plano vantajoso com esta realidade.

Nesse cenário a indústria 4.0 como vem sendo chamada pela Alemanha ou Manufatura Avançada, como intitulam os americanos está influenciando as indústrias a pesquisar formas de auto-gestão e interligação plena de informações, a procurar novas formas de processo que viabilize a máxima customização de seus produtos bem como levar estas indústrias a avaliar as melhores formas de conectar as informações de produção e logística. O que era antes apenas uma iniciativa pontual de automação, passou agora a ter uma visão muito mais abrangente de gestão e fornecimento de indicadores de forma plena e automática.

Para a Volkswagen, esse novo conceito nada mais é do que uma fusão completa dos sistemas de produção com as atuais tecnologias da chamada ITC (*Information Technology and Communication*). Isto descreve o desenvolvimento real de nossas habilidades atuais e uma interligação inteligente e completa de pessoas, objetos e sistemas, utilizando todas as possibilidades tecnologicas em toda a cadeia de valor. A abordagem principal dessa manufatura avançada é equipar futuros produtos e sistemas de produção com sistemas embarcados baseados em sensores e atuadores inteligentes para possibilitar a comunicação e controle de operação inteligente.

A indústria automotiva é uma das manufaturas mais complexas em quantidade de peças e informação além de possuir um alto grau de automação em seus processos, cada veículo nasce de milhares de peças, e neste processo, cada etapa esta gerando e solicitando informação. Hoje a produção é governada pelo fluxo de informações. Os pedidos dos clientes nascem nas concessionárias e chegam desde os níveis corporativos até o chão de fábrica, para o estágio final de produção.

O sistema mundial da Volkswagem utiliza um sistema de controle e informação da produção para execução da manufatura, este sistema fornece para cada estágio individual de

montagem a informação necessária. O sistema recebe *feedback* instantâneo do processo no nível produtivo e acompanha o produto até o seu estágio final controlando toda informação e processo.

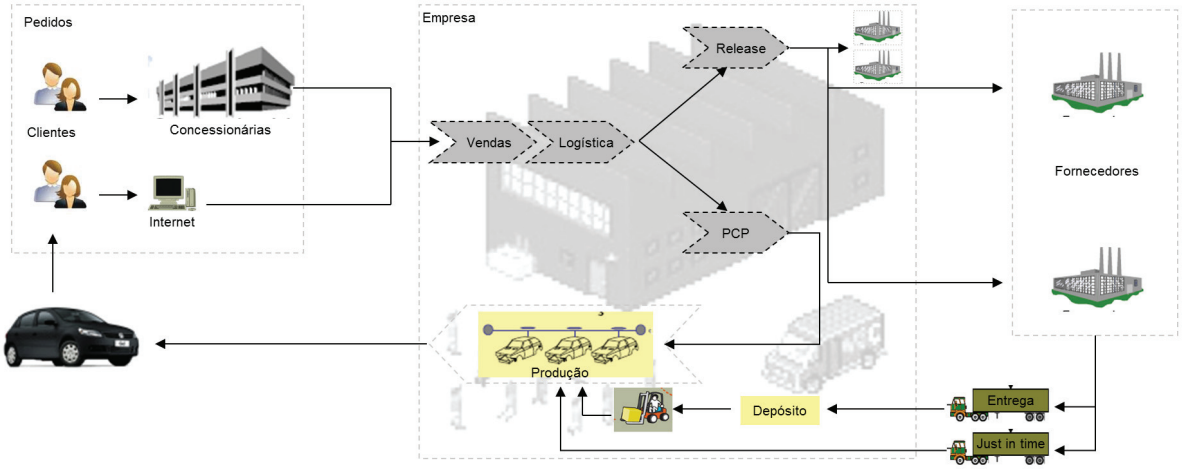

Figura 1 - Visão Geral do Processo

No grupo Volkswagen os veículos são manufaturados no nível do estado da arte. No entanto o desenvolvimento nunca para, novas tecnologias e métodos são agregados constantemente para tornar a manufatura de veículos em uma Fábrica Completamente inteligente, seguindo a tendência global da manufatura inteligente.

Este artigo demonstra através de cases, quais são as tecnologias bases da manufatura inteligente que já estão em funcionamento e quais os próximos passos na visão da Volkswagen do Brasil em relação a crescente popularização do tema.

2 Sistema de Controle e Informação da Produção

Na era da manufatura inteligente, toda a informação da produção é integrada, um conceito conhecido como integração vertical e horizontal das informações, na integração horizontal toda a cadeia de processo se comunica entre si, de forma que a informação é compartilhada por toda a linha de produção.

Na integração vertical, a informação também é compartilhada com os demais sistemas da fábrica de modo que os sistemas de controle de produção se comunicam com os sistemas de ERP (*Enterprise Resource Planning*) ou desenvolvimento do produto (PLM - *Product Life Management*).

Como exemplo de Integração horizontal, a Volkswagen possui o seu sistema de controle e informação da produção. Um sistema utilizado globalmente para a fabricação de veículos em todas as plantas e controle de qualidade dos produtos Volkswagen.

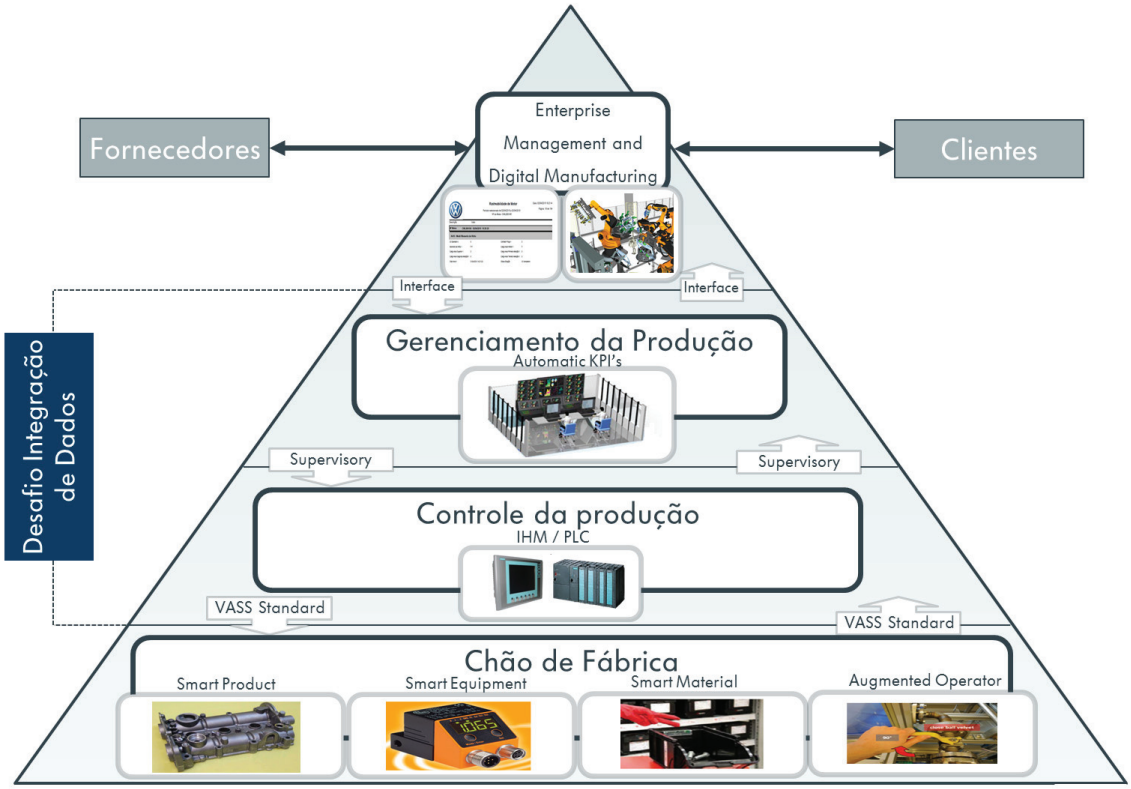

Figura 2 - Integração horizontal e vertical

Quando o pedido entra para a produção, o processo de manufatura do veículo se inica, a estamparia manufatura peças para a armação na quantidade e modelo solicitado. Uma vez que as peças existem, isso é onde os *bits* e *bytes* se juntam a carroceria pela primeira vez. Cada peça bruta recebe um tag RFID (*Radio-Frequency Identification*), que é utilizado tanto no processo de solda de carroceira, quanto no processo de pintura, onde a informação no sistema de controle determina a cor do carro. No armazenamento sequecial, o sistema determina a produção ideal para a sequência da montagem final. Os pontos de checagem do processo fornecem informações e operações de pré montagem com informações sobre cada parte, dizendo onde e quando são necessárias, até que na montagem final o veículo é finalmente produzido.

Figura 3 - Etapas do processo

Uma das tecnologia de manufatura inteligente que já faz parte da utilização na Volkswagen, é a tecnologia de identificação e acompanhamento de processos por *transponders* (RFID).

2.1 RFID na Indústria moderna

A identificação de carrocerias cria um grau de independência do processo produtivo perante o sistema central de planejamento e controle de produção. As informações necessárias para a produção da carroceria são gravadas em um elemento de identificação, e posteriormente lidas em todos os pontos de tomada de decisão, como a seleção de uma lateral de duas ou quatro portas, escolha do tipo de teto, acabamentos, etc. permitindo que o processo seja executado sem a constante comunicação com o PCP.

Na indústria automobilística é comum a utilização de elementos como etiquetas com código de barras, *Data Matrix* e marcações nos *skids* de transporte para a identificação de modelos.

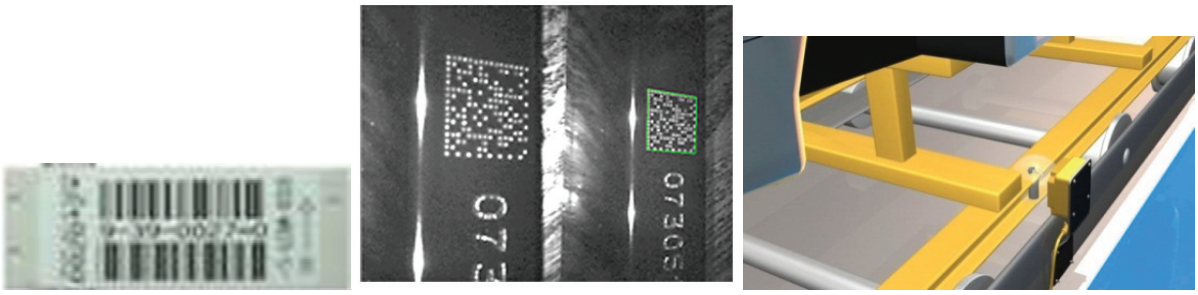

Figura 4 - Etiquetas de marcação utilizadas na indústria automobilística

Atualmente usada nos mais diversos segmentos e para as mais diversas finalidades, como pagamentos *mobile* (NFC), controle de rebanhos da pecuária, controles de acessos, entre outros, o RFID é uma tecnologia de identificação por rádio frequência para rastreabilidade e acompanhamento, que basicamente envolve a comunicação entre um receptor e uma etiqueta. A aplicação de RFID rompe barreiras e abre uma gama de oportunidades dentro da indústria.

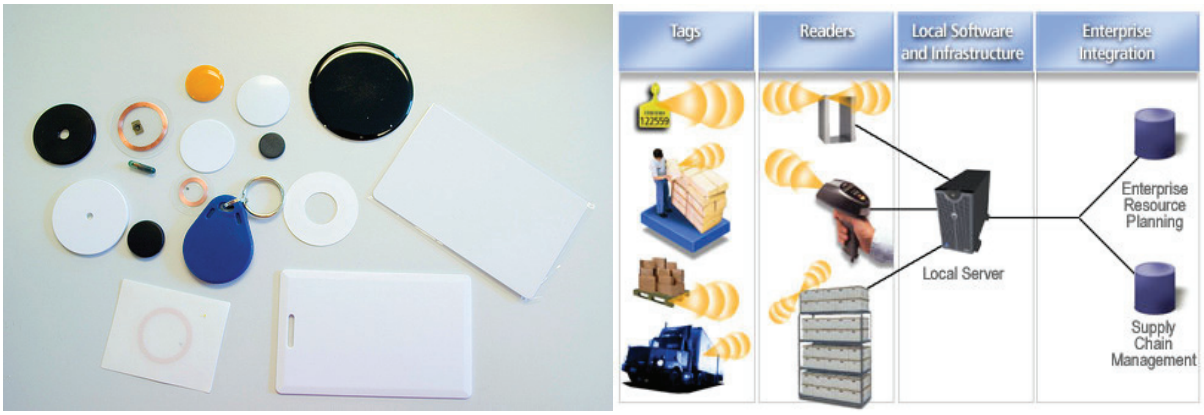

Figura 5 - Tecnologia RFID

Na linha de produção, o RFID armazena nas etiquetas, informações de montagem, dados de qualidade e mão-de-obra.

Em lugar de simplesmente se colocar uma etiqueta e seguir passivamente um produto dentro de uma linha de produção, o RFID fornece muito mais informações e poderá até interferir na produção. Por exemplo, se a resposta à consulta ao sistema for que determinada peça está acabando no estoque, ele pode informar isso e então todas as outras máquinas na fábrica podem ser reprogramadas para fabricar os produtos com as peças em estoque, enviando a informação a um fornecedor remoto de que um novo item é necessário, automaticamente sendo enviado à máquina certa a tempo. Ao mesmo tempo, uma segunda fonte de fornecedores pode ser alertada. O resultado pode ser enormes economias em tempo e custos sem afetar a capacidade produtiva das fábricas.

Essa tecnologia permite também uma interação maior entre o planejamento e o processo produtivo através de um sistema de gestão ou software MES (*Manufaturing Execution System*), gerando uma maior agilidade em atender um cliente, um importante diferencial competitivo.

2.2 Controle e rastreabilidade do processo: medição e controle da carroceria

Outra tecnologia já utilizada pela volkswagen é o controle dimensional automático, o sistema de controle e rastreabilidade do processo é realizado automaticamente através da medição da carroceira, por equipamentos instalados na linha de produção. Com isso, é realizada a medição de 100% da produção, assegurando melhorias de qualidade;são detectadas as tendências de falha antes de a falha ocorrer, reduzindo custos de retrabalho e desperdício; e permitir o controle do processo a distância eliminando complexidade no processo de medição em salas de medida.

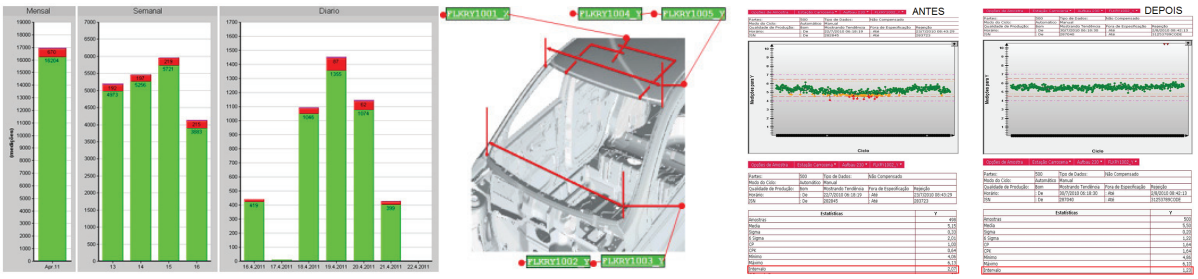

Figura 6 – Relatórios de medição

Na linha de produção, os robôs realizam o controle dimensional em tempo real ao produzido. Todas as carrocerias são controladas e o sistema gera informações para um banco de dados armazenando as informações de cada produto, permitindo gerar relatórios de acordo com as necessidades da área de ajuste e qualidade. O sistema permite configurar alertas para as relações dimensionais que se aproximam dos limites de rejeição e tolerâncias, podendo ser por mensagem SMS ou e-mails. As linhas de produção param automaticamente quando um

produto ultrapassa desvios permissíveis. Todas as plantas da Volkswagen do Brasil possuem estações de controle dimensional em seus processos.

Figura 7 - Robôs de Medição

Para essa nova era da Indústria 4.0, o desafio para a Volkswagen é a conectividade. Um dos objetivos é estar diretamente conectado com os processos de nossos fornecedores e seus bancos de dados de controles dimensionais, permitindo que a certificação e monitoramento da Volkswagen aos processos de seus fornecedores sejam feita a distância e eliminar a necessidade de re-certificação após que os produtos dos fornecedores adentrem as plantas da Volkswagen.

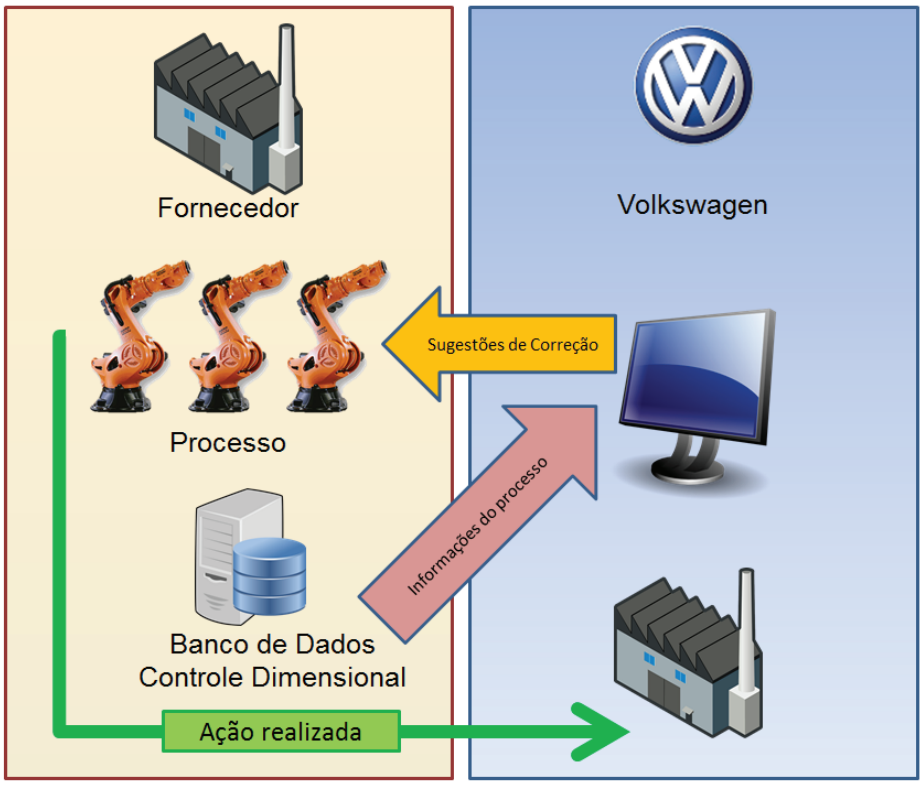

Figura 8 - Desafio de conectividade para Volkswagen do Brasil

Outro objetivo da conectividade é que os sistemas de controle dimensionais automatizados estejam conectados aos processos produtivos de forma a sugerir aos especialistas das linhas os ajustes necessários no processo sem necessidade de interpretar relatórios, ou seja, a máquina irá interpretar os desvios e sugerir que etapas do processo devem ser corrigidos e como devem ser corrigidos.

Um passo mais longe, o sistema permitirá que o processo se auto corrija de acordo com os resultados obtidos na medição.

Apesar da tecnologia ainda não estar em pleno funcionamento devido a restrições de infra-estrutura, a mesma já existe e está pronta para ser utilizada a partir do momento que os demais processos, também estiverem conectados, formando a rede que vem sendo chamada de integração horizontal.

2.3 Rastreabilidade de Torque na Montagem Final

No processo de montagem final do veículo, existe o controle de rastreablidade de torque para parafusadeiras e parafusos que é uma tecnologia que também já faz parte do cenário 4.0.

Na montagem final do automóvel as peças são acopladas à carroceria por vários métodos de fixação como: cola, rebite, encaixe mas o processo mais frequente sem dúvida são as juntas parafusadas.

Através de parafusos são montados desde peças pequenas com função apenas estética até grandes peças de segurança como rodas ou cintos de segurança.

Os parafusos têm a função não de simplesmente unir, mas unir garantindo determinada força de união. Não é possível medir diretamente a força de união entre duas peças, então o que se faz é a analogia com o torque aplicado no parafuso.

O torque é o produto entre a força tangencial e a distância que esta força é aplicada do centro do parafuso.

Para todas as especificações de torque existe uma tolerância e classificação conforme sua severidade:

- A: Itens de segurança: afetam diretamente a segurança ou legislação. Exemplo: freio, combustível, suspensão, direção, cintos de segurança;
- B: Itens significativos: Inviabilizam a dirigibilidade ou que tem histórico de problemas. Exemplo: cabos massa, ar condicionado;
- C: Quando não se enquadra nos itens A e B.

Abaixo, um exemplo da quantidade de fixações no Golf e a proporção entre categorias de torque:

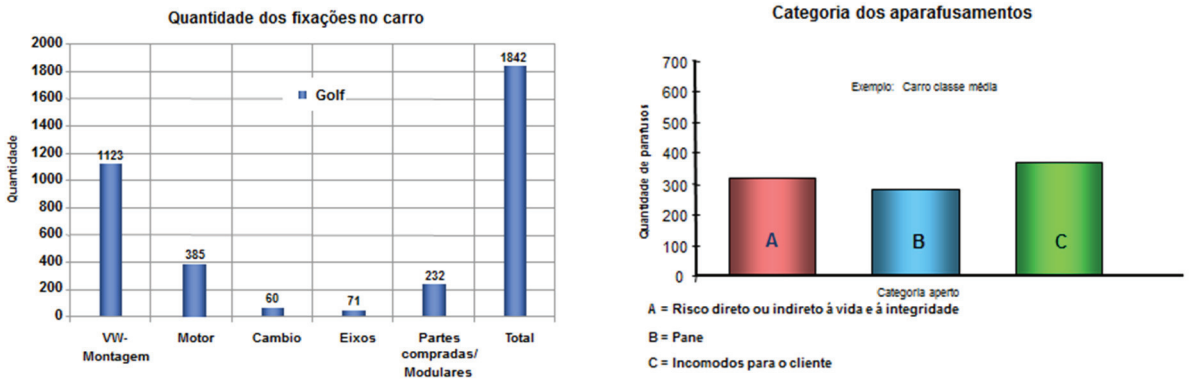

Figura 9 - Quantificação de fixações golf e Categorias de parafusamento

Para os torques de categoria A e B é feito um processo de rastreabilidade eletrônica de torques.

A rastreabilidade de torque significa determinar quando, onde, com que torque e por quem um produto individualmente foi processado.

A informação da rastreabilidade é armazenada em servidores por 15 anos para eventuais consultas posteriores.

Abaixo o fluxo de informações para coleta e armazenamento dos dados dos apertos.

- Entrada da carroceria na Montagem Final;
- Gravação da identificação e acabamentos do veículo em um "*Data Tag*". (VIN, motorização, opcionais, cores);

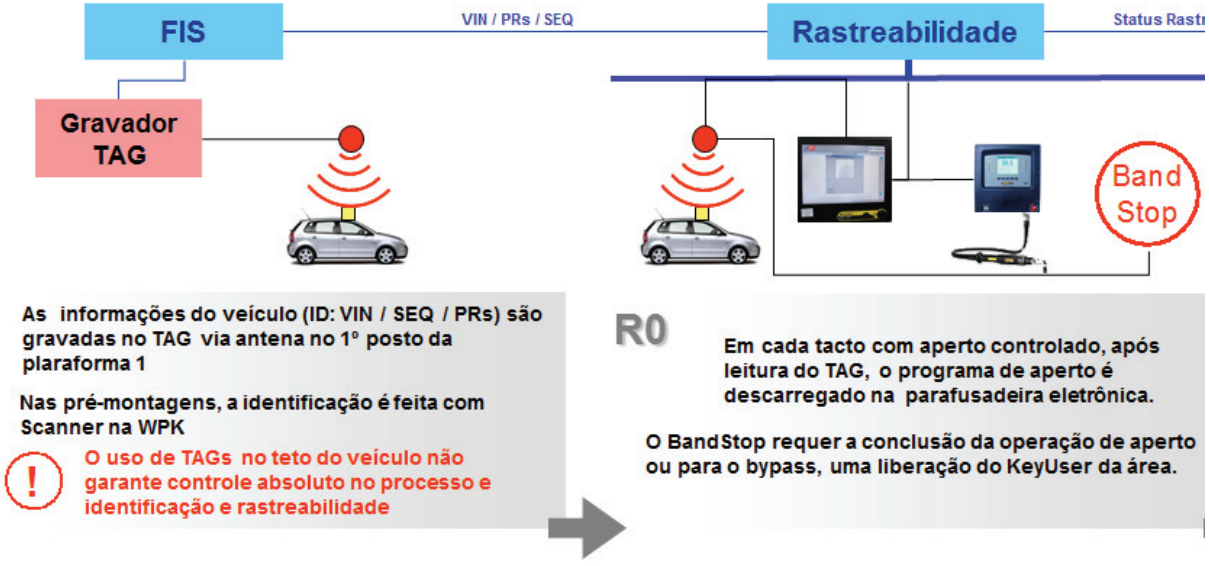

Figura 10 - Fluxo de informações

- Ao entrar no posto de trabalho um computador faz a leitura do *Data Tag* e define quais operações e torques devem ser aplicados pelo operador com uma parafusadeira eletrônica;

Figura 11 - Parafusadeira eletrônica e Leitor de tag

- Ao final da operação no posto o computador reúne os resultados de aperto, data, hora e identificação do operador e envia para um banco de dados no servidor. Somente após isso a carroceria é liberada para seguir ao próximo posto;
- Ao passar por toda a linha o veículo pronto terá a identificação no banco de dados com as resultantes de aperto podendo ser rastreado conforme necessidade.

Esses são alguns exemplo que demonstram como a integração horizontal está operando na Volkswagen.

No entanto quando falamos de integração vertical a Fábrica Digital é um dos pilares que sustenta esse conceito. A Fábrica Digital compõe um conjunto de tecnologias de softwares que integram diversas informações em um ambiente virtual. A Digitalização visa dominar a complexidade de processos e sistemas em rede para uma tomada de decisão rápida, transparente e sistemática no processo operacional oferecendo economias em custos para o empreendimento, tais como, redução do Desenvolvimento do Produto e Processo, Comissionamento antecipado das instalações, aumento da disponibilidade do processo, redução de retrabalhos, antecipação da identificação das interferências do Produto no processo.

3 Fábrica Digital no contexto da Indústria 4.0

De acordo com Rüßmann, M, 2015 do BCG (*The Boston Consulting Group*), nove tecnologias avançadas são bases para a Indústria 4.0, Robôs autônomos, Simulação, Integração horizontal e vertical de sistemas, a internet das coisas, segurança da informação, núvem de dados, manufatura aditiva, realidade aumentada, *Big data* e *Analytics*.

Quando falamos de simulação, na fase de engenharia, simulações 3D de produtos, materiais e processos de produção já são utilizados, a Fábrica Digital compreende um conjunto de tecnologias virtuais que integram diversas informações em um ambiente virtual, possibilitando a simulação, análise, quantificação e planejamento dos processos.

Na simulação virtual o ambiente físico é criado virtualmente antes de sua implementação, no entanto dentro do contexto da Indústria 4.0, esse ambiente virtual representa também uma parte da chamada digitalização da produção, como um espelho do mundo físico no mundo virtual. Utilizando os dados dos processos reais é possivel realizar otimizações de processo e ter ganhos de produtividade significativos sem a necessidade de realizar testes no ambiente de produção, também permite o teste e otimização das configurações de máquinas para a próxima linha de produção que ainda está em planejamento no mundo virtual, antes mesmo de realizar mudanças no mundo físico, garantindo um ganho de tempo no *setup* de máquinas e uma melhora na qualidade. (Rüßmann, et al., 2015).

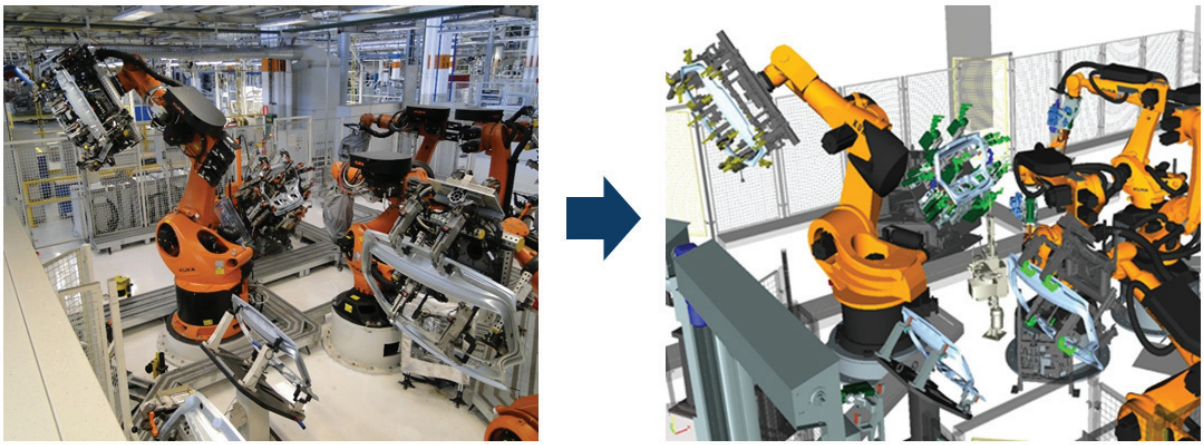

Figura 12 - Ilha de Solda: ambiente físico e ambiente virtual

No futuro, quando a digitalização da produção estiver completa e a integração vertical dos sistemas estiver em pleno funcionamento, a integração com as simulações virtuais será plena de forma que o ambiente virtual terá a informação que está sendo utilizada na máquina em tempo real, sendo assim possível realizar otimizações que serão diretamente aplicadas a produção retro-alimentando o ciclo.

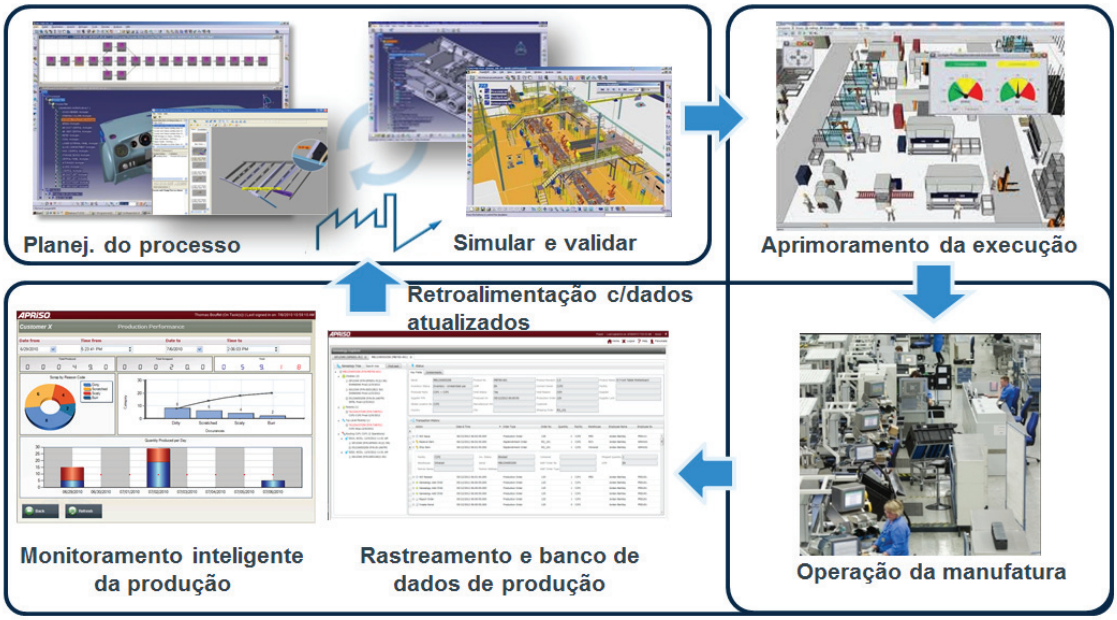

Figura 13 - Futuro da Fábrica Digital com a Industria 4.0

Hoje a Fábrica Digital tem auxiliado na implantação de novos processos e também na otimização de processos existentes, a nova pintura de Taubaté é um exemplo de como a Fabrica Digital tem ajudado na implantação de tecnologias que já estão preparadas para o ambiente 4.0.

4 Case: Nova Pintura de Taubaté

A Nova Pintura da fábrica da Volkswagen em Taubaté inaugurada em outubro de 2012 estabelece novos padrões de tecnologia e proteção ambiental, se tornando referência na indústria automobilística brasileira. Com a mais alta tecnologia mundial. A Nova Pintura da Fábrica de Taubaté é ecológica e permite reduzir em 30% o consumo de energia e em 20% o consumo de água, sempre por veículo produzido, em comparação a um processo de pintura convencional.

Entre suas diversas inovações podemos destacar:

- Automação: A unidade conta com 110 robôs, que tornam a pintura interna e externa dos veículos 100% automatizada. Essa nova tecnologia permite eliminar uma camada de tinta do processo (*Primer*). Nesse processo os robôs fazem medição a laser, sem tocar na carroceria, para garantir a espessura da camada final aplicada. A tecnologia também oferece ganho ambiental, pois se elimina a energia necessária a uma etapa de secagem referente ao *Primer*;
- Limpeza externa da carroceria antes da aplicação do esmalte realizada por robôs, que operam com escovas eletrostáticas, garantindo a qualidade da camada final.

Uma característica muito relevante no processo compacto de pintura utilizado em TBT é quanto ao controle de camadas de tinta uma vez que o processo é isento de *Primer*. Para este processo, a camada de referência de Base é de 15 a 30 µm, e é dependente da cor.

Para controle de camadas e retroalimentação às estações de aplicação é utilizado um sistema automático de medição de camada de Base que não requer contato entre o instrumento e a chapa do veículo.

Neste processo são utilizados:

- 4 Robôs (2 + 2);
- 4 Equipamentos a laser (2 + 2);
- 40 Pontos de medição / corpo de prova (carroceria) – no mínimo;
- 120 Disparos ópticos / corpo de prova.

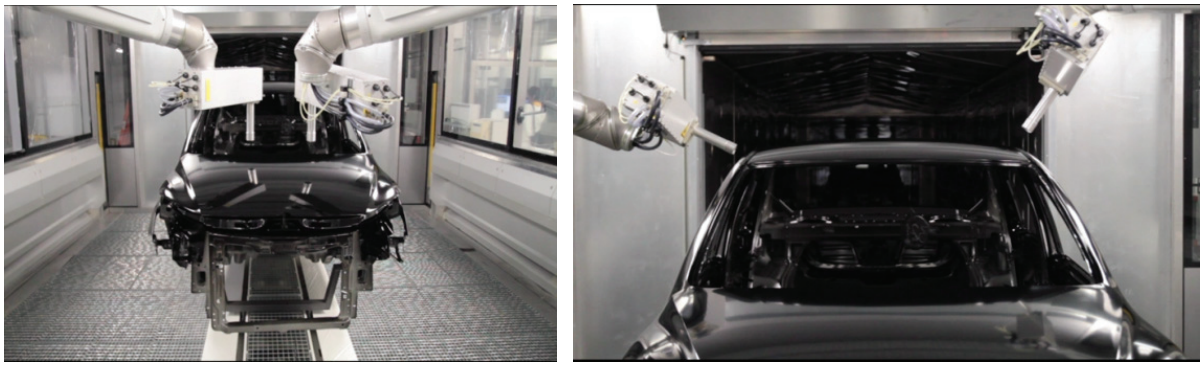

Figura 14 - Exemplo Robôs executando medição de camadas sem contato

As medições de camadas são feitas e avaliadas pelo sistema de controle de processo em tempo real. Ajustes necessários nos parâmetros de aplicação são retroalimentadas para o sistema de aplicação também em tempo real.

A aprovação da modificação dos parâmetros é feita pelo operador especialista que tem ainda a autonomia de confirmar as tendências de parâmetros antes de fazer a correção em definitivo.

4.1 Simulação e Ambiente 3D

O projeto da Nova Pintura da Fábrica da Volkswagen em Taubaté foi desenvolvido com auxílio da "Fábrica Digital Volkswagen", uma tecnologia do Grupo Volkswagen que consiste em softwares que simulam virtualmente as construções de unidades industriais e os processos produtivos, antes de serem implementados fisicamente.

As simulações da Nova Pintura, realizadas durante um ano e meio via computador, em ambiente 3D, permitiram a agilidade do projeto e a análise prévia de todas as possíveis

interferências da obra. Além da construção, a Fábrica Digital também simulou o fluxo produtivo, garantindo que a nova área tenha a produtividade esperada.

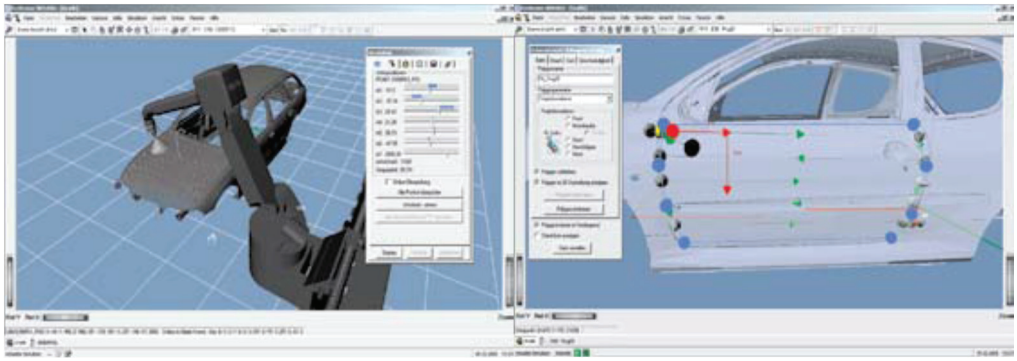

Figura 15 - Simulação virtual de Processo de Pintura

4.2 Comissionamento virtual

Além de atuar na simulação de novos processos, a Fabrica Digital também visa a atuação em processos existentes ou já planejados, a fim de otimizar e evitar erros no *start up* das instalações.

O comissionamento é uma das principais fases na implementação de um projeto. Ele consiste em integrar e testar os componentes da instalação para assegurar seu funcionamento conforme planejado.

O comissionamento era realizado após a instalação física dos componentes mecânicos e elétricos, como robôs, pinças de solda e garras de manipulação. Qualquer modificação decorrente de ajustes no processo gerava retrabalho mecânico e de software. Todo esse retrabalho era realizado on-line.

Nessa nova fase da manufatura avançada (Indústria 4.0) a Volkswagen do Brasil utiliza o comissionamento virtual, onde toda a interface de software entre o homem e a máquina é testada via PLC real. Assim, toda a etapa de ajustes e retrabalhos pode ser antecipada, reduzindo o tempo de instalação.

Figura 16 - Comissionamento Virtual – Processo

Ao final da instalação mecânica, o software já comissionado virtualmente pode ser implementado no processo. O que antes levava em torno de 5 dias, atualmente em não mais de 8 horas seu processo está pronto para operação. Testes de compatibilidade de sinais e ajuste de parâmetros são necessários, mas a redução no tempo de comissionamento on-site é significante.

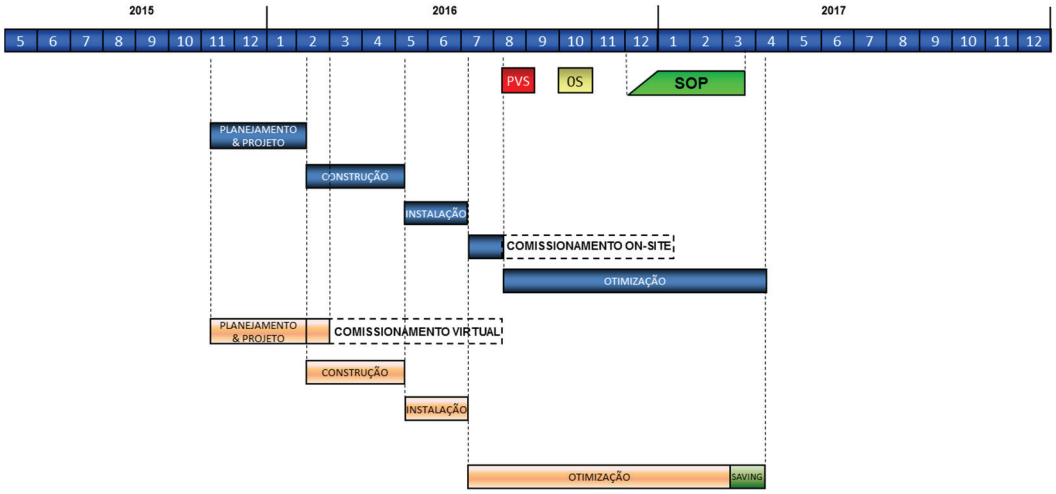

Figura 17 - Ganho de tempo de planejamento e instalação

4.3 Simulação de Estampagem: Etapa Fundamental na Construção de Ferramentas

No que diz respeito a utilização e integração das simulações provenientes da Fábrica Digital com o desenvolvimento dos produtos, podemos destacar a simulação no processo de estampagem.

O processo de Estampagem consiste em conformar chapas planas em produtos das mais variadas formas, o processo pode ser realizado a frio ou a quente, as operações geralmente são executadas em ferramentas instaladas em prensas.

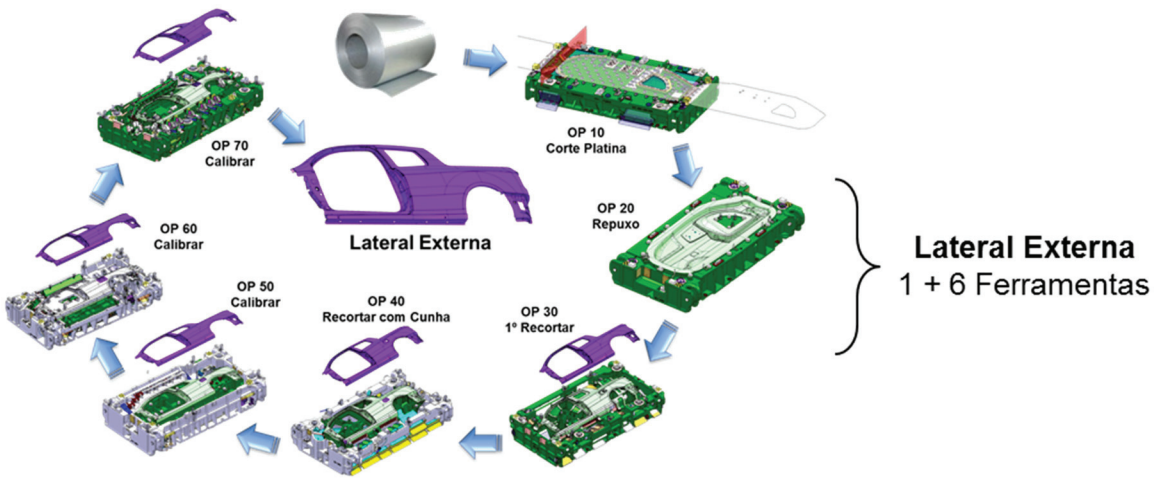

Figura 18 - Processo de Estampagem

Por ser um processo complexo está sujeito a inúmeras variáveis, por este motivo se faz necessária uma avaliação criteriosa de todo o processo antes mesmo da construção do ferramental. Para tanto estão disponíveis no mercado diversos softwares capazes de simular todo o processo de estampagem, desde os produtos mais simples até os mais complexos. O cálculo nestes softwares é realizado através do método de elementos finitos, o software transforma a geometria da ferramenta e da chapa em uma malha de triângulos e simula os movimentos da ferramenta, calculando o impacto destes deslocamentos em cada nó (elemento finito).

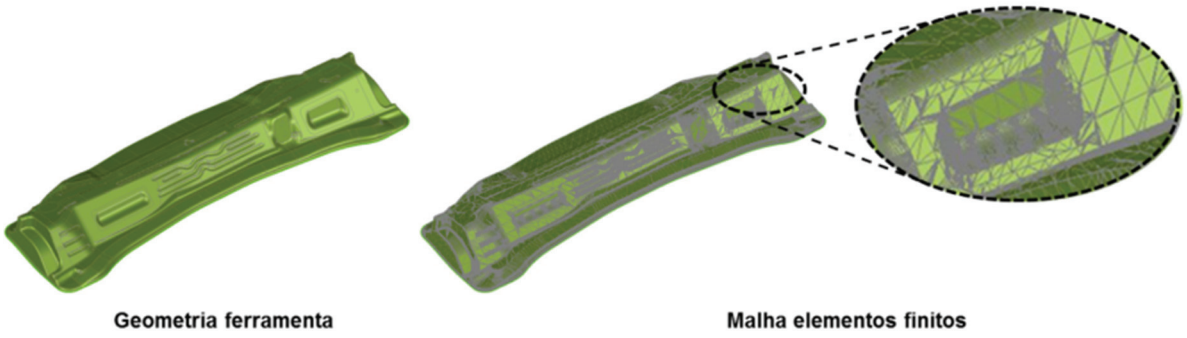

Figura 19 - Malha de elementos finitos na estampagem

Após a simulação avaliam-se os resultados como estiramento da chapa, afinamento da espessura, rugas, retorno elástico etc. e aplicam-se as devidas correções no processo ou no produto ainda em fase de desenvolvimento onde o custo com correções e modificações é inferior.

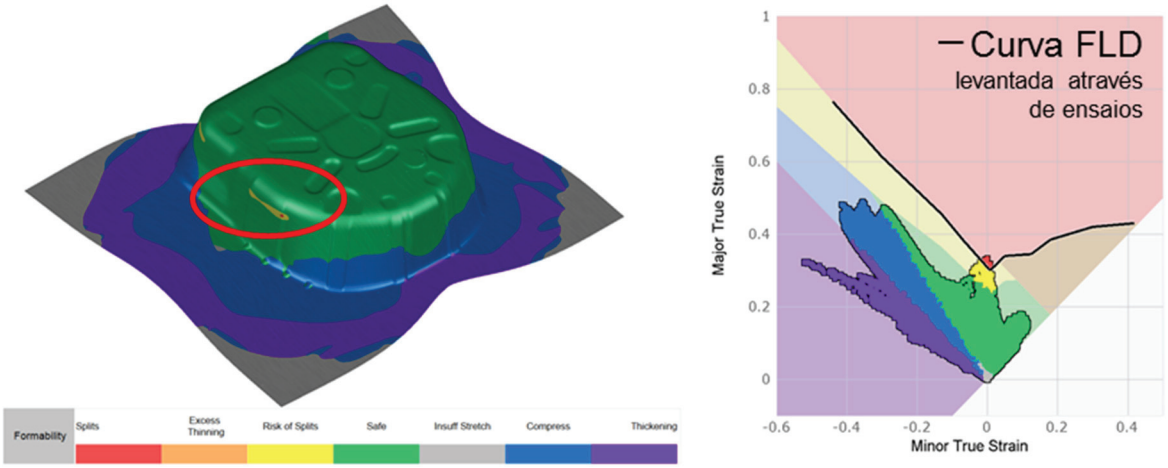

Figura 20 - Análise de peças antes da estampagem

5 Próximos Passos

A indústria automobilística vem demosntrando um alto grau de conformidade aos conceitos inerentes a Indústria 4.0, no entanto quais os próximos passos?

Na Volkswagen, projetos futuristas já estão em vigor.

5.1 Big Data Monitor

O *Big Data Monitor* permite a rápida conversão visual da informação de 1200 fornecedores da AUDI, onde é possivel verificar, onde estão os gargalos? Quais são os custos? Onde é necessário agir? E a resposta está a apenas um clique de distância.

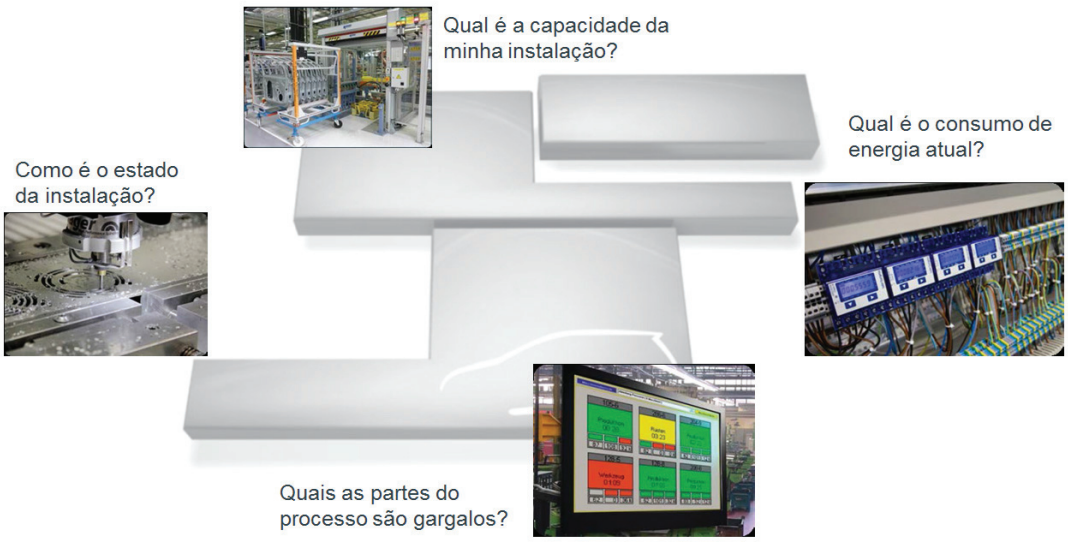

Figura 21 - Visão da Fábrica Inteligente

5.2 Prensas Inteligentes

Outro exemplo são as prensas inteligentes, que utilizam sensores pré-instalados para monitorar e responder as flutuações do processo, que procura automaticamente garantir a qualidade durante o processo de estampagem.

A conexão dos dados originais permite a otimização de todas as ferramentas inteligentes no sistema.

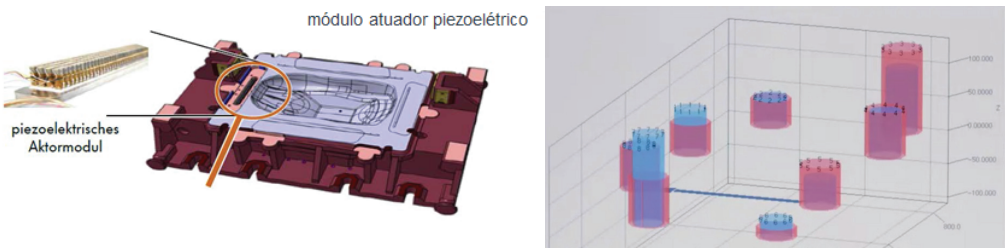

Figura 22 - Atuado inteligente no Processo de estampagem

5.3 Robôs colaborativos

Interação homem-robô, no grupo Volkswagen os robôs estão prontos para realizar tarefas não ergonômicas como montagens acima da cabeça, liberando o operador para se concentrar em outras tarefas na mesma área de trabalho. Hoje a interação homem-robô, está aumentando a produtividade da Audi.

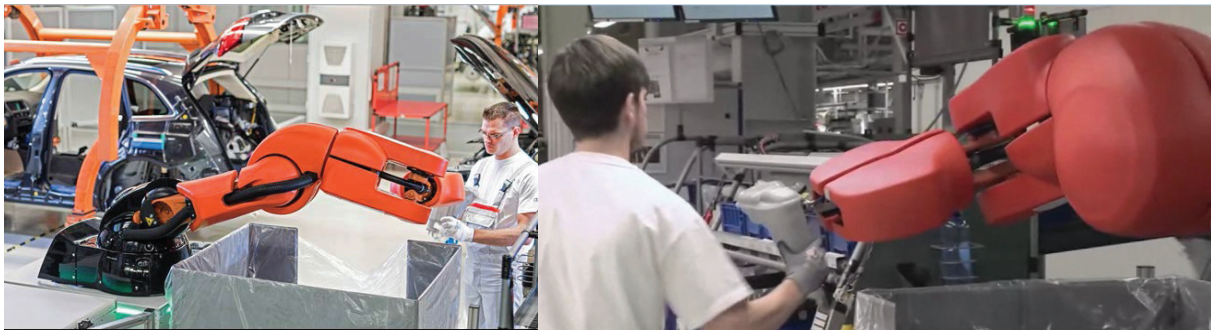

Figura 23 - Robôs colaborativos

6 Conclusão

Por mais que a indústria automotiva esteja avançada em relação a utilização de tecnologias referentes a manufatura inteligente ainda existem muitos desafios a serem superados como os *gaps* de tecnologias existentes:

Estudos na área de IA (Inteligência Artificial) devem ser desenvolvidos com objetivo de implantar nos novos equipamentos inteligentes, modelando a capacidade de tomar decisões por si mesmo ao invés de receber instruções pré-definidas, de modo que esses equipamentos tenham sua autonomia e sociabilidade ampliadas.

Também devem ser desenvolvidas pesquisas em protocolos de comunicação de alta velocidade que sejam capazes de suportar a quantidade de informação gerada nesse novo ambiente 4.0, os atuais protocolos industriais existentes ainda não são capazes de suportar todo o tráfego de informação, e os protocolos conhecidos que poderiam suportar, ainda não são desenvolvidos para usos industriais.

O propósito final da Indústria 4.0 é que o processo seja capaz de se auto-organizar, no entanto a teoria da auto-organização afirma que isso pode levar a situações inesperadas como o caos, por isso estão sendo desenvolvidos modelos de sistemas e análise que buscam deduzir equações dinâmicas e o controle adequado para aplicações industriais dos métodos de auto-organização.

A fábrica inteligente sofre maiores problemas de segurança do que aplicações de internet tradicionais, devemos proteger várias informações sobre os clientes, fornecedores, estratégias comerciais, e *know-how*. Criptografia e controle de acesso são geralmente usados

em domínio de segurança cibernética, mas esses mecanismos não são suficientes. Novos mecanismos que são especialmente concebidos para a fábrica inteligente estão sendo desenvolvidos, para viabilizar a implementação dessas tecnologias.

Outros desafios como estabelecer os novos papéis dos colaboradores na indústria além do reflexo que a Indústria 4.0 proporcionará na economia e na sociedade, onde novas relações entre homem e tecnologia e homem e ambiente devem surgir, novas formas de trabalho que podem ser executadas fora da fábrica em ambientes de trabalho virtuais e móveis. A abordagem sócio-técnica da Indústria 4.0 irá desbloquear um novo potencial para o desenvolvimento de inovações que são claramente necessárias, com base em uma maior consciência da importância do trabalho humano no processo de inovação.

Cabe a nós como indústria manter o desenvolvimento constante, juntamente com universidades e parcerias governamentais, para podermos alcançar o objetivo do ambiente 4.0.

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Manufacturing companies in Germany on their way to *Industrie 4.0* First results from a Delphi Study

Abstract

This Delphi Study analyses the current progress of manufacturing companies in terms of Industrie 4.0. The study aims to evaluate the maturity of manufacturing companies in the context of Industrie 4.0, to compare their performance levels and to show their fu-ture orientation as well as their technology development based on scenarios. For this study a dedicated maturity model has been developed which combines the two dimen-sions "manufacturing attributes" and "Industrie 4.0 attributes". It was verified by means of literature research and expert interviews previous to the elaboration of the study. For the final evaluation four out of nine fields of action have been prioritized and analyzed. The four main fields of action are: "Connectivity through horizontal and ver-tical integration", "Production & Logistics", "Marketing, Sale & Services" and "Man & Organization." As a result the current progress of the analyzed companies in terms of Industrie 4.0 varies strongly within all four fields of action. On the basis of 49 evalua-tion criteria a significant correlation between progress of Industrie 4.0 and progress in process management as well as progress in information technology in production can be proved. A correlation between the product portfolio of a company (customized products vs. standardized products) and the maturity in Industrie 4.0 has been falsified. In addi-tion to this there is no correlation of strategic focus of a company (differentiation strate-gy vs. cost leadership) and Industrie 4.0 maturity. For the applied Industrie 4.0 maturity model the structure and the classification of the Process and Enterprise Maturity Model (PEMM) of HAMMER has been used. Content and fields of action can be derived from the elaborated Industrie 4.0 maturity model and from the identified study results. Preliminary results of the referenced study were pub-lished at the 28th annual conference of the "Arbeitskreis Wirtschaftsinformatik" (AKWI), September 2015 [PSM15] in Luzern. The study has been expanded for the "International High-Tech Symposium in Brazil."

Keywords

Industrie 4.0; Maturity Model; Delphi Study.

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Four-level Model
of Future-oriented Corporate Management

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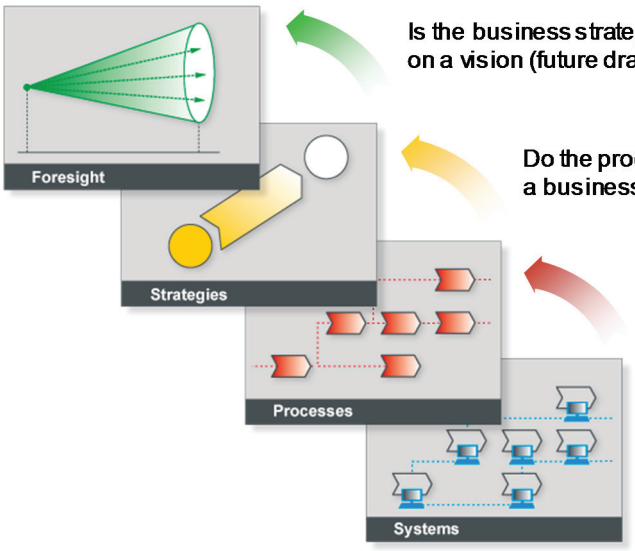

Is the business strategy based on a vision (future draft)?

Do the processes follow a business strategy?

Are the targeted business processes defined, stable and repeatable?

Industrie 4.0

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Industrie 4.0
Industrial Revolutions Overview

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4. INDUSTRIAL REVOLUTION
Autonomous products and decision-making process control value-adding networks in almost real-time

INTERNET ON THE SHOP FLOOR

3. INDUSTRIAL REVOLUTION
Automation of production processes by electronics and IT

COMPUTER

2. INDUSTRIAL REVOLUTION
Mass production of goods based on division of labor and with help of electric energy

ELECTRIC ENERGY

1. INDUSTRIAL REVOLUTION
Introduction of mechanical production facilities

STEAM ENGINE

Each industrial revolution caused an improvement in productivity and was accompanied by fundamental changes in society.

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Designing an Industrie 4.0 Production

The Value Added of Tomorrow – IP-Enabled Work Pieces ...

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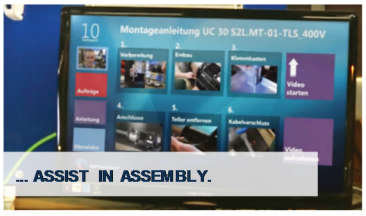

Industrie 4.0 helps us to control variances, to reduce complexity and to make manufacturing processes more transparent.

The Vision of Industrie 4.0

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- **Individualization** (batch size 1) of the economic conditions of a mass manufacturer becomes reality.
- Production is **highly flexible**, highly productive (up to +50%) and urban friendly, resource-friendly (up to -50%).
- Value creation processes are optimized **in real time demand**: education ad-hoc virtual organizations.
- **Reconciliation of work and family** with regard to the individual availability of employees.
- Older workers benefit from **intelligent assistance systems**.
- The existing infrastructure can be **upgraded step by step**.

A high wage economy competitiveness is secured. Made in Germany.

Source: Kagermann, 2013

1.7% Additional Growth each Year through Industrie 4.0

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Gross value added 2013 of selected industries in Germany (billion €)

TOTAL 343.3

1.7% ANNUAL INCREASE

Gross value added 2025* of selected industries in Germany (billion €)

TOTAL 422.1

*Prediction

Key

Chemicals | Automobiles & Parts | Engineering | Electrical equipment | Agriculture and forestry | ICT-Industry

Industrie 4.0 is a vision of the future, which begins today. Almost all major economies have launched several initiatives in order to use the digitization of traditional industry for a competitive advantage in the world market.

Source: Fraunhofer IAO/BITKOM

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"Industrie 4.0" Understanding
Evolution and Categorization

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Many users, 1 computer

MAINFRAME

1 user, 1 computer

DATA WAREHOUSES, INTERNET, PC

1 user, many computers

BIG DATA, CLOUD COMPUTING, SMART DEVICES

INDUSTRIE 4.0

INTERNET OF DATA AND SERVICES

+

INTERNET OF THINGS & SERVICES

EMBEDDED SYSTEMS

+ Sensors, actuators
+ Integration of high performance electronics and mini computers

CYBER-PHYSICAL SYSTEMS (CPS)

+ IP-Capability
+ Semantic description
+ Connected, Internet, M2M
+ Wireless communication

PHYSICAL OBJECTS, TOOLS, EQUIPMENT

+ only mechanical components

Source: German Research Union And acatech, 2013

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Internet of Things and Services (IoTS)

Inter-connectivity and Digitalization of Different Living Environments

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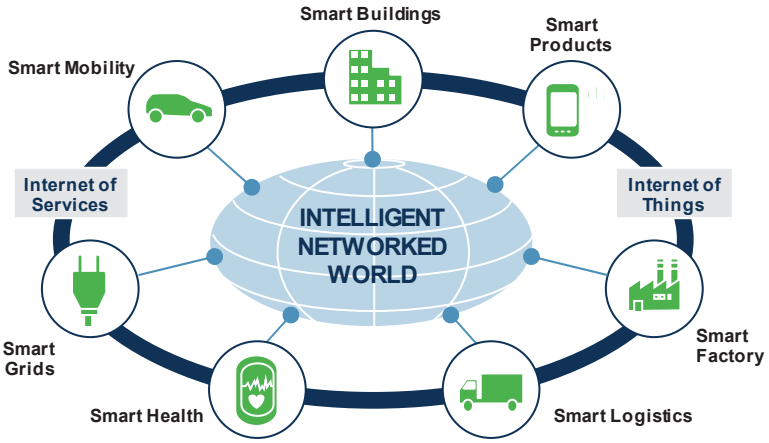

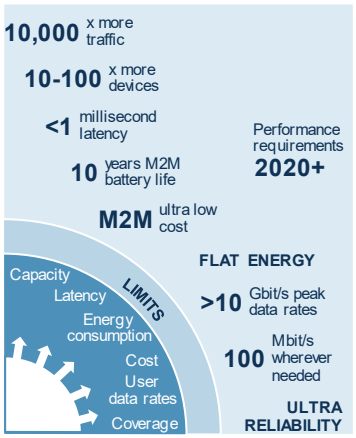

It not only concerns production, but also the digitalization and networking of all environments. New risks as well opportunities as are created for all participants!

Source: Forschungsunion, 2012; Nokia 2016

Research Projects – INBENZHAP & GEMINI

UNITY CONSULTING & INNOVATION

INBENZHAP
International Benchmark Industrie 4.0
Future Options in Production worldwide

HEINZ NIXDORF INSTITUT UNIVERSITÄT PADERBORN
acatech DEUTSCHE AKADEMIE DER TECHNIKWISSENSCHAFTEN
WZL RWTH AACHEN
Bundesministerium für Bildung und Forschung
PTKA Projektträger Karlsruhe im Karlsruher Institut für Technologie

GEMINI
Business Models dedicated to Industrie 4.0

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages
HEINZ NIXDORF INSTITUT UNIVERSITÄT PADERBORN
UNITY CONSULTING & INNOVATION
RUB RUHR UNIVERSITÄT BOCHUM
SLM SOLUTIONS
Atos
Fraunhofer IPT
CONTACT SOFTWARE

Key Questions:

- What **level of development** have leading industrial nations attained?
- What framework **conditions** must exist in order for Germany to become a **leading market**?
- Where are the markets for the German **leading provider industry** and what do they require?
- What **competitors** will the German supplier industry encounter?
- How does the supplier industry need to **develop** in order to be **successful** in future markets?
- How does this **affect** work organization and structure? Is Industrie 4.0 accepted by relevant stakeholders?
- What kind of dedicated **Business Models** based on Industrie 4.0 principles evolve?

Digitalization in Production is a Global Trend

Feasible Scenarios per Country

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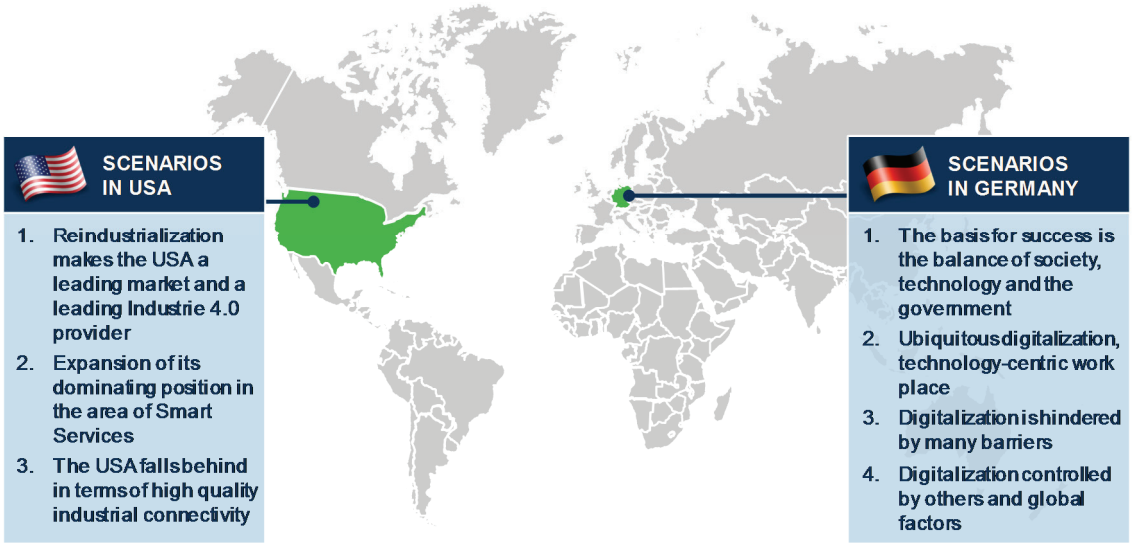

SCENARIOS IN USA

1. Reindustrialization makes the USA a leading market and a leading Industrie 4.0 provider
2. Expansion of its dominating position in the area of Smart Services
3. The USA falls behind in terms of high quality industrial connectivity

SCENARIOS IN GERMANY

1. The basis for success is the balance of society, technology and the government
2. Ubiquitous digitalization, technology-centric work place
3. Digitalization is hindered by many barriers
4. Digitalization controlled by others and global factors

Source: INBENZHAP, International Benchmarks, Future Options and Recommendations for Action in Production Research

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Culture in Silicon Valley

Christoph Keese, 2014

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TECHNOLOGY-CULT	„Problems, give us problems“	▪ Technicians, not salespeople dictate decisions in Silicon Valley ▪ **Difficult tasks will be taken on.** ▪ The greater the challenge, the better ▪ What appears to be hopeless is often the most profitable ▪ Wealth is more likely to be created by chance
UNLIMITED INNOVATION	„No one is safe from constant attacks from below“	„**Disruptive Innovation**“ is the magic formula. Silicon Valley is a master at recognizing weaknesses in the business models of well established companies. It attacks aggressively and is often victorious. **„If someone wants to eat your food, be sure that it is you.“** Gilles BianRosa, CEO von Fanhattan
SCALE OR LOSE	„From the age of platforms“	**Everything** that can be, **will be digitalized.** In the future, automobiles, airplanes and refrigerators will be mere sheets of metal that will barely generate revenue. Winners will be the intermediaries, thanks to network effects. **„Information is currency in an information society.“** Geoffrey Moore

Source: Silicon Valley, Christoph Keese, 2014, page 91

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Industrie 4.0
Strategies in Countries and Regions!

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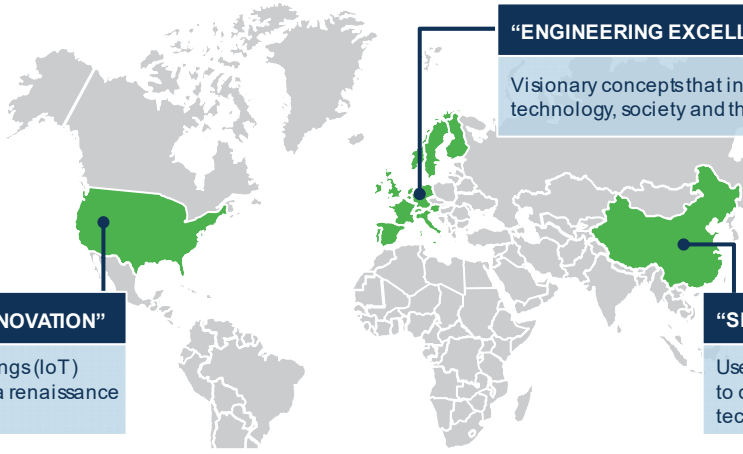

"ENGINEERING EXCELLENCE"
Visionary concepts that integrate technology, society and the economy

"RADICAL INNOVATION"
Internet of Things (IoT) start-ups and a renaissance in production

"SPEED"
Use of mature technologies to develop strategic key technologies

Critical focus areas | Strategic direction | Recommendations for action

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Overcoming the Bridging Challenges with Office Work 4.0
The Dual Management System for Aligning Employees and Organization

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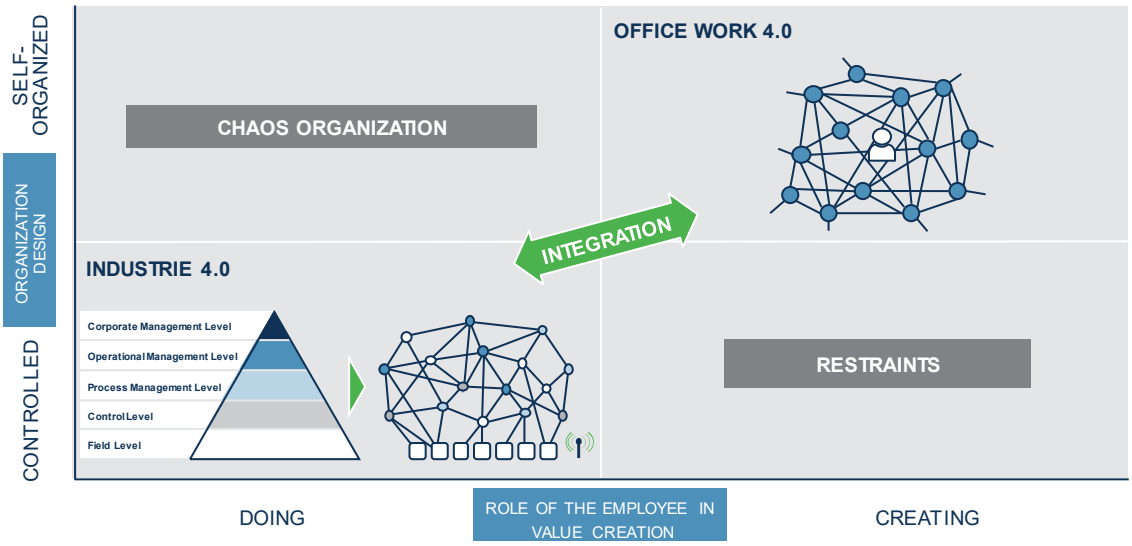

Source: Technology Management Gruppe

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Overcoming the Bridging Challenges with Office Work 4.0

The Dual Management System for Aligning Employees with Organization

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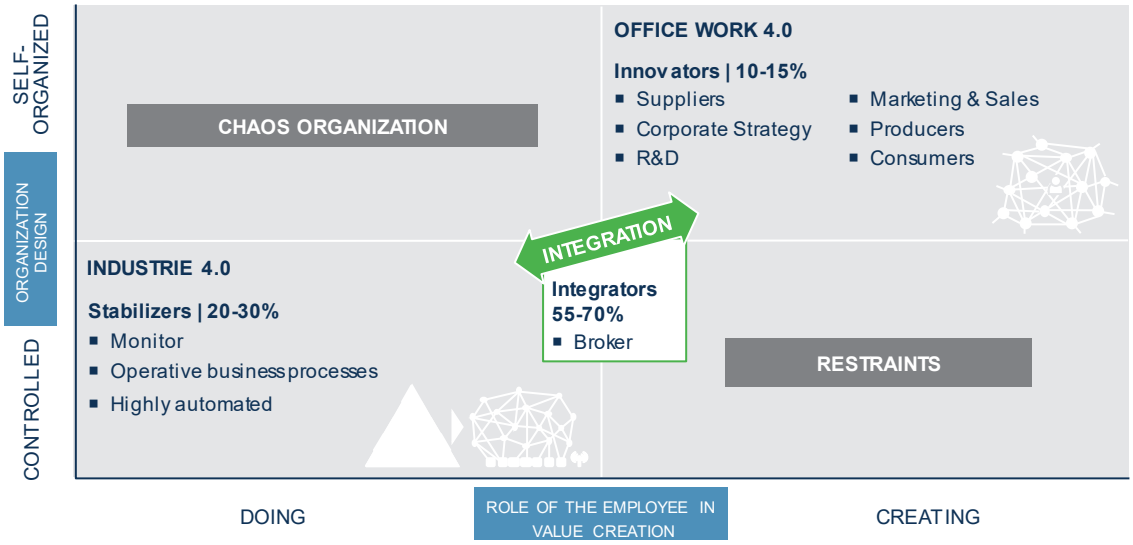

Source: Technology Management Gruppe

Development of Business Models

Technology Area: Shop Floor/Core Business

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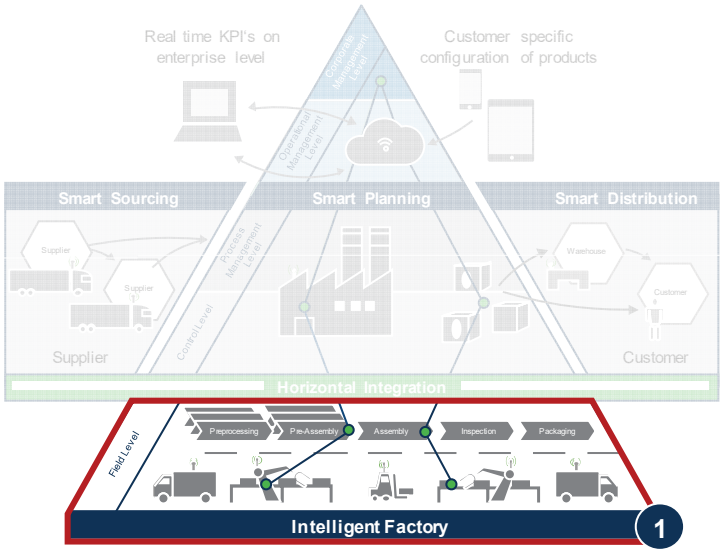

1 SHOP FLOOR/ CORE BUSINESS

- Location bound
- Manufacturing/Production

Development of Business Models
Technology Area: Company

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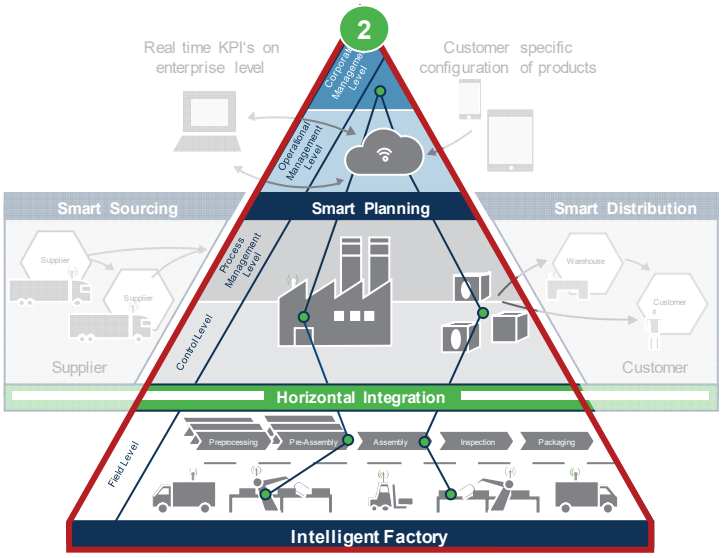

2 COMPANY

- View of the entire company
- Spans all locations
- Across all functional areas

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Development of Business Models
Technology Area: Open Company

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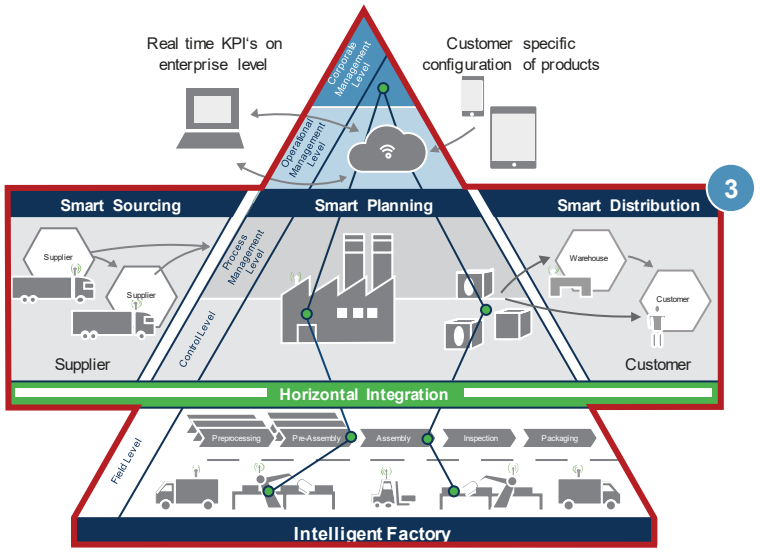

3 OPEN COMPANY

- Company-wide and cross-sector
- Overall added value
- Involvement of all stakeholders

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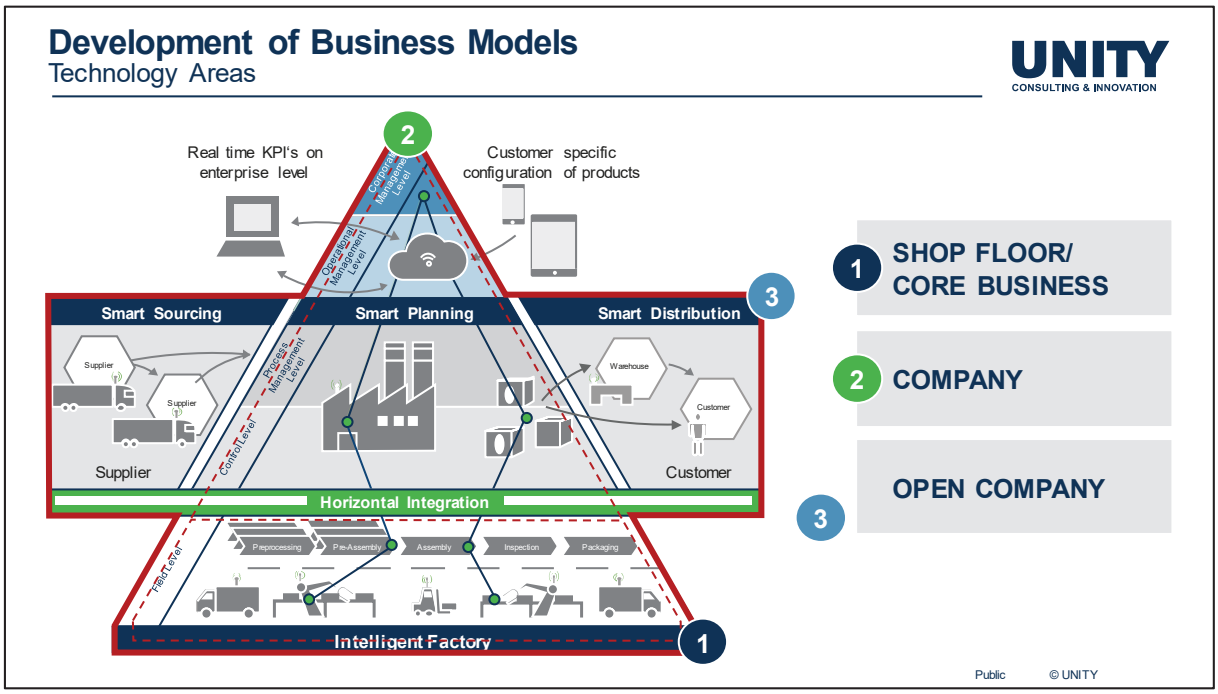
Development of Business Models
Technology Areas
UNITY
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Real time KPI's on enterprise level
Customer specific configuration of products
2
Smart Sourcing
Smart Planning
Smart Distribution
3
Supplier
Supplier
Supplier
Warehouse
Customer
Customer
Horizontal Integration
Preprocessing
Pre-Assembly
Assembly
Inspection
Packaging
Intelligent Factory
1
1 SHOP FLOOR/ CORE BUSINESS
2 COMPANY
3 OPEN COMPANY
Public
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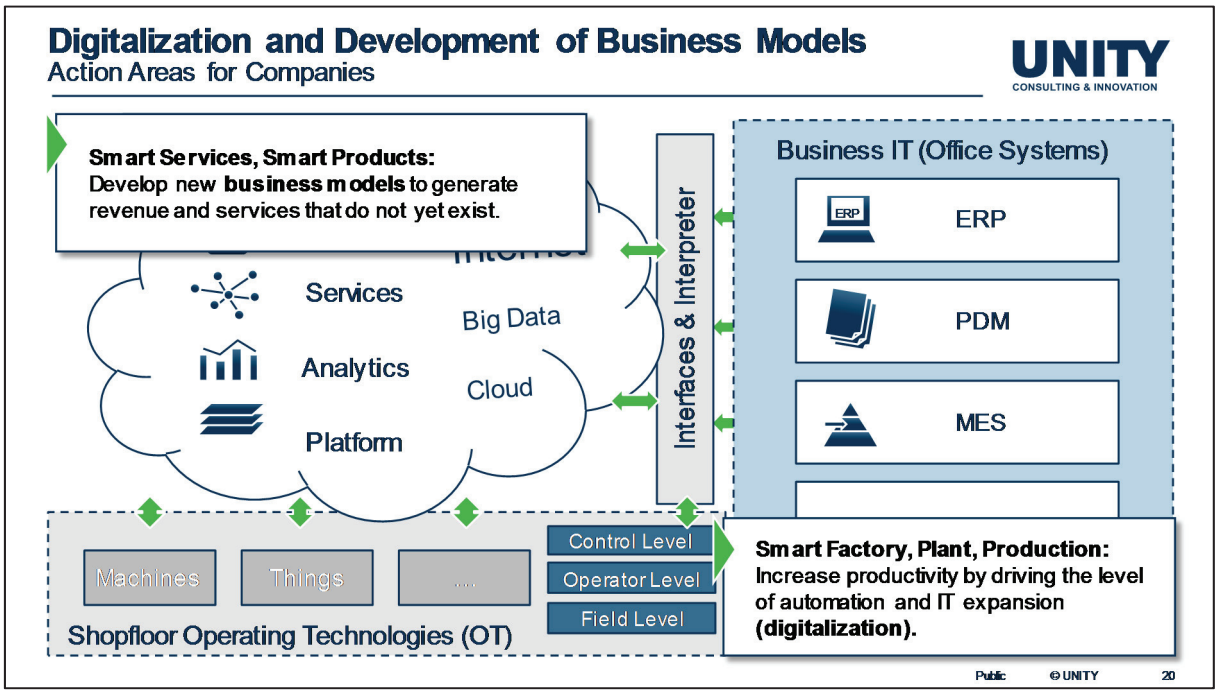
Digitalization and Development of Business Models
Action Areas for Companies
UNITY
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Smart Services, Smart Products:
Develop new business models to generate revenue and services that do not yet exist.
Services
Big Data
Analytics
Cloud
Platform
Interfaces & Interpreter
Business IT (Office Systems)
ERP
ERP
PDM
MES
Machines
Things
....
Shopfloor Operating Technologies (OT)
Control Level
Operator Level
Field Level
Smart Factory, Plant, Production:
Increase productivity by driving the level of automation and IT expansion (digitalization).
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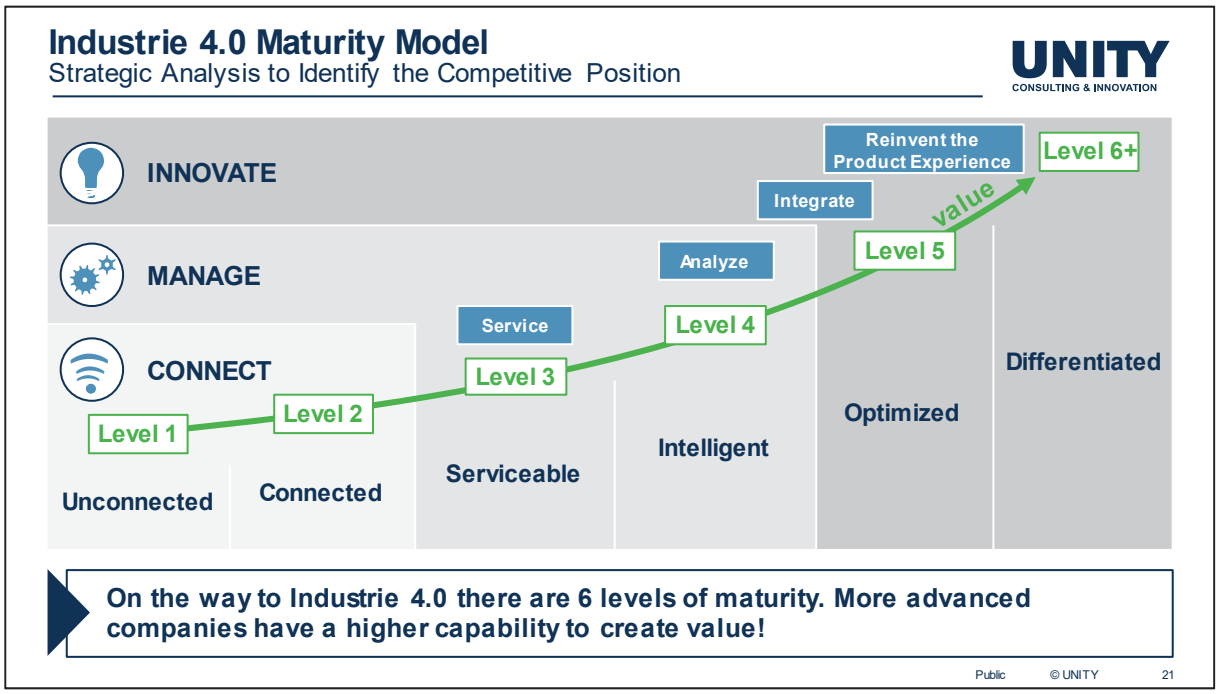
Industrie 4.0 Maturity Model
Strategic Analysis to Identify the Competitive Position
UNITY
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INNOVATE
MANAGE
CONNECT
Reinvent the Product Experience
Level 6+
Integrate
value
Level 5
Analyze
Level 4
Service
Level 3
Level 2
Level 1
Unconnected
Connected
Serviceable
Intelligent
Optimized
Differentiated
On the way to Industrie 4.0 there are 6 levels of maturity. More advanced companies have a higher capability to create value!
Public
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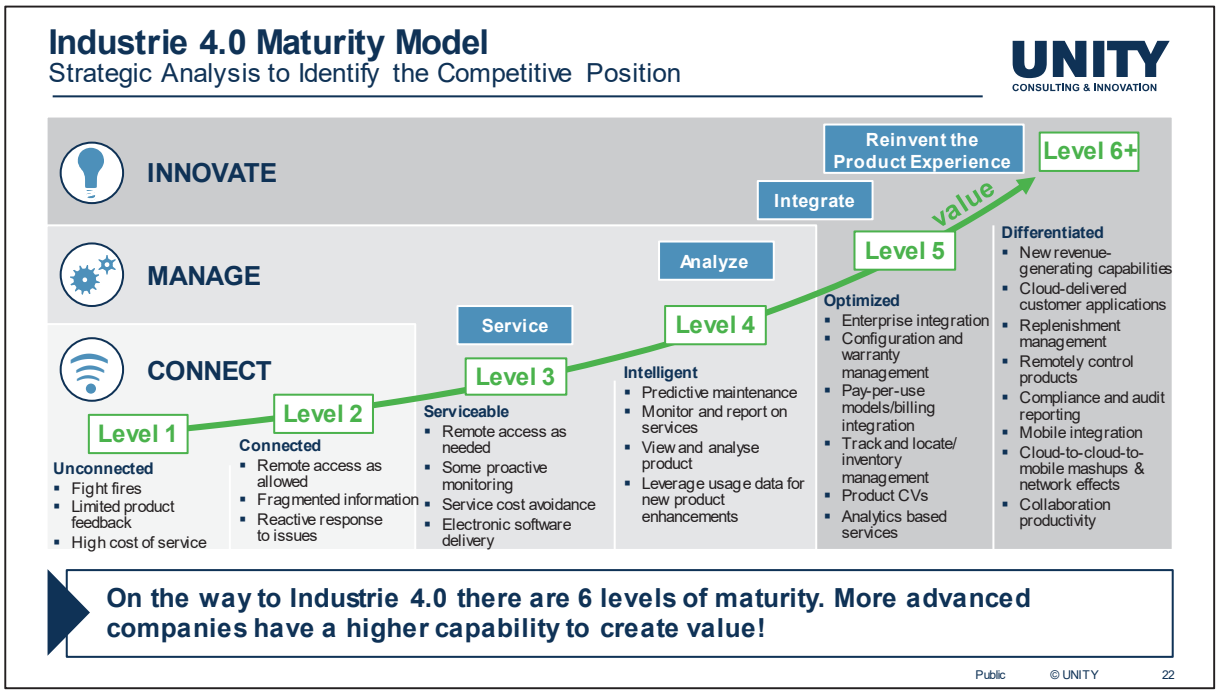
21


Industrie 4.0 Maturity Model
Strategic Analysis to Identify the Competitive Position
UNITY
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INNOVATE
MANAGE
CONNECT
Reinvent the Product Experience
Level 6+
Integrate
value
Level 5
Analyze
Level 4
Service
Level 3
Level 2
Level 1
Unconnected
▪ Fight fires
▪ Limited product feedback
▪ High cost of service
Connected
▪ Remote access as allowed
▪ Fragmented information
▪ Reactive response to issues
Serviceable
▪ Remote access as needed
▪ Some proactive monitoring
▪ Service cost avoidance
▪ Electronic software delivery
Intelligent
▪ Predictive maintenance
▪ Monitor and report on services
▪ View and analyse product
▪ Leverage usage data for new product enhancements
Optimized
▪ Enterprise integration
▪ Configuration and warranty management
▪ Pay-per-use models/billing integration
▪ Track and locate/ inventory management
▪ Product CVs
▪ Analytics based services
Differentiated
▪ New revenue-generating capabilities
▪ Cloud-delivered customer applications
▪ Replenishment management
▪ Remotely control products
▪ Compliance and audit reporting
▪ Mobile integration
▪ Cloud-to-cloud-to-mobile mashups & network effects
▪ Collaboration productivity
On the way to Industrie 4.0 there are 6 levels of maturity. More advanced companies have a higher capability to create value!
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Trend Setters on the Way to Industrie 4.0
Machinery and Plant Engineering

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INDUSTRIE 4.0 – MILESTONES

KOLBUS GMBH & CO. KG
- Use of augmented reality in the assembly of complex clamping systems
- Virtual template –immediate comparison of the real image with the 3D CAD model
- Color coding when fitted incorrectly
- Fast training of new assembly processes

SIEMENS AG
- Independent control of parts throughout the factory
- Communication at every work station and retrieval of processing operations
- Realization of multi-variant production capabilities

DMG MORI SEIKI AG
- Innovative machine operating concept: continuous and digitalized management, documentation and visualization of order, process and machine data
- Networked with ERP and MES systems as well as CAD-CAM applications

WEIDMÜLLER INTERFACE GMBH & CO. KG
- Self-correcting machines in production
- Integration of measurement technology
- Self-correcting algorithms for intelligent controls enable continuous fulfillment of product requirements

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Concepts and technologies (based on IoT Analytics)

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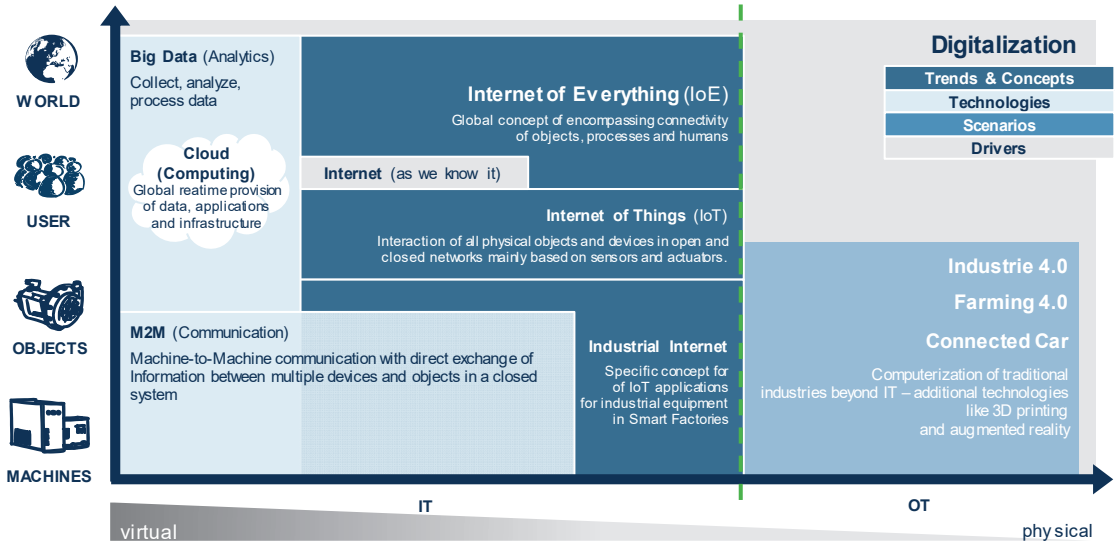

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Reference Architectures for Industrie 4.0
Current Architectures and Models

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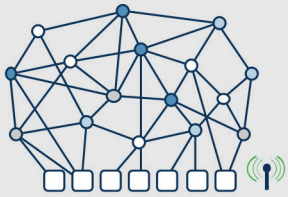
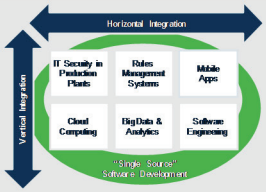
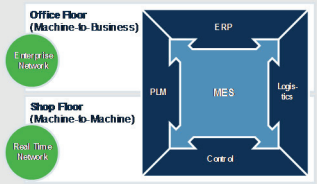
CPS WITH DISTRIBUTED SERVICES



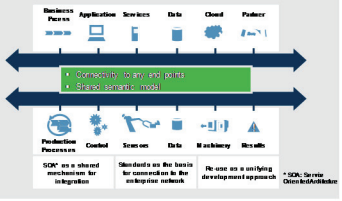
"SINGLE-SOURCE" SOFTWARE DEVELOPMENT



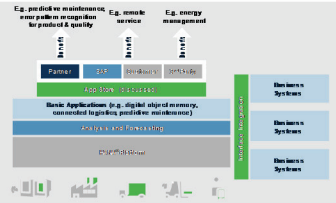
MES AS A CENTRAL PLATFORM



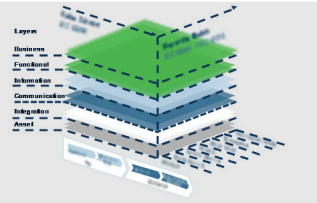
CENTRAL CONNECTIONS BETWEEN OFFICE FLOOR AND SHOP FLOOR



OPEN BASIC CONCEPT OF THE IOT PLATFORM



REFERENCE ARCHITECTURAL MODEL INDUSTRIE 4.0



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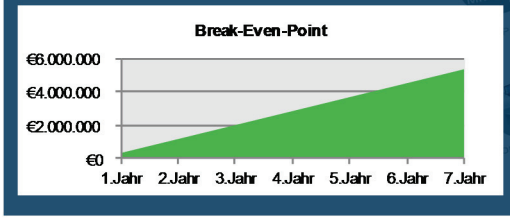
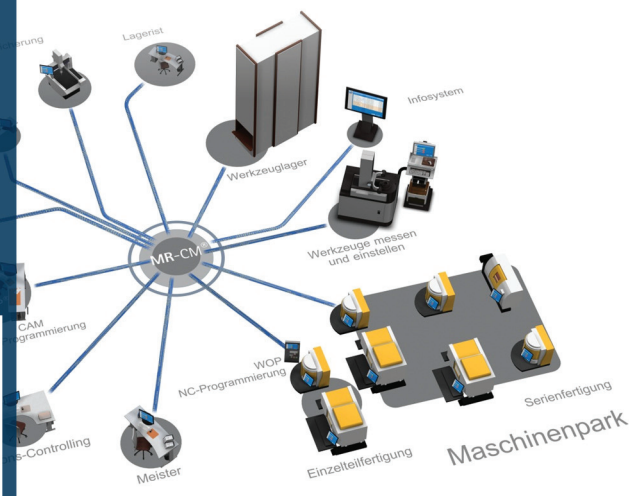
INDUSTRIE 4.0-CAPABLE MES-SYSTEM

- Integrated networking of all equipment and systems involved in production
- Autonomous/customized rough plan and detailed order scheduling considering delivery times, capacity and resources
- Provision of all production information at required locations
- Complete transparency of orders, capacity and resources



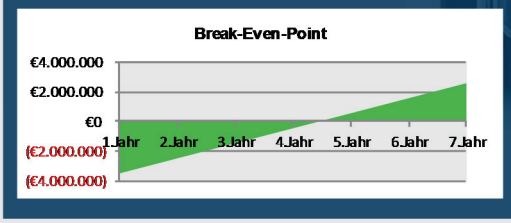


Source: Maschinenfabrik Reinhausen GmbH, 2010

26

UNIVERSAL MACHINES

- Complete machining of up to four different processes on one machine
- Operator guidance during order planning and set-up
- Integrated management, documentation and visualization of all data including tools and material management
- Innovative machining operations: Kinematics testing and correction, laser measurements, dynamic workspace monitoring etc.



Source: DMG Mori Seiki AG, Universalbearbeitungszentren

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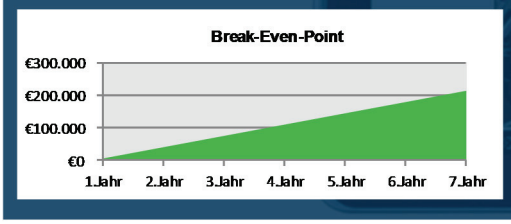
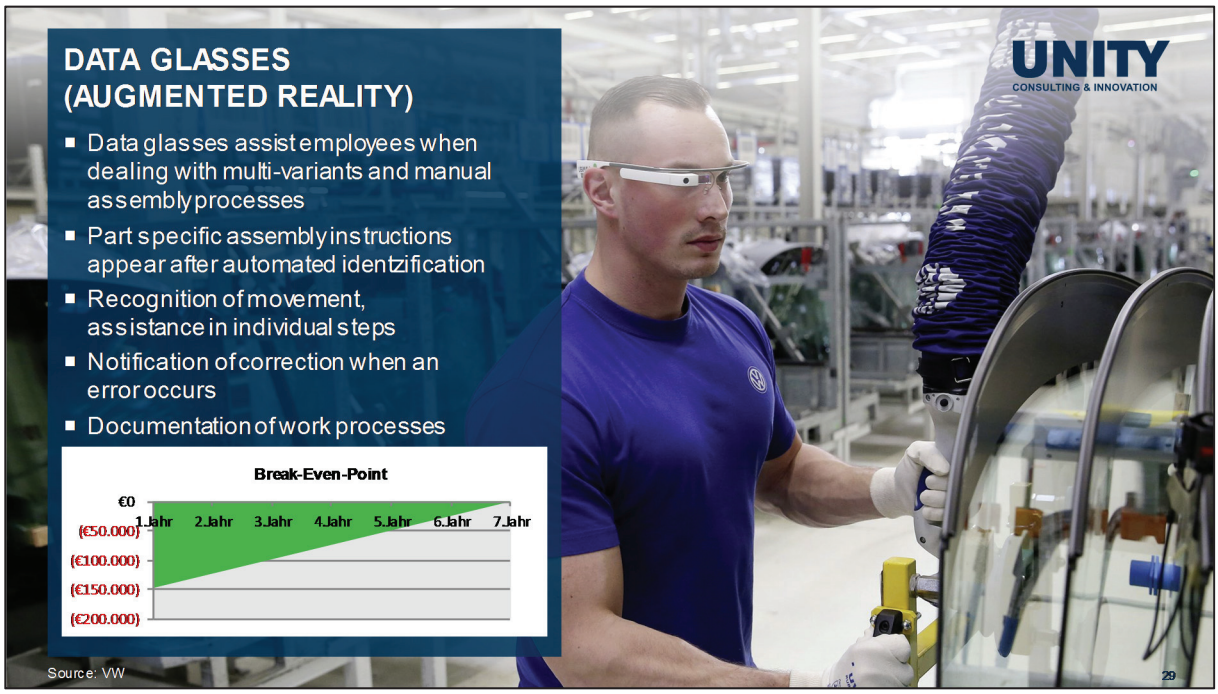
DIGITAL MAINTENANCE SERVICE

- Rapid elimination of machine downtimes
- Real-time sharing of image, audio and video files with Technical Support
- Editing of images and supplementing it with additional information



Source: Trumpf GmbH & Co. KG, Digitaler Instandhaltungsservice

28


DATA GLASSES
(AUGMENTED REALITY)
Data glasses assist employees when dealing with multi-variants and manual assembly processes
Part specific assembly instructions appear after automated identzification
Recognition of movement, assistance in individual steps
Notification of correction when an error occurs
Documentation of work processes
Break-Even-Point
€0
(€50.000)
(€100.000)
(€150.000)
(€200.000)
1.Jahr
2.Jahr
3.Jahr
4.Jahr
5.Jahr
6.Jahr
7.Jahr
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Source: VW
29

MILKRUN 4.0
Control of "Milkrunners" by software
Intelligent scheduling algorithm for calculating the optimal travel times
Demand detection in real-time and accurate virtual image of material supply and parts
Consumption-based supplies on the machine
Break-Even-Point
€6.000.000
€4.000.000
€2.000.000
€0
1.Jahr
2.Jahr
3.Jahr
4.Jahr
5.Jahr
6.Jahr
7.Jahr
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Source: share.sew-eurodrive.de
30

AUTONOMOUS WAREHOUSE SYSTEMS
Product storage and retrieval by autonomous systems
Managing storage processes using intelligent software
Real-time monitoring
Commissioning support through assistance systems
Break-Even-Point
€10.000.000
€5.000.000
€0
(€5.000.000)
1.Jahr 2.Jahr 3.Jahr 4.Jahr 5.Jahr 6.Jahr 7.Jahr
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Source: www.techbriefs.com
31

Thank You for your Attention!
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OPPORTUNITY
FACTS FOR DECISION MAKERS
Seize the Opportunity of Industry 4.0
SMART LOGISTICS
SMART HEALTH
SMART MOBILITY
SMART FACTORY
SMART BUILDINGS
SMART PRODUCTS
SMART GRIDS
Any one dismissing this development as temporary hype is in danger of ending up just like Quelle or Karstadt: these trading companies did not take the use of internet within their business seriously meaning that the new players in this sector are now eBay, Amazon, and Zalando. This is a mistake which should not be repeated in the manufacturing industries.
The two key action areas for companies are digitization, i.e. an increased degree of automation to boost productivity, and the development of new business models to generate services and sales.
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Beijing - Berlin - Braunschweig - Cairo - Cologne - Hamburg - Munich - Nuremberg - Paderborn - São Paulo - Shanghai - Stuttgart - Vienna - Zurich
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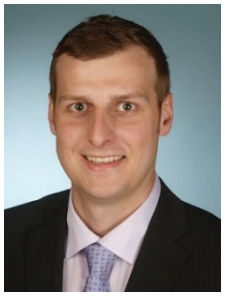


M.Sc. Alexander Arndt

Alexander Arndt obtained Bachelor of Engineering in Product Development and Design from Koblenz University of Applied Sciences (*Hochschule Koblenz*) in 2010. Afterwards Mr. Arndt studied MPE (Mechanical and Process Engineering) at the *Technische Universität Darmstadt* until 2013. His master's thesis involved conceptual design of a compatibility test for mixed material bodies in CATIA V5. Since March 2013 he has been employed as a research associate at the Department of Computer Integrated Design (DiK). The research focus of Mr. Arndt is additive manufacturing. Additive manufacturing technologies are currently subject to ongoing development. This results in a comprehensive examination of those processes from the research perspective. Therefore, the digital process chain including all relevant process steps is profoundly illuminated at DiK. The process chain involves creating computer-based 3D-CAD models, preparation of the construction process, the physical construction process as well as the post-processing and the application of the component. Here Mr. Arndt works on solutions for the optimization and further development of additive manufacturing processes.

✉ arndt@dik.tu-darmstadt.de

DiK, TU Darmstadt

The Department of Computer Integrated Design (DiK) was founded in 1993 at the Faculty of Mechanical Engineering of *Technische Universität Darmstadt* and is since then directed by Prof. Dr.-Ing. Reiner Anderl. Task of DiK is to reflect the importance of information technology for mechanical engineering. Therefore, the Department represents an interface between these two disciplines. Information technology is seen as an integral part of engineering and its application with respect to teaching and research constantly advances at the department. Computerized methods and tools are developed to improve and redesign the entire product development process up to the usage of the product.The DiK operates in the field of basic and applied research as well as contract research. The skills acquired here directly transfer into the development of lectures for the Bachelor and Master programs. Core-competencies of the department include the areas *Industrie 4.0*, Information Integration, Virtual Product Creation, and Distributed and Cooperative Work.

Additive Manufacturing - Automation in Customized Production

Abstract

Significant time and cost advantages can be derived from the use of additive manufacturing processes. These advantages result from the fact that within additive manufacturing processes neither costly tools nor time-consuming preparations are needed for the manufacturing of prototypes and components. The characteristic of the process chain enables additional time and cost advantages for each of its use cases. The expression of the process chain is particularly suitable for the manufacturing of small lots to batch size 1. The additive manufacturing process chain starts with the creation and use of 3D CAD data. Further essential steps within the process chain include pre-processing, manufacturing, post-processing, and component use. Particularly the progress towards the digitalization of the manufacturing process chain requires a comprehensive concept and implementation of the process chain 3D CAD for Additive Manufacturing. The process steps modelling, nesting, and slicing as well as the universal usage of a uniform data format require extensive research activities to enable the utilization of the aforementioned advantages. To achieve optimal and high-quality results through additive manufacturing, the process- and technology-specific orientation and positioning of components within the virtual space, the so-called nesting, is essential. Today, the process chain is expressed strongly manually. The goal is to automate the process chain. This results in an enormous competitive advantage for a company.In this paper, the process chain for additive manufacturing is discussed, especially addressing the digital process steps. It provides an overview on the basics, restrictions, state of readiness and examples of impacts on components. Further approaches for different goals for the automation of the process chain are identified. The presentation is thus an insight into the process chain for additive manufacturing and shows challenges and opportunities for businesses, which lead to a profitable customized manufacturing.

Keywords

Additive Manufacturing; 3D Printing; Process Chain; 3D CAD; Mass Customization; Virtual Product Creation.

1 Introduction and Motivation

Additive manufacturing open wide fields of application in various industries. These include, for example, aerospace, automotive, general mechanical engineering, medical technology, electronics, and consumer goods such as fashion or art objects. In a study by Gartner additive manufacturing was defined as one of the fastest growing technologies [1]. Further analyses and studies confirm these statements. Additive manufacturing is regarded as a revolution. The additive manufacturing industry recorded a rapid growth. In the past decade, sales of additive manufacturing systems and services has risen by about 25% annually. Future forecasts continue to expect double-digit annual growth rates. Wohlers Report says that in 2020 an annual turnover of 21 billion US dollars is expected [2], see Figure 1 on the left. Very similar Forecasts are predicted by Frost & Sullivan. Here the automotive sector are allocated a share of more than 20% [3]. According to a BMWi (*Bundesministeriums für Wirtschaft und Energie*) study from 2013 [4] German companies have generated only about 15-20% of the worldwide turnover in the year of 2010. Key message of the study is that "continuous innovation and opening up new fields of application" is a basic requirement for the successful implementation. The great relevance of additive manufacturing is also reflected in the number of scientific publications and patent applications, see Figure 1 on the right.

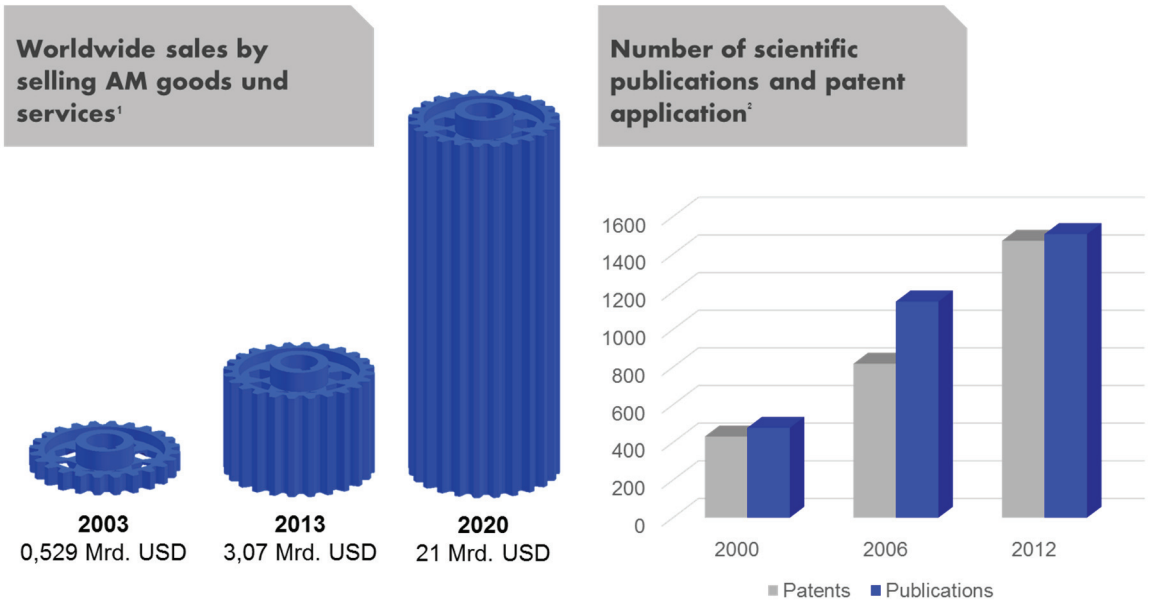


Figure 1: Current Developments in Additive Manufacturing.
Source: [1] Wohlers (2014)[2] Fraunhofer IGD (2013)

A study by the DMRC (Direct Manufacturing Research Center, Paderborn) says the current developments and research are carried out only on a few topics. These topics include mechanical properties of components, new materials, material quality, material creation and

production process (machine optimization) [5]. In contrast, the research and development in the field of "process chain for manufacturing additives and their automation" is very low. Here, the same technologies and methods have been used for about 20 years.

Additive manufacturing processes enable the customization of new components. The complexity of the components a small impact on the manufacturing time have in contrast to classical manufacturing processes. This also leads to lower manufacturing costs. In addition, complex structures can be manufactured. This allows weight and material cost savings. In addition to the potential complexity, the process chain allows, in particular for small quantities, a profitable customization compared to conventional processes. This enables manufacturers to meet individual customer requests and niche markets can be served. Figure 2 shows the effects of lot size and complexity to cost per component. The curves are given qualitatively. The blue line depicts additive manufacturing processes and the gray line conventional manufacturing processes.

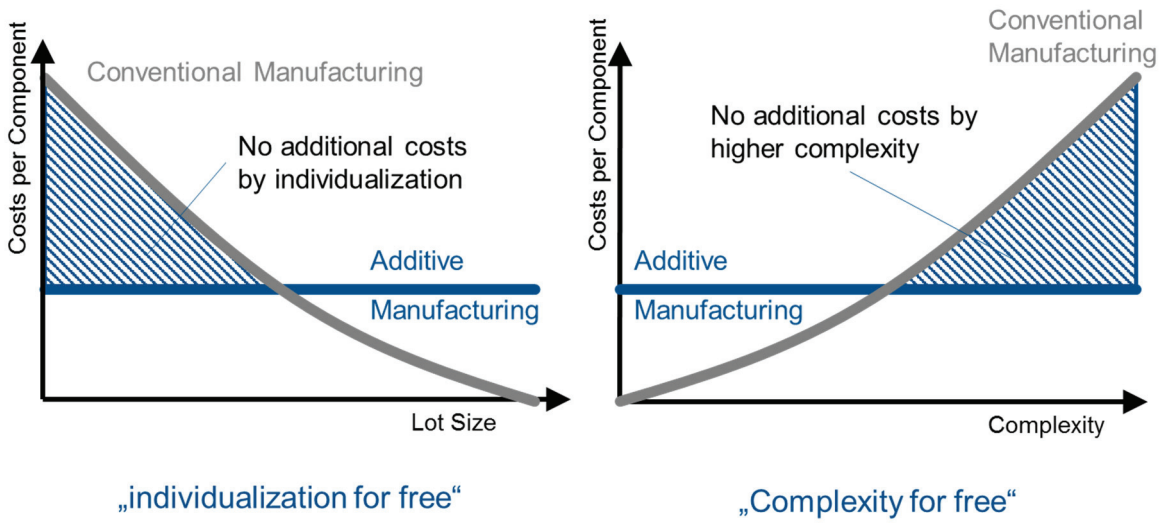


Figure 2: Effects of Lot Size and Complexity to the Cost per Component - Additive Manufacturing Processes against Conventional Manufacturing Processes

The complexity of components and small batch size enables customized production. An example of this in the medical field is the production of prostheses or dental implants. The trend of individualization is also found in the private customer market. Here shoes and inserts, for example, are specifically scanned and produced for the customer. The challenge for the manufacturer of individual components is that in a building process in a machine up to 300 different customer-specific components have to be processed simultaneously. As of today, there is an expensive manual order-specific assignment of the components. Special effort is in the computer internal building process preparation. The process chain for additive manufacturing is mainly digital. Models are made directly on the basis of 3D CAD data models and the pre-processing is also predominantly done digitally. This fact requires a holistic conception and implementation of the process chain 3D CAD for additive manufacturing.

For the profitable manufacturing of customized components, the process chain needs to be automated. By automating the process chain, the customer receives a cost reduction. In addition, the order processing time is shortened and the procedure to reach individualized components immensely simplified. Another significant advantage lies in the paperless integrated quality assurance, which is achieved by the definition of the process chain. The virtual representation of customer orders achieved in this area give an unprecedented transparency, similar to the order and parcel tracking in the consumer logistics.

This need for requirement of automation is also confirmed by a study of the VDI [6]. Here fields of action of the additive manufacturing are discussed. The topics include the holistic understanding of the process and an integrated quality assurance. The automation of the process chain is a common challenge and requirement. The following considerations and approaches serve these fields of action.

2 Basic Information and State of the Art

The structure of the process chain for additive manufacturing is always very similar. Depending on the approach, process steps are added to or deleted. In the following chapter the relevant process chain including all steps for this paper will be explained. The process chain is from the perspective of a contract manufacturer without own development.

Figure 3 shows the discussed process chain. The whole process is divided into two main areas. The digital process steps and the physical process steps. In total, there are eight key process steps. These process steps are carried out sequentially and in part parallel. The whole process takes place under the targets time, quality and cost. Input for the process comes in the form of customer product data and the necessary raw material. The output of the process are customized additive manufactured components and related data sets.

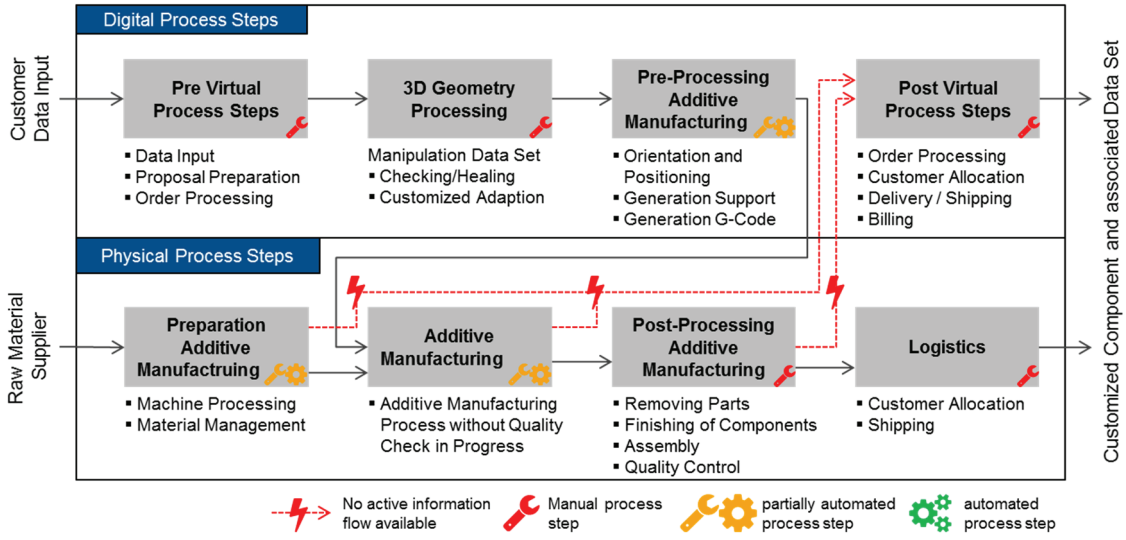


Figure 3: Process Chain for customized Additive Manufacturing - State of the Art. Based on [7]

The individual process steps are explained in more detail. The focus is on the digital process steps.

Pre Virtual Process Steps

The whole process starts with the input of a customer request. This input takes place for example via e-mail. Basis are geometry data of the component, for example STL files (Standard Tessellation Language), STEP files (STandard for the Exchange of Product model data*)* or native CAD data. Then the manufacturer checks the data and manually creates an offer. The customer can then confirm this offer and thus start an order. The whole pre virtual process steps include manual processing of data in the ERP (Enterprise Resource Planning) system. For further processing, the geometric data of the customer are converted into the de facto standard STL (except if the data input was already in the STL format). The STL format is approximated by facets [8]. Figure 4 shows the structure of a facet. It is described on the key vertex and the surface normal. The use of this data format has great weaknesses. It can cause incorrect files, this includes descriptive, design or implementation errors [9]. Figure 4 shows these types of errors as well as an example for an incorrect file.

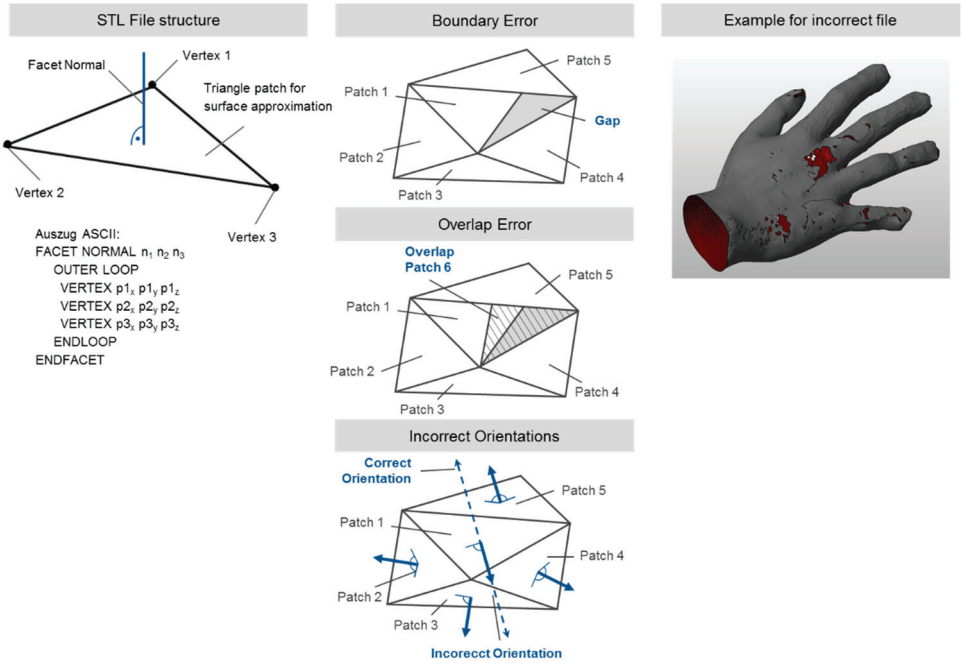


Figure 4: left: STL File Structure; middle: Occurring errors types; right: Example for incorrect file

In addition to the errors that occur, information is lost in the transformation, as shown in Figure 5. This information includes:

- Material properties (color characteristics, material characteristics);
- Tolerances;
- Production Information.

However, this information can be important for manufacturing. This creates a large media and information break. The manufacturer must now add this lost data manually.

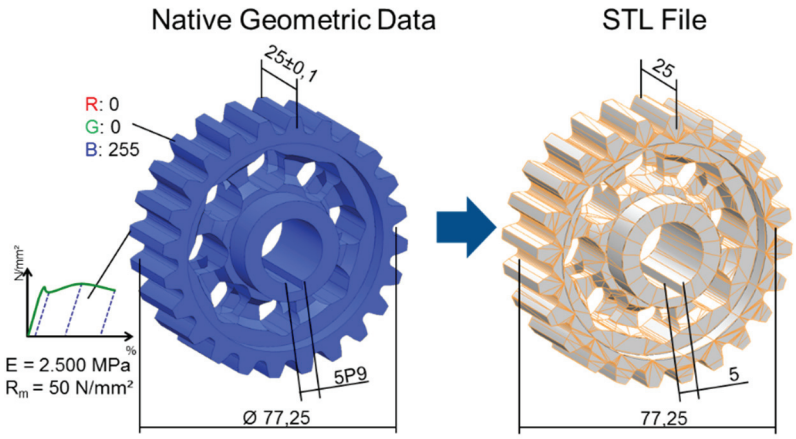


Figure 5: Transformation from Native 3D Model Data to STL File

3D Geometry Processing

In the next process step, the STL data are checked. Errors are healed here. For this purpose, there are different solutions and approaches. However, these are all run manually. First solutions are proposed in [10, 11, and 12]. If the geometry information is accurate the 3D geometry models are further processed. The further processing comprises especially the customizable processing. As described in the beginning, up to 300 components are processed in one job. Therefore, a marking of the components is required. Only in this way can a part be easily associated with a customer afterwards. As of today, this rarely takes place. If it happens it is done manually by the employee. The necessary expertise rests in the mind of the employee. The so-called methodological knowledge is not equally available for all employees. This leads to different applications of markings on components. Existing software applications offer support here. However, the marking is only supported based on economic variables. Visible or functional surfaces are not recognized and considered. The employee must decide again. Indeed, there are component surfaces on which no markings should be mounted. Currently available Software applications cannot determine this. In summary, it can be said that the 3D geometry processing now runs error prone and manually. From this follow different information gaps, see the information flows in figure 3.

Pre-Processing Additive Manufacturing

One of the most important and mission critical steps in the process chain is represented by the pre-processing for additive manufacturing. In this step the components that are to be manufactured are virtually oriented and positioned together in one space. Furthermore, support structures are calculated and generated. Finally, the component is virtually divided into layers, the so-called slicing process. The result of these steps is a machine-readable code that sets the exposure paths of the laser machine or the extruder of the 3D printer. With this

information, the actual production of the components begins. Figure 6 shows an overview of the pre-processing for additive manufacturing.

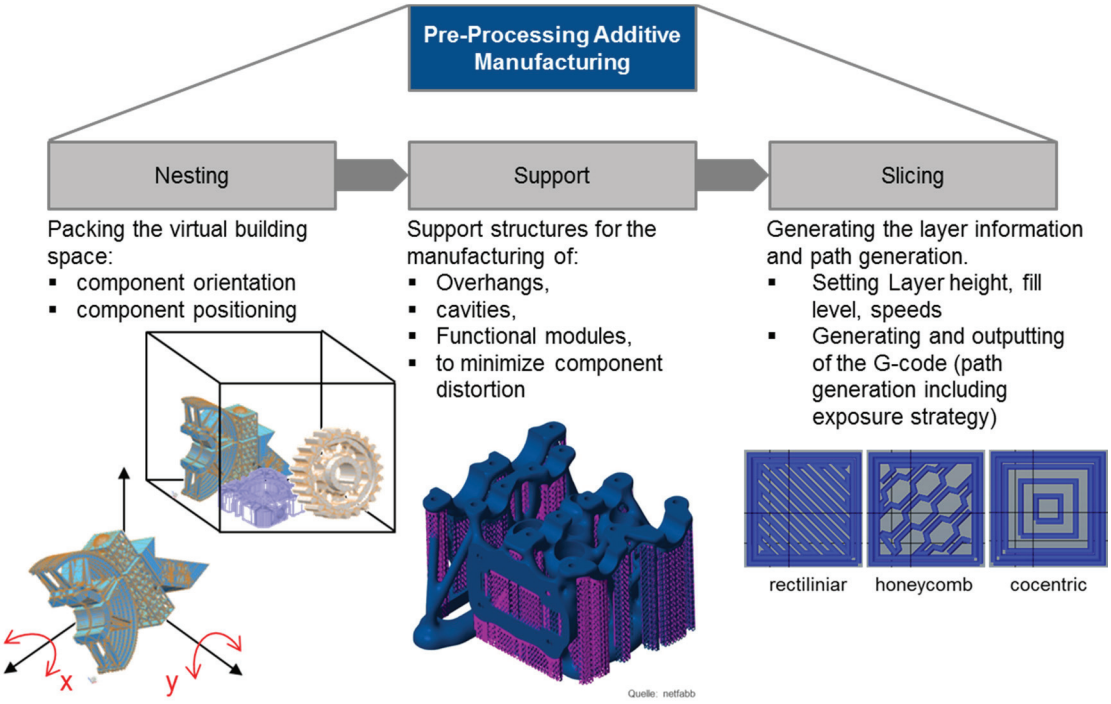


Figure 6: Overview of Process Steps of the pre-processing additive Manufacturing

In a first step, the components are individually oriented and then positioned together in space, the so-called nesting. In addition to the manual positioning of components commercial programs exist for component orientation and positioning. Of special interest here is the optimal three-dimensional packing of the components in the virtual space. Important parameters such as the strength values of the components are not taken into account here [13]. First works describe the most significant variables and constraints to successful nesting [14], however, a holistic approach is still missing including all manufacturing and component restrictions.

When all components are oriented and positioned the creation of support structures follows. Support structures are needed to produce overhangs, cavities, functional modules, and to minimize component distortion. After this process step, the oriented, positioned, and virtual supported components are mathematically separated into layers, the so-called slicing process. Here the user can adjust the layer height or the fill level. Based on this information the machine-readable code is generated. The user carries out these process steps manually.

Post Virtual Process Steps

The last digital process step takes place after the physical manufacturing and post-processing. In this process, the customer orders are processed manually. Based on the manufactured components, bills are created and the shipment to the customer is prepared.

Physical Process Steps

In addition to the digital process steps, there are four physical process steps. The first step involves the direct preparation of the machine, for example, the material management. When the machine is prepared and the data from the pre-processing available, the components are physically manufactured. When the components are manufactured, they are removed from the machine and manually cleaned by the employee. The components are then assigned to each customer with great effort. Normally, this allocation is based on customer orders on paper, which are also triggers for the distribution and delivery of the components to the customer. In the present form of the process chain, no automated communication between physical and digital process steps takes place. The transfer of information and data is done manually between the process steps.

3 Challenges and Objectives for Automation in Customized Production

After describing and analyzing the state of the art a number of challenges and tasks exist on the automation of the process chain.

- Integrated process chain: Already on the market existing software modules form no quality-oriented improvement of the level of automation. These consider the additive manufacturing purely economical and require an intensive manual operation;
- Process automation: The whole process of customized additive manufacturing is distinct mainly manually. An automation of the digital process steps is necessary to reduce the processing time significantly;
- Knowledge-based additive manufacturing: There is no active data or information flow between the digital and physical process steps. The process is solely dependent on employee knowledge. The integration of knowledge is required for an efficient and effective additive manufacturing;
- Identification for order processing: A customer specific identification of the components does not take place under quality assurance aspects. For successful additive manufacturing technology-based information must be considered;
- Integration into overall system: There must be a holistic enterprise-wide implementation. This requires the consideration of technical and economic variables. Commercial programs or currently existing scientific approaches are not able to consider all of these important requirements.

In order to meet the challenges, the following primary objectives are defined for a new process chain for customized additive manufacturing.

- Increase of effectiveness in the customized order processing by automating the process chain for the additive manufacturing;
- Reduction of media breaks along the complete process chain for customized additive manufacturing;
- Implementation of a paperless, digital and integrated quality assurance and component tracking of individual customer orders.

Based on the challenges and targets a concept will be presented in the next chapter. This concept represents a proposal to achieve the objectives. It is, as already described, focusing on the digital process steps. Because therein lies the greatest potential for automation of the process chain.

4 Concept for Automation in Customized Production

Figure 7 shows the redefinition of the process chain for automated customized additive manufacturing. The process chain is still divided into physical and digital domains. The eight process steps also remain. The central component of the redefined process chain is a knowledge data base. In this database all the necessary data is stored and accessed. Between the individual process steps and the database, an information exchange takes place. This is mainly bidirectional. The individual digital process steps with their new features are described below.

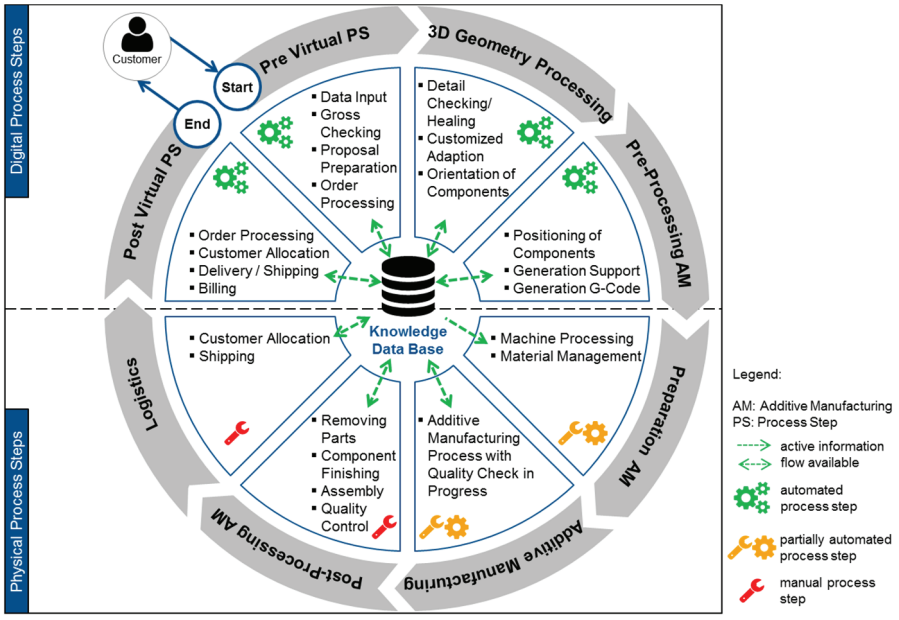


Figure 7: Process Chain for customized Additive Manufacturing – Redefinition

The automated process chain starts with the **Pre Virtual Process Steps**. The customer sends the component to be manufactured trough a web platform. In addition, the customer specifies

his priorities regarding manufacturing. Here the classical constraints time, cost and quality are used. The customer gives therefore on if he wants the part quickly, cheaply or with a high quality. A combination of the target variables is also possible. This operation triggers the automated process. An algorithm provides an automated processing of the proposal and of the order. In a first step, the cost of the component is determined through the surface volume ratio. The customer receives an offer directly on the web platform. Unlike the old process chain, the customer data can be tested directly for gross errors. Iterative loops and queries are avoided. When the offer is confirmed, the order starts. The necessary information is stored in the knowledge data base. The sales order from now on controls the entire automated process.

In the second process step, the **3D Geometry Processing**, the components are retrieved from the database and checked for errors in detail. In a first step, all input data are converted to the de-facto standard STL. Existing software modules can already be used for the automated testing of STL files. These software modules check the files for gaps, overlaps, and whether the surface is closed. If errors occur, the algorithm resolves them so that an error-free file is created, see Figure 8 on the left side. After repairing, the updated geometry data is associated with the customer order and stored in the knowledge data base.

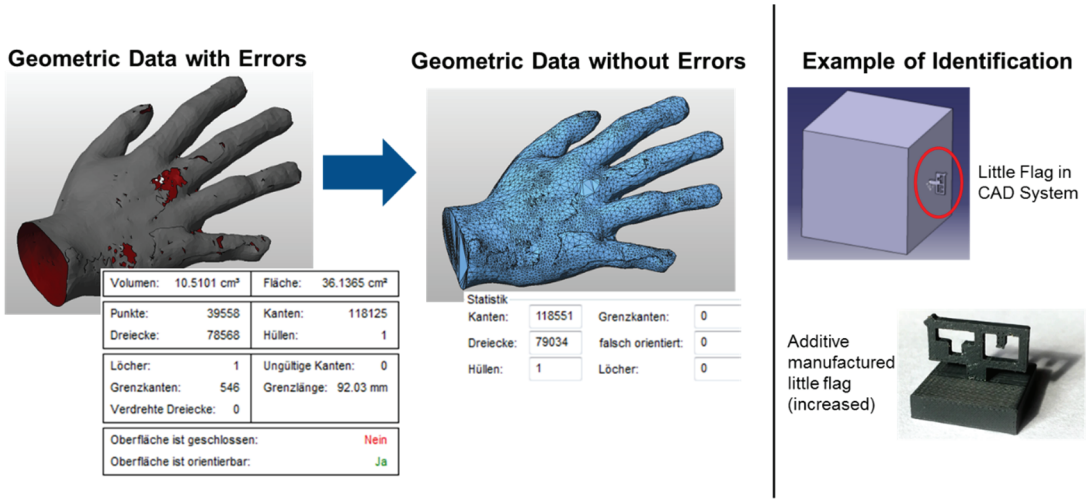
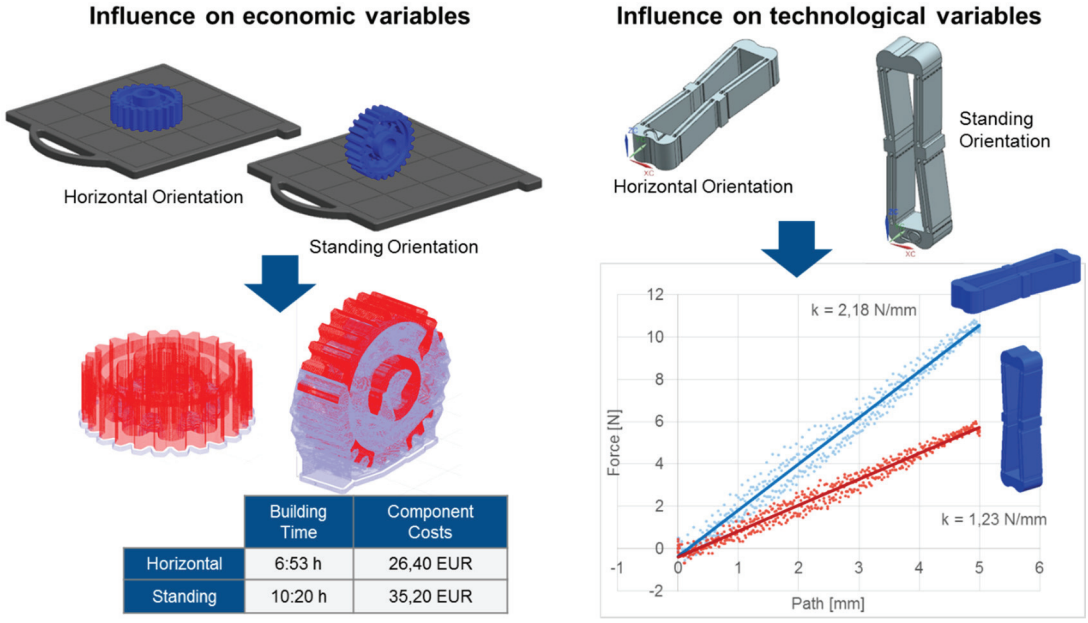


Figure 8: 3D Geometry Processing; Detail checking and healing - left; Example of Identification – right

As described in the initial situation will be made up to 300 components per building process. These components can be completely different from each other. This large number of different parts requires a clear identification of components. There are a number of identification techniques. Today especially optical and electromagnetic systems are used. These include, for example, bar code systems, two-dimensional codes (matrix codes), Optical Character Recognition (OCR), or Radio Frequency Identification (RFID). Consideration of form specific process boundaries and evaluation of all options makes a variant most suitable. This is a little flag, which is attached to the component. Characters (letters) perform the identification. The advantage of this is, this type of marking is readable by man and machine, Figure 8 (right) shows the little flag. Of course, other variants are possible. At first, the automated marking

must determine the so-called no-go areas. This includes visible surfaces or functional surfaces, for example hole basis fits. This requirement is subject to research needs. The new labeled component is stored in the knowledge date base.

Another step in the CAD system is the automated optimal orientation of the components. Orientation of the components has a great effect on the costs of manufacturing and the quality of the components. These targets need to be considered in this step. Figure 9 shows different influences of the orientation on the component costs, the building time and mechanical properties, here the working spring rate. At the beginning of the process chain (Pre Virtual Process Steps) the customer queries the economic targets. If the customer wants the component to be cheap, it is for example manufactured in a horizontal orientation, see the wheel in Figure 9 left. More difficult is the specification of the desired mechanical properties. The load case in the use phase is automated very difficult to detect. Therefore, the customer must request this load case. One way would be to attach forces or bending moments in a simple input mask (in the first process step in the file upload by the customer). This requirement needs further development and research. The necessary manufacturing knowledge is already available from first tests, see Figure 9 right. For complex loading cases FEM analyses have to be carried out. The results of this analysis leading to an optimal orientation of complex components. At the end of the process step “3D geometry processing” the error-free, oriented, and marked components are assigned to the customer and stored in the knowledge data base.



	Building Time	Component Costs
Horizontal	6:53 h	26,40 EUR
Standing	10:20 h	35,20 EUR

Figure 9: Influence of the orientation on the process and components [15]

The next digital process step before the actual building process involves the **Pre-Processing Additive Manufacturing**. All collected components to be manufactured are automatically positioned together in a virtual space. The primary endpoint is the smallest possible packing density. This allows many customized components to be manufactured in a single building job.

Urgent orders are previously positioned as time uncritical. This is decided by the selected beginning prioritization by the customer. The positioning ends when the virtual space is full. Depending on the process support structures are generated. For selective laser sintering for example, this is not necessary. Finally, the G-code is generated with the defined parameters. The G-code generation involves cutting the building job into mathematically described layers of the same thickness. The G-code is stored in the database. All customer orders included in the building job are referenced to this G code. This allows a unique assignment.

Figure 10 shows a summary of all the necessary data and information in the knowledge data base. All customer orders are structured so that they are assigned to a building job. The building job displayed here has the ID 15. For every building job general information is stored. These include the G-code as well as all customer orders and the current machine status. These data are obtained from the physical process step of AM. For example, here the current manufacturing time and the type of machine is saved. Information from the process step Preparation AM and post-processing AM are stored in the folder for quality management. For each customer order the complete information is collected from the process steps, for example here for the customer with the ID 15.1. Here all related and changed records are stored. This has the advantage of a continuous tracking of all process steps and is also used for quality control. If the building job is done, the automated **Post Virtual Process Steps** are initiated. This includes the creation and sending of bill and order information. All these documents are again assigned to the order in the knowledge data base. The automated customized additive manufacturing is completed. For more customers and building jobs, the knowledge data base will be continued analogously.

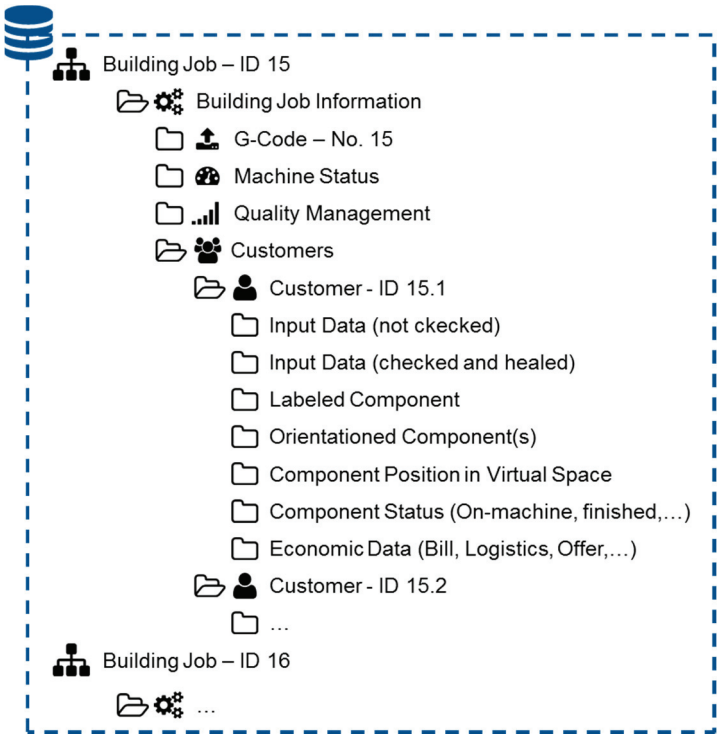


Figure 10: Customer orders in the knowledge data base – structure

5 Conclusion

The shown redefined process chain is an approach for the automation of customized additive manufacturing. The central component is the knowledge data base. Here all the necessary information are compiled. By connecting and providing all the information media breaks or information gaps between the process steps are avoided. In addition to the central database, another important aspect is the automation of the individual process steps. Above all, the knowledge-based processing of customer orders is to be named here. Orders are then processed not only from economic target parameters, but also in technological targets. This represents an advancement over existing solutions. The marked components enable an integrated quality assurance.

The concept shown the perfect basis for new business models for industry. The effort for customized additive manufacturing is kept very low through automation. For example, manufacturers can change with no extra effort from series production to batch size 1. When using the concept savings will take place particularly in the area of data processing. There are also positive effects in the area of resource efficiency. By technology-based additive manufacturing all parameters are taken into account, for example, machines are optimally utilized and there is less waste.

In further research the addressed process steps can be further automated. Here new algorithms are needed. The focus will be on technology-based customized additive manufacturing. To fill the knowledge data base more machine tests need to be carried out. To exploit the full potential the physical process steps must also be considered. The goal is to automate the complete process chain for additive manufacturing.

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Additive Fertigung – Automatisierung in der kundenindividuellen Fertigung

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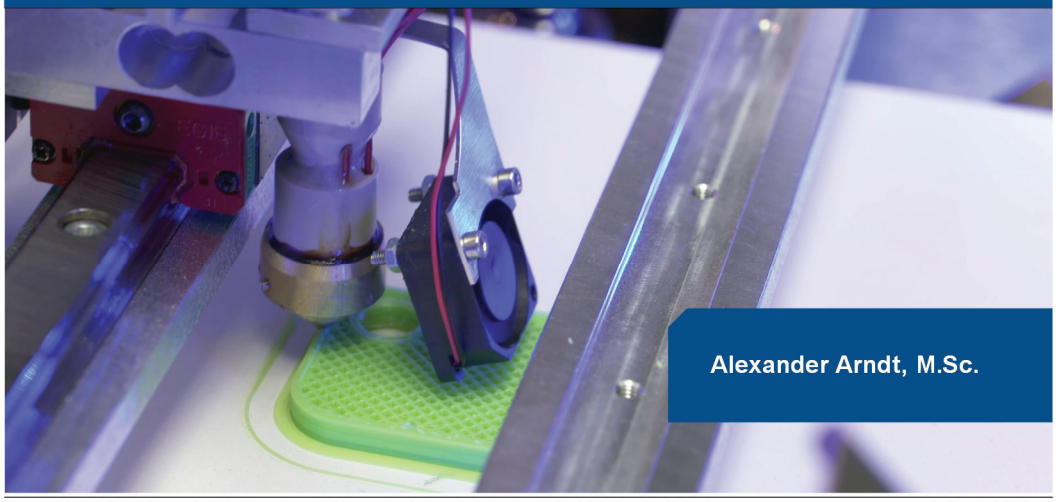
Manufatura aditiva - automação na produção customizada



Alexander Arndt, M.Sc.

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   Desafios para a nova cadeia de processos
4. **Konzept für eine kundenindividuelle additive Fertigung**
   Conceito para a manufatura aditiva personalizado
5. **Ausblick und Zusammenfassung**
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Additive Fertigung – Aktuelle Entwicklungen
Manufatura aditiva – desenvolvimentos recentes

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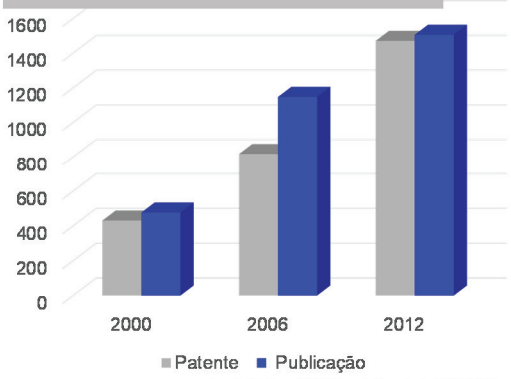

[1] nach Wohlers (2014) [2] nach Fraunhofer IGD (2013)

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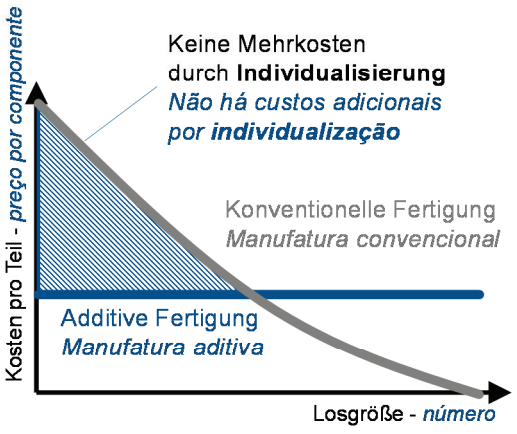
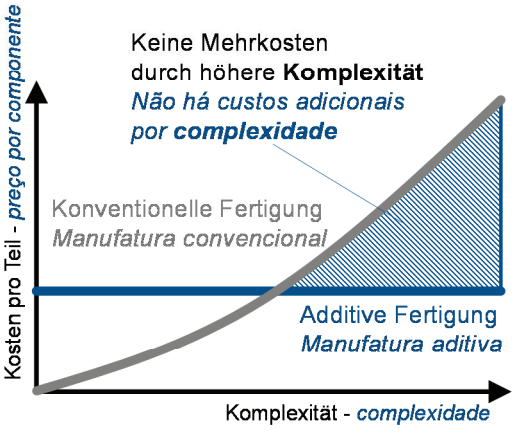


„individualization for free“



„Complexity for free“

Anwendungsbereiche Additive Fertigung
Manufatura aditiva - âmbito de aplicação

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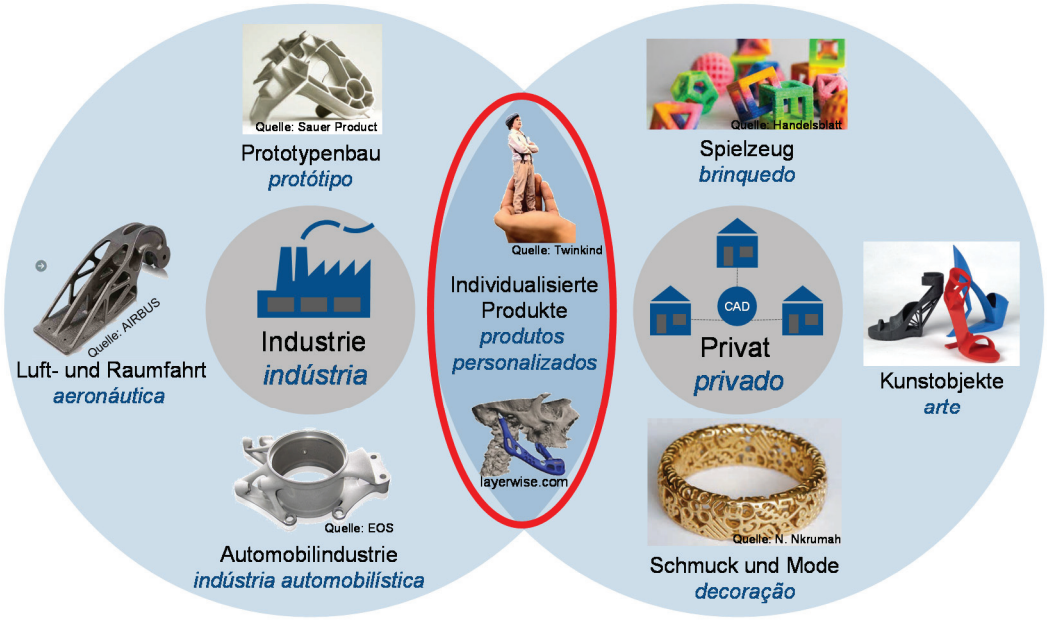

Kundenindividuelle Fertigung
Produção personalizada

TECHNISCHE UNIVERSITÄT DARMSTADT

- Bis zu 300 Bauteile in einem Baujob
  Até 300 componentes em um processo de construção

Brillen - *Óculos*

Quelle: 3Ddruck.com/mykita

Zähne - *Dente*

Quelle: EOS

Turbinenschaufeln - *Pá de turbina*

Quelle: Fraunhofer ILT

Spielzeug - *Brinquedos*

Quelle: F.A.T. Lab, Sy-Lab/CC BY-NC-SA

Gliederung
Estrutura

TECHNISCHE UNIVERSITÄT DARMSTADT

1. **Einführung und Motivation**
   Introdução e motivação
2. **Grundlagen und Stand der Technik**
   Fundamentos e estado da técnica
3. **Herausforderungen an neue Prozesskette**
   Desafios para a nova cadeia de processos
4. **Konzept für eine kundenindividuelle additive Fertigung**
   Conceito para a manufatura aditiva personalizado
5. **Ausblick und Zusammenfassung**
   Perspectiva e resumo

Prinzip der Additiven Fertigung
Princípio de manufatura aditiva

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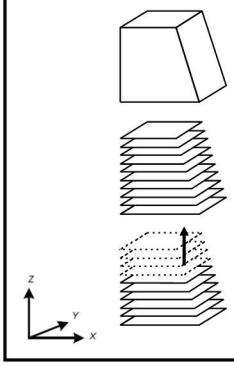
„Generativ (lat. generare) - erzeugend, urformend - hier: Aufbauende Verfahren, z.B. elementweise oder schichtweise, additiv.“

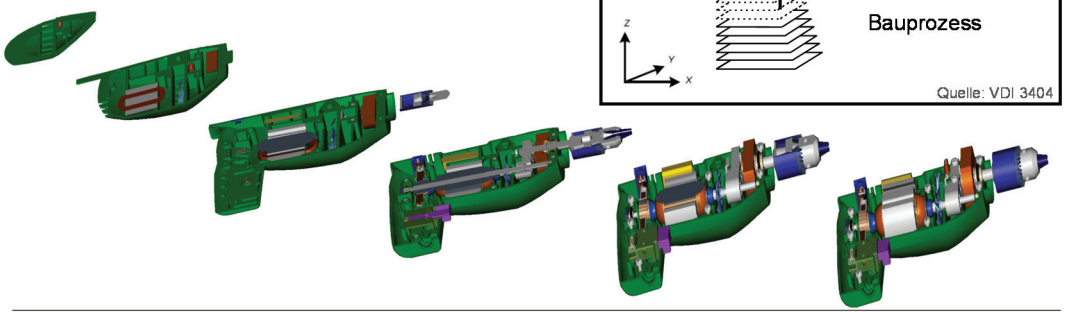
[Quelle: VDI 3404]

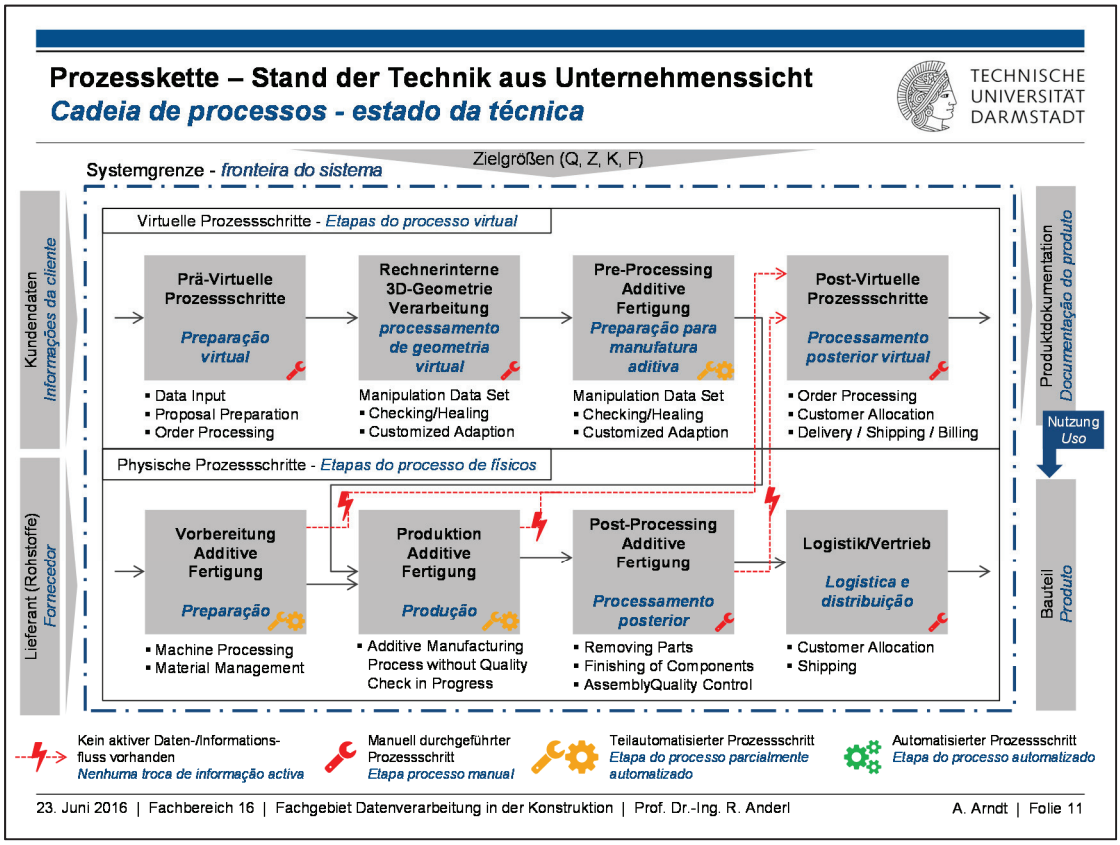
“Additive fabrication refers to manufacturing processes which employ an additive technique whereby successive layers or units are built up to form a model.” *[Quelle: VDI 3404]*

Bauprinzip - *princípio de design*



Quelle: VDI 3404




Prozesskette – Stand der Technik aus Unternehmenssicht
Cadeia de processos - estado da técnica
TECHNISCHE UNIVERSITÄT DARMSTADT
Zielgrößen (Q, Z, K, F)
Systemgrenze - fronteira do sistema
Kundendaten Informações da cliente
Lieferant (Rohstoffe) Fornecedor
Virtuelle Prozessschritte - Etapas do processo virtual
Prä-Virtuelle Prozessschritte
Preparação virtual
▪ Data Input
▪ Proposal Preparation
▪ Order Processing
Rechnerinterne 3D-Geometrie Verarbeitung
processamento de geometria virtual
Manipulation Data Set
▪ Checking/Healing
▪ Customized Adaption
Pre-Processing Additive Fertigung
Preparação para manufatura aditiva
Manipulation Data Set
▪ Checking/Healing
▪ Customized Adaption
Post-Virtuelle Prozessschritte
Processamento posterior virtual
▪ Order Processing
▪ Customer Allocation
▪ Delivery / Shipping / Billing
Physische Prozessschritte - Etapas do processo de físicos
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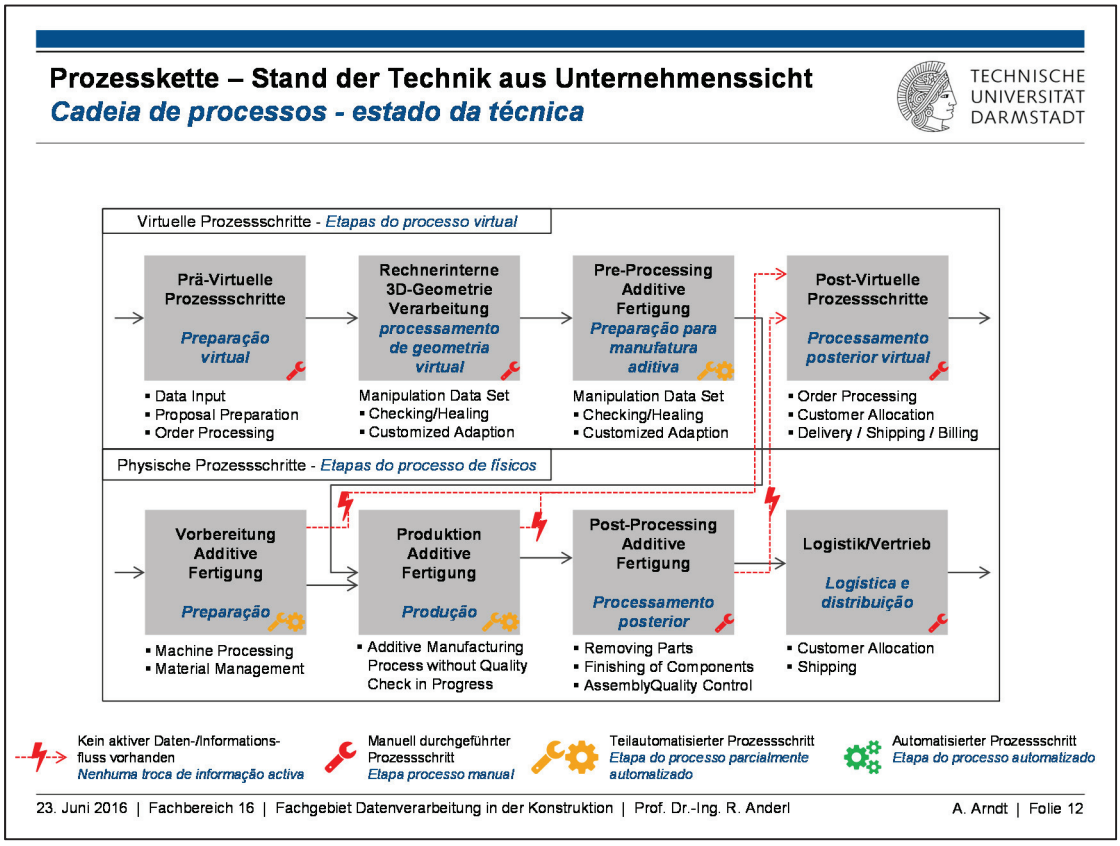
Preparação
▪ Machine Processing
▪ Material Management
Produktion Additive Fertigung
Produção
▪ Additive Manufacturing Process without Quality Check in Progress
Post-Processing Additive Fertigung
Processamento posterior
▪ Removing Parts
▪ Finishing of Components
▪ AssemblyQuality Control
Logistik/Vertrieb
Logística e distribuição
▪ Customer Allocation
▪ Shipping
Produktdokumentation Documentação do produto
Nutzung Uso
Bauteil Produto
Kein aktiver Daten-/Informations-fluss vorhanden
Nenhuma troca de informação activa
Manuell durchgeführter Prozessschritt
Etapa processo manual
Teilautomatisierter Prozessschritt
Etapa do processo parcialmente automatizado
Automatisierter Prozessschritt
Etapa do processo automatizado
23. Juni 2016 | Fachbereich 16 | Fachgebiet Datenverarbeitung in der Konstruktion | Prof. Dr.-Ing. R. Anderl
A. Arndt | Folie 11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A. Arndt | Folie 12

Prozesskette – Stand der Technik aus Unternehmenssicht
Cadeia de processos - estado da técnica

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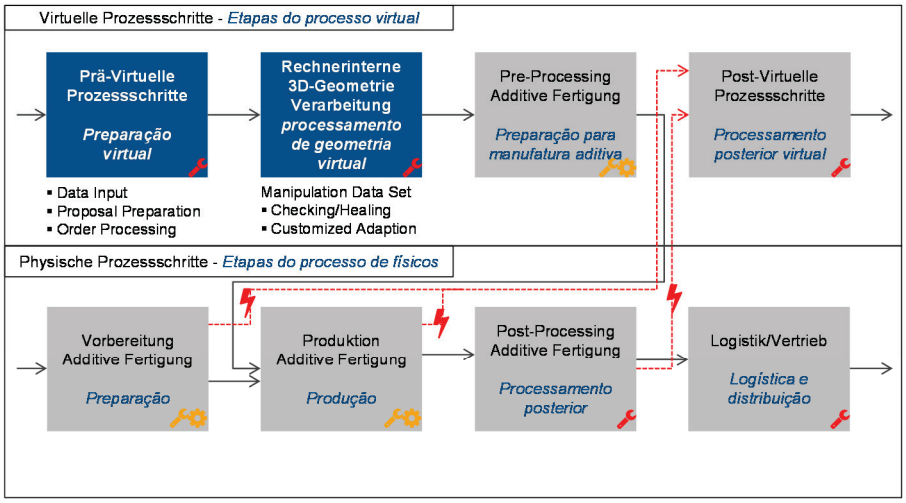

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Teilautomatisierter Prozessschritt
Etapa do processo parcialmente automatizado

Automatisierter Prozessschritt
Etapa do processo automatizado

Dateneingang und Manipulation/Transformation
Entrada de dados e manipulação/transformação

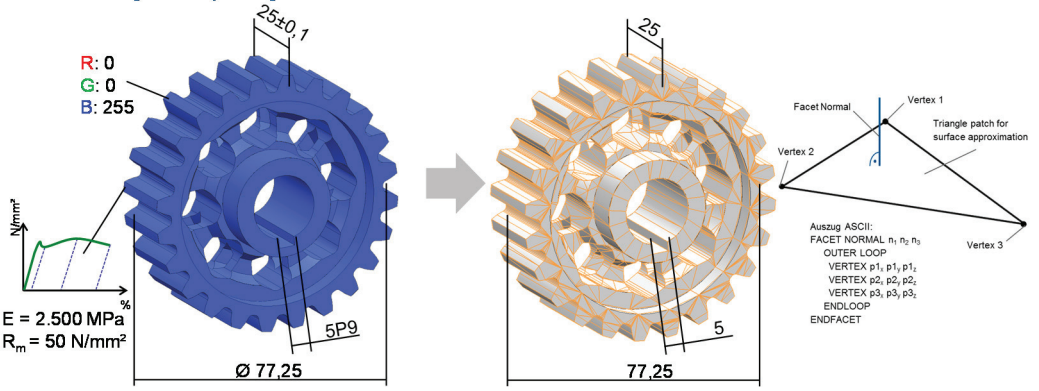
TECHNISCHE UNIVERSITÄT DARMSTADT

Dateneingang
Entrada de dados:

- Geometrie - *Geometria*
- Werkstoffeigenschaften - *Propriedades do material*
- Toleranzen – *Tolerâncias*
- Fertigungsinformationen - *Informações de produção*

Manipulation/Transformation
Manipulação/transformação:

- **Industriestandard** in additiver Fertigung bildet das **STL Format** (Standard Tesselation Language)
Padrão da indústria em manufatura aditiva é o formato STL.



Probleme bei der Manipulation/Transformation
Problemas durante a manipulação/transformação

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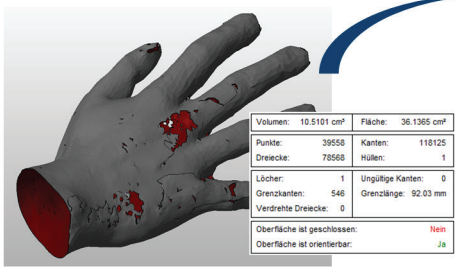
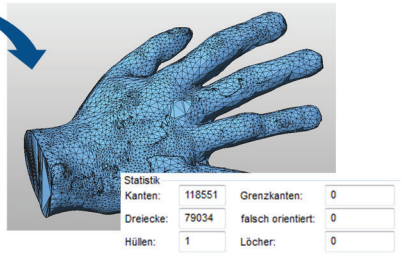
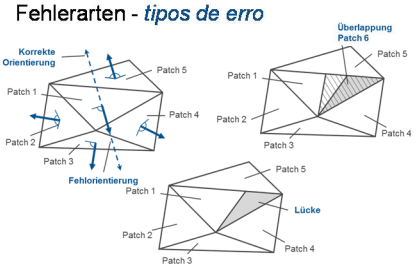
Fehlerbehaftete Geometriedaten
Dados quebrados:



Fehlerfreie Geometriedaten
Dados sem erros:



Fehlerarten - *tipos de erro*

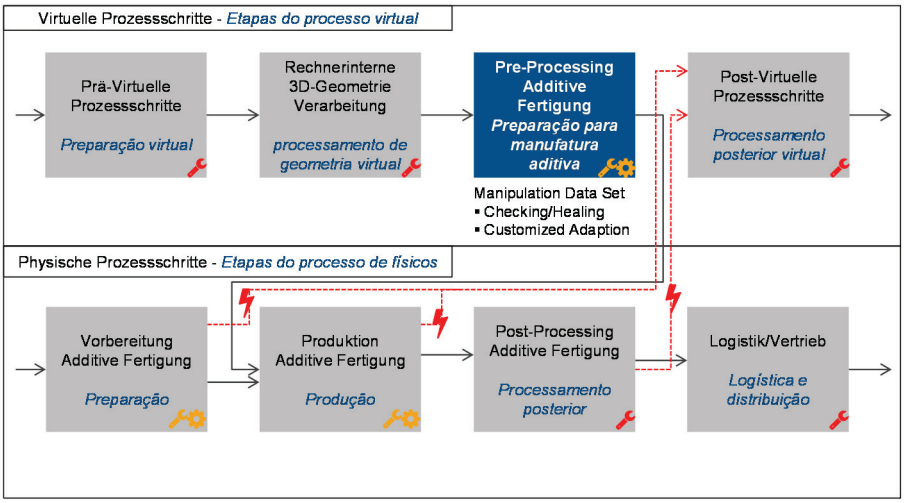


Alternativen vorhanden → Transfer in Industrie notwendig
Alternativas existentes → Transferência necessário na indústria

Bewertungskriterien	STL	AMF	3MF	DXF	VRML	3DS	IGES	JT	OBJ	PLY	STEP	...
Triangulierte Darstellung	+	+	+	+	+	+	o	+	+	+	o	
CSG-Repräsentation	-	-	-	o	+	+	+	+	o	o	+	
Farbinformationen	-	+	+	+	+	+	+	+	+	+	+	
Materialeigenschaften	-	+	+	+	+	+	+	+	+	+	+	
PMI	-	o	o	o	o	o	+	+	o	o	+	
Baugruppenstrukturen	-	o	-	o	o	+	+	+	o	o	+	
Skalierbarkeit (LOD)	-	-	-	-	+	-	-	+	o	o	o	
Redundanzfrei	-	+	+	+	+	-	+	o	+	+	o	
Geringe Dateigröße	-	+	+	-	-	+	o	o	+	+	+	

Prozesskette – Stand der Technik aus Unternehmenssicht
Cadeia de processos - estado da técnica

TECHNISCHE UNIVERSITÄT DARMSTADT



Kein aktiver Daten-/Informations-fluss vorhanden
Nenhuma troca de informação activa

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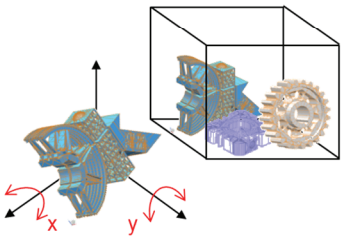
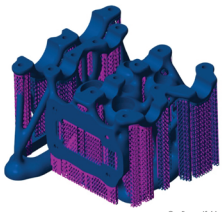
Pre-Processing Additive Fertigung
Preparação para manufatura aditiva

TECHNISCHE UNIVERSITÄT DARMSTADT

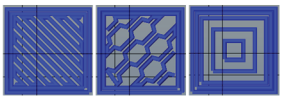
Packen des **virtuellen Bauraums** der zu fertigenden Bauteile:
- Bauteilorientierung
  Orientação componente
- Bauteilpositionierung
  Posicionamento do componente



Stützstrukturen zur Fertigung von:
- Überhängen - *Sobrenadante*,
- Hohlräumen - *Cavidade*,
- Baugruppen - *Módulo*,
- zur Minimierung von Bauteilverzug - D*istorção componente*

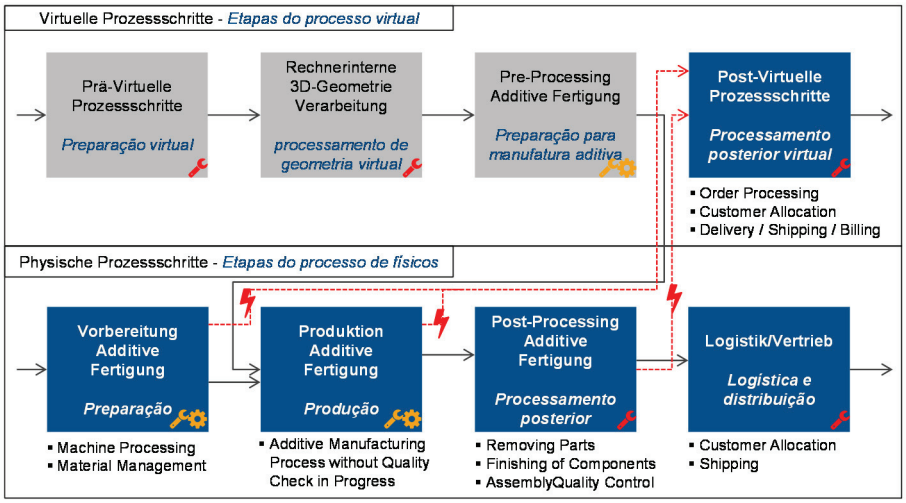


Erzeugung der **Schichtinformationen** und **Pfadgenerierung**.
- Layerhöhe - *Altura da camada*,
- Füllgrad - *Nível de enchimento*,
- Geschwindigkeiten – *Velocidade*,
- Generierung und Ausgabe des G-Code (Pfadgenerierung samt Belichtungsstrategie)
  Código legível por máquina



Prozesskette – Stand der Technik aus Unternehmenssicht
Cadeia de processos - estado da técnica

TECHNISCHE UNIVERSITÄT DARMSTADT



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Physische Prozessschritte – Post-Processing
Etapas do processo de fisicos - Processamento posterior

TECHNISCHE UNIVERSITÄT DARMSTADT

- Bis zu 300 Bauteile in einem Baujob
  Até 300 componentes em um processo de construção

Ausgraben
Escavar

Säubern
Limpar

Sandstrahlen
Jateamento

Quelle: 3DSystems

Quelle: 3Ddruck.com/mykita

Gliederung
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TECHNISCHE UNIVERSITÄT DARMSTADT

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Herausforderungen an neue Prozesskette
Desafios para a nova cadeia de processos

TECHNISCHE UNIVERSITÄT DARMSTADT

- Durchgängige Prozessketten - *Cadeias de processo contínuo*:
  Existierende Softwaremodule bilden keine qualitätsgerechte Verbesserung des Automatisierungsgrades.
  → rein wirtschaftlich und intensive manuelle Bedienung
  → *Puramente econômica e intensa operação manual*
- Prozessautomatisierung und Digitalisierung - *Automação de processos e digitalização*:
  Gesamter Prozess der kundenindividuellen Additiven Fertigung ist Stand heute manuell ausgeprägt.
  → Automatisierung der digitalisierten Prozessabläufe zur Reduzierung der Abwicklungszeiten notwendig.
  → *Automatização de processos digitalizados necessário*
- Wissensbasierte Additive Fertigung - *Manufatura aditiva baseada no conhecimento*:
  Kein aktiver Daten- bzw. Informationsfluss von Material-, Produktions- und Post-Processing-Daten in die post-virtuellen Prozessschritte oder das ERP-System.
  → Integration von Wissen und Standardisierung von Prozessketten sind erforderlich.
  → *Integração de conhecimento exigido.*
- Identifikation zur (Verfolgung der) Auftragsabwicklung - *Identificação de processamento de pedidos*:
  Kundenspezifische Identifikation der Bauteile findet manuell statt – Stand heute lediglich wirtschaftliche Zielgrößen
  → automatisierte und qualitätssichernde Identifikation von kundenindividuellen Bauteilen.
  → *Identificação de garantia de qualidade*
- Unternehmensweite Betrachtung und Implementierung - *Implementação em toda a empresa*:
  Durchgängige Verknüpfung mit der betriebswirtschaftlichen Unternehmenssoftware ist kaum vorhanden.
  → nicht nur technische sondern auch betriebswirtschaftliche Durchgängigkeit in der Prozesskette
  → *Continuidade econômica da cadeia de processos*

Gliederung
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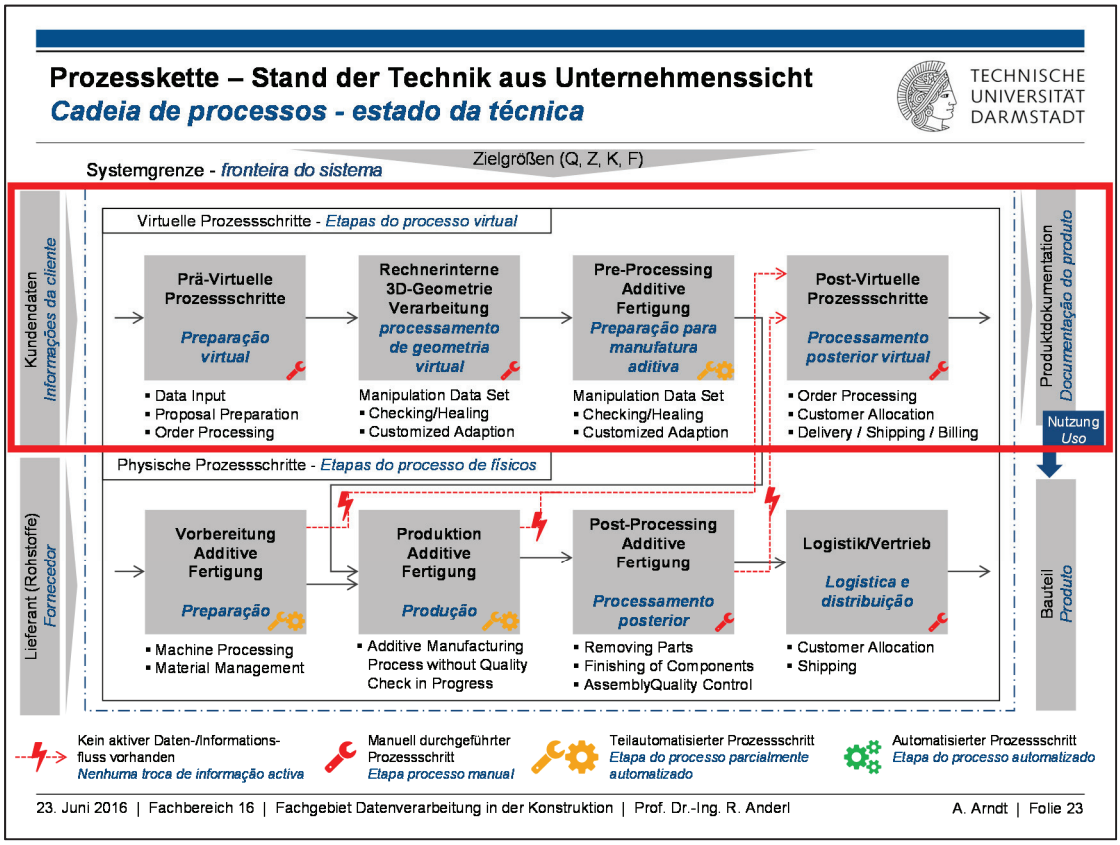
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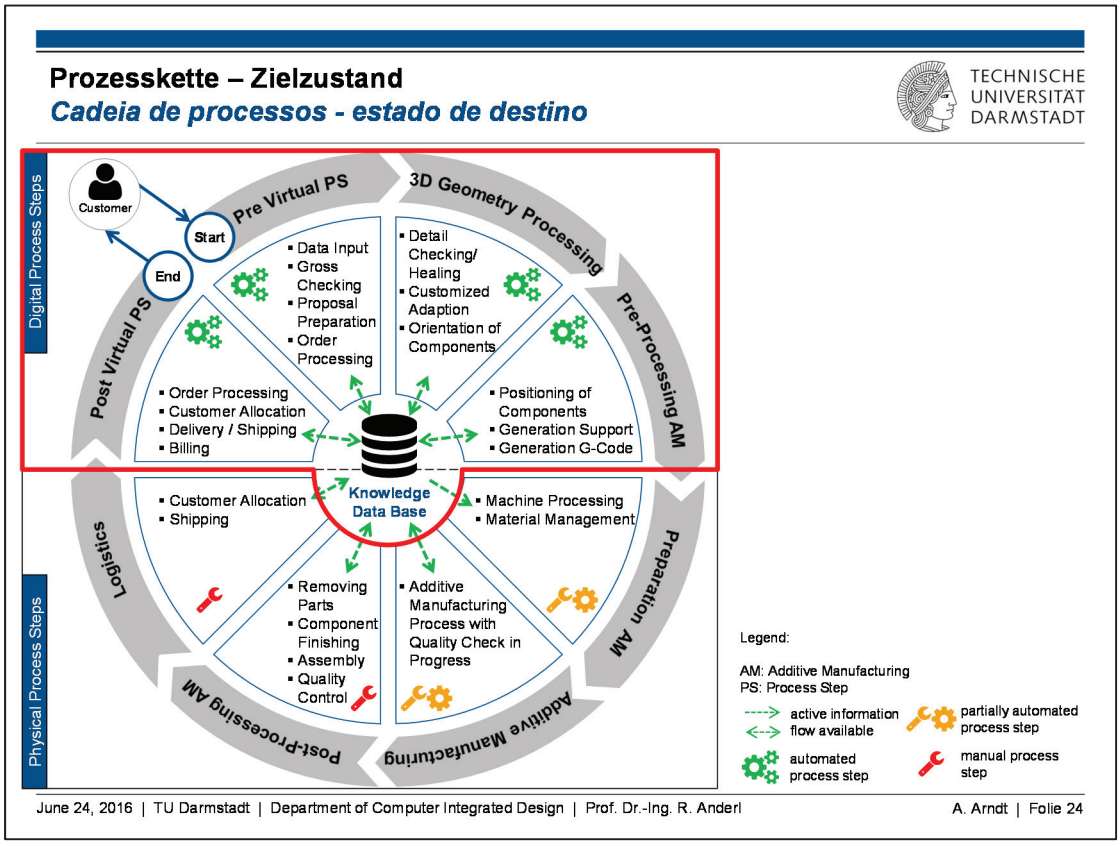
23. Juni 2016 | Fachbereich 16 | Fachgebiet Datenverarbeitung in der Konstruktion | Prof. Dr.-Ing. R. Anderl
A. Arndt | Folie 23

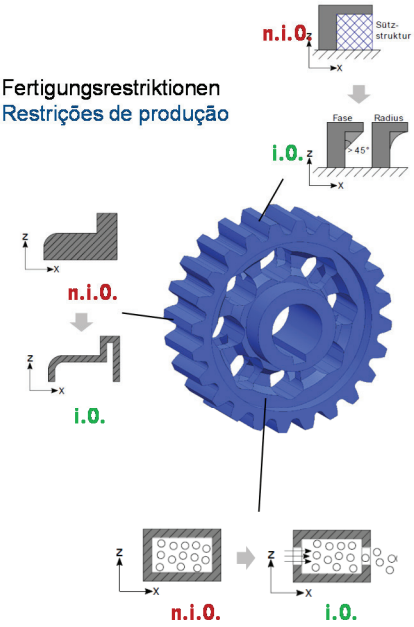

Prozesskette – Zielzustand
Cadeia de processos - estado de destino
TECHNISCHE UNIVERSITÄT DARMSTADT
Digital Process Steps
Physical Process Steps
Customer
Start
End
Pre Virtual PS
3D Geometry Processing
Pre-Processing AM
Preparation AM
Additive Manufacturing
Post-Processing AM
Logistics
Post Virtual PS
▪ Data Input
▪ Gross Checking
▪ Proposal Preparation
▪ Order Processing
▪ Detail Checking/ Healing
▪ Customized Adaption
▪ Orientation of Components
▪ Positioning of Components
▪ Generation Support
▪ Generation G-Code
▪ Machine Processing
▪ Material Management
▪ Additive Manufacturing Process with Quality Check in Progress
▪ Removing Parts
▪ Component Finishing
▪ Assembly
▪ Quality Control
▪ Customer Allocation
▪ Shipping
▪ Order Processing
▪ Customer Allocation
▪ Delivery / Shipping
▪ Billing
Knowledge Data Base
Legend:
AM: Additive Manufacturing
PS: Process Step
active information flow available
partially automated process step
automated process step
manual process step
June 24, 2016 | TU Darmstadt | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl
A. Arndt | Folie 24

Zentraler Bestandteil – Wissensdatenbank
Elemento central – Base de conhecimento

TECHNISCHE UNIVERSITÄT DARMSTADT

- Building Job – ID 15
  - Building Job Information
    - G-Code – No. 15
    - Machine Status
    - Quality Management
    - Customers
      - Customer - ID 15.1
        - Input Data (not ckecked)
        - Input Data (checked and healed)
        - Labeled Component
        - Orientationed Component(s)
        - Component Position in Virtual Space
        - Component Status (On-machine, finished,…)
        - Economic Data (Bill, Logistics, Offer,…)
      - Customer - ID 15.2
        - …
- Building Job – ID 16
  - …

Fertigungsrestriktionen
Restrições de produção



Zentraler Bestandteil – Wissensdatenbank
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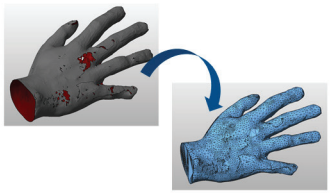
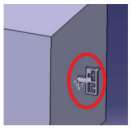
      - Customer - ID 15.2
        - …
- Building Job – ID 16
  - …

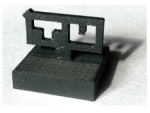
Gross and Detail Checking



Example of Identification



Little Flag in CAD System



Additive manufactured little flag (increased)

Zentraler Bestandteil – Wissensdatenbank
Elemento central – Base de conhecimento

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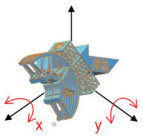
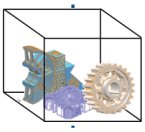
- Building Job – ID 15
  - Building Job Information
  - G-Code – No. 15
  - Machine Status
  - Quality Management
  - Customers
    - Customer - ID 15.1
      - Input Data (not ckecked)
      - Input Data (checked and healed)
      - Labeled Component
      - Orientationed Component(s)
      - Component Position in Virtual Space
      - Component Status (On-machine, finished,…)
      - Economic Data (Bill, Logistics, Offer,…)
    - Customer - ID 15.2
      - …
- Building Job – ID 16
  - …





input
Components (STL) | parameter
Optimization of the component **orientation**
Optimization for all components done?
no
yes
- component geometry
- component orientation
- distance between components
Optimization of the component **positioning**
pack (orientation and positioning)
output

Einflussfaktoren auf Nesting
Factores que influenciaram o nesting

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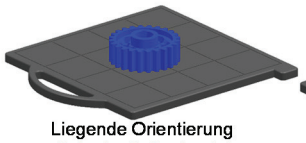
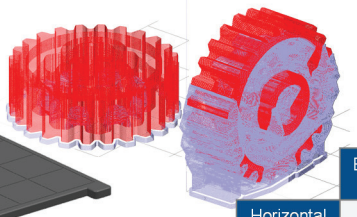
- Einfluss auf wirtschaftliche Kenngrößen
  Impacto sobre parâmetros econômicos:



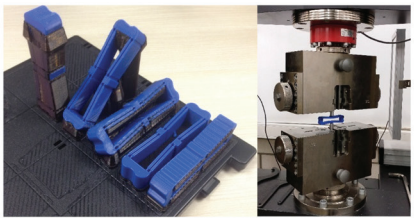
Liegende Orientierung
Orientação horizontal

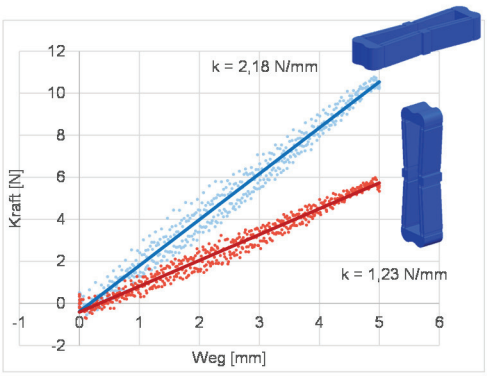
Stehende Orientierung
Orientação vertical



	Bauzeit - *Tempo*	Baukosten - *Custo*
Horizontal	6:53 h	26,40 EUR
Vertical	10:20 h	35,20 EUR

- Einfluss auf mechanische Eigenschaften
  Influência sobre as propriedades mecânicas:





Zentraler Bestandteil – Wissensdatenbank
Elemento central – Base de conhecimento

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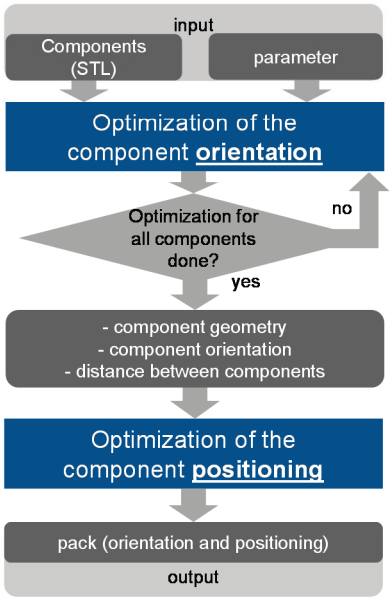

Gliederung
Estrutura

TECHNISCHE UNIVERSITÄT DARMSTADT

1. **Einführung und Motivation**
   Introdução e motivação
2. **Grundlagen und Stand der Technik**
   Fundamentos e estado da técnica
3. **Herausforderungen an neue Prozesskette**
   Desafios para a nova cadeia de processos
4. **Konzept für eine kundenindividuelle additive Fertigung**
   Conceito para a manufatura aditiva personalizado
5. **Ausblick und Zusammenfassung**
   Perspectiva e resumo

Ausblick und Zusammenfassung
Perspectiva e resumo

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Allgemein – *Geral*:

- Vom Prototypenbau hin zu Endprodukten - *De protótipos para os produtos acabados*
- Insbesondere für kleine Stückzahlen und individualisierte Produkte geeignet - *Manufatura aditiva é particularmente adequado para pequenas quantidades.*
- Chance für neue Geschäftsmodelle - *Manufatura aditiva leva a novos modelos de negócios.*

Ausblick – *Perspectiva*:

- Tiefgehende Analyse von Fertigungsverfahren → Füllen der Wissensdatenbank
  Análise de processos de fabricação → Encher o banco de dados de conhecimento
- Weitere Entwicklung und Implementierung soll Durchlaufzeit von kundenindividuellen Aufträgen um ca. 15-20% reduzieren.
  Implementação para reduzir tempo de processamento de ordens em cerca de 15-20%.

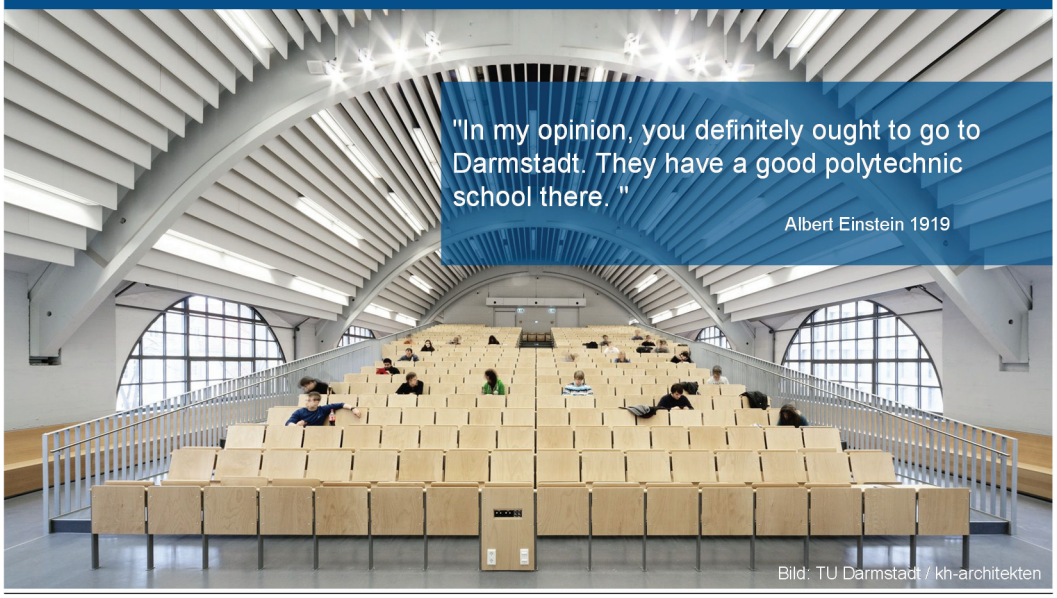
Zusammenfassung – *Resumo*:

- Reduktion von Medienbrüchen entlang der gesamten Prozesskette
  Redução de quebras de media
- Effektivitätssteigerung in der kundenindividuellen Auftragsbearbeitung
  Aumentar a eficácia
- Einführung einer papierlosen, digitalen und integrierten Qualitätssicherung
  Garantia de qualidade contínua

June 24, 2016 | TU Darmstadt | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | A. Arndt | Folie 31

Vielen Dank für Ihre Aufmerksamkeit!
Obrigado pela sua atenção!

TECHNISCHE UNIVERSITÄT DARMSTADT



June 24, 2016 | TU Darmstadt | Department of Computer Integrated Design | Prof. Dr.-Ing. R. Anderl | Folie 32

Eng. Silvia Takey

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✉ silviatakey@gmail.com

DEV Tecnologia

A DEV Tecnologia é uma *Design house spin off* da Escola Politécnica da USP que oferece soluções completas para IoT, desde o projeto eletrônico dos dispositivos conectados até o software em nuvem de interface com o usuário. Somos especialistas em eletrônica embarcada de baixo consumo de energia e banda, rede de sensores sem fio, tratamento de dados em série temporal, comunicação RF (sub giga, WiFi, BLE, Zigbee, 6LowPAN, 2/3/4G). Em 2016 lançará também produtos próprios OEM, como a solução DEV Track que combina sensores e comunicação sem fio para gerenciamento de ativos e pessoas *indoors*.

Internet das Coisas por brasileiros pela melhoria da eficiência da indústria brasileira

Resumo

Um grande desafio da indústria brasileira para se modernizar são os altos custos e dificuldade de integração de novos equipamentos mais modernos e a coexistência com bens de capital antigos que ainda estão operacionais. Tendo em vista este cenário, a DEV Tecnologia, empresa de base tecnológica incubada na Universidade de São Paulo spin off da Escola Politécnica da USP desenvolveu uma tecnologia que permite a baixo custo e fácil instalação o retrofit de máquinas existentes tornando-as conectadas à Internet, habilitando seu monitoramento e controle remotos em tempo real.

Palavras - Chave

Internet das Coisas; Indústria 4.0; Retrofit; Eficiência operacional.

1 Introdução

A DEV Tecnologia é uma empresa de base tecnológica incubada na Universidade de São Paulo, é uma *spin off* da Escola Politécnica da USP Paulo e tem como objetivo posicionar-se como referência em Internet das Coisas no Brasil. Com uma equipe de 20 engenheiros e estudantes de engenharia, possui competência para desenvolver hardware, software embarcado, protocolos de comunicação sem fio, softwares de infraestrutura em nuvem e softwares de aplicação, incluindo aplicativos para *smartphones*.

Em 2014, a empresa realizou a primeira fase do projeto “Aplicação de Internet das Coisas para viabilização de Sistemas Produto-Serviço (PSS)” dentro do programa de Pesquisa Inovativa para Pequena Empresa da Fundação de Amparo à Pesquisa no Estado de São Paulo (PIPE da FAPESP), com participação dos professores Eduardo Zancul do Departamento de Engenharia de Produção da Escola Politécnica da USP e Paulo Cauchick Miguel, do Departamento de Engenharia de Produção da Universidade Federal de Santa Catarina.

Em decorrência deste projeto de pesquisa realizou-se uma prova de conceito tornando uma máquina recicladora de solventes tradicional em uma máquina conectada à Internet, passível de monitoramento e controle à distância em tempo real, visando a redução de custos de manutenção e possibilitando ao fabricante da máquina um modelo de negócio com cobrança por volume de solvente reciclado ao invés da venda do bem de capital como um ativo. Após a primeira etapa bem-sucedida, a DEV Tecnologia foi selecionada pela FAPESP para um programa de empreendedorismo ministrado pela *George Washington University* dos Estados Unidos.

Dentro deste programa foram entrevistadas mais de 100 pessoas relacionadas à indústria de manufatura no Brasil, como diretores da Associação Brasileira de Máquinas e Equipamentos (ABIMAQ), sócios proprietários de empresas fabricantes de máquinas e equipamentos, bem como diretores e gerentes industriais de grandes fabricantes de produtos como AmBev, BRF, JBS, Scania, Dupont e Braskem.

Como conclusão deste trabalho de pesquisa, verificou-se que de fato há uma demanda por aumento de eficiência operacional para tornar a indústria brasileira competitiva em nível global. No entanto, apesar da crescente oferta de sistemas e equipamentos altamente automatizados e conectados por fabricantes internacionais que visam a obtenção da máxima produtividade, a indústria brasileira enfrenta hoje dificuldades de financiar a modernização completa de seu parque de equipamentos e de integrar diferentes elementos do sistema produtivo de forma rápida e customizada para resolver os problemas específicos de seu processo fabril.

Neste contexto, a DEV Tecnologia, dentro da segunda fase do projeto PIPE FAPESP está desenvolvendo a tecnologia DEV FieldConnect que permitirá a baixo custo e fácil instalação o retrofit de máquinas existentes tornando-as conectadas à Internet, habilitando o monitoramento e controle remotos em tempo real e assim auxiliar gestores industriais a atingir novos patamares de produtividade.

2 Panorama de Internet das Coisas em mercados B2B

Internet das Coisas ou *Internet of Things* (IoT) é definida como um novo paradigma em que "coisas" ou objetos equipados com Identificação Rádio Frequência, etiquetas, sensores, atuadores, etc. – através de um endereçamento único – são capazes de interagir entre si e cooperar com seus vizinhos para chegar a um objetivo em comum (GIUSTO et al., 2010).

Internet of Things também pode ser definida de um ponto de vista mais técnico como "uma rede de objetos interconectados com endereçamento únicos a partir de normas de comunicações (INFSO, 2008); ou de um ponto de vista mais prático: "o IoT possibilita um mundo onde os objetos podem se comunicar automaticamente entre si e com computadores, fornecendo serviços para o benefício do ser humano (DUNKELS, 2008).

Por outro lado, o IoT sozinho não tem a capacidade de transformar essa grande quantidade de dados em conhecimento útil. Para isso, deve-se se apoiar em ferramentas de análises de Big Data para traduzir os dados que o IoT tem a oferecer.

Desse modo, a Internet das Coisas tem um grande potencial para desenvolvimento na indústria. De acordo com Prince et al. (2014), IoT irá criar novas formas de valor ao realizar mudanças significativas no modo em que companhias e a indústria opera.

A DEV Tecnologia classifica o mercado de Internet das Coisas (ou *Internet of Things* - IoT) em três segmentos: i) B2C (*business-to-consumer*), ii) B2B (*business-to-business*) e iii) B2B2C (*business-to-business-to-consumer*). No mercado B2C há produtos voltados para a pessoa conectada (pulseira Fitbits, por exemplo), carro conectado (dispositivo conectado à porta OBD2 que coleta as informações do computador de bordo e manda para a Internet, permitindo análises de falhas do carro, comportamento do motorista) e casa conectada (Nest da Google, *SmartThings* comprada pela Samsung, por exemplo, fornecem dispositivos que permitem a automação sem fio e sensoriamento de diversos itens dentro da casa).

No mercado B2B, existem principalmente produtos que visam melhoria de eficiência, como medidores de energia sem fio que permitem uma gestão em tempo real do consumo de energia ao invés de esperar uma conta consolidada no final do mês, dispositivos que tornam máquinas conectadas para monitoramento e controle à distância (parte do que se denomina Indústria 4.0), sensoriamento de condições ambientes como temperatura, umidade, vibração com envio da informação para a Internet, dispositivos para gestão de ativos (cada ativo tem um tag que se comunica sem fio com pontos de referência, indicando sua localização *indoors*).

Por fim, no B2B2C temos casos de aplicação de IoT por empresas estatais ou concessionárias em seus ativos visando a prestação de um serviço público (por exemplo tornar cada luminária do parque de iluminação pública conectada à Internet para garantir o nível de serviço de luminosidade nas vias públicas aos cidadãos).

Em três anos de atuação no mercado brasileiro, percebe-se que o setor B2B, incluindo o segmento industrial, é o que mais tem trazido demandas de negócios concretos utilizando soluções de IoT. Para este segmento, o critério mais importante é o retorno sobre o investimento. Neste sentido, elaboramos uma curva de nível de maturidade de IoT e respectivos valores associados a cada nível.

Em um primeiro nível, temos o caso desconectado, em que não é possível capturar nenhum dado remotamente. Este ainda é o caso de uma parte significativa da indústria brasileira em que as máquinas operam com ou sem automação localmente, e as informações são obtidas mediante apontamentos em papel. Em um segundo nível, os dados das máquinas já podem ser monitorados pela internet. Porém os dados devem servir para resolver algum problema em específico para começar a gerar valor efetivamente. Este valor é gerado a partir do nível 3, em que um serviço é associado aos dados recebidos. Por exemplo, se os dados estiverem disponíveis visualmente de forma adequada para um analista técnico, ele poderá identificar causas de problemas, evitando visitas de reparo ou pelo menos aumentando a taxa de reparo na primeira visita. Com isso tem-se atendimentos mais rápidos e maior tempo de disponibilidade da máquina para produção.

Em um quarto nível de maturidade, que denominamos de Inteligente, o próprio sistema realiza a análise das informações obtidas das máquinas para suporte à tomada de decisão, sem a necessidade do analista técnico. Por exemplo, a partir do perfil de uso da máquina pode-se prever quando será necessário realizar manutenções preditivas, ou reposição de materiais de consumo, reduzindo tempo médio entre falhas e desperdício de insumos. No quinto nível, o Otimizado, tem-se uma total integração com os sistemas transacionais da organização (ERP), reduzindo-se trabalhos e erros operacionais, e atingindo o máximo de eficiência. No sexto nível, o Diferenciado, tem-se um refinamento do produto e da experiência do consumidor, oferecendo para ele o acesso remoto aos dados do produto e serviços associados, ou comprovação da redução da pegada de carbono da empresa, por exemplo.

Dispositivos de IoT são normalmente reativos, isto é, eles estão constantemente respondendo de acordo com os eventos que se passam no seu meio. Além disso, eles podem ser dinâmicos e adaptativos, uma vez que sua reação muda conforme a situação em que está presente. Toda essa informação capturada pelo dispositivo é armazenada para apoiar as decisões do usuário, de uma maneira que a interação humana e o aplicativo é essencial para que o sistema funcione eficientemente e que o sistema como um todo consiga se aprimorar com o tempo (KROGSTIE, 2011).

Um exemplo de solução em IoT no meio industrial é o monitoramento de fatores / parâmetros, como a conservação da temperatura do meio em um armazém de produtos perecíveis ou a vibração de motores numa usina (caso a vibração atinge um limite, o processo cessa para evitar acidentes) (ATZORI et al., 2010).

Desse modo, um dos maiores objetivos e desafios do IoT é a criação de meios inteligentes que estejam constantemente cientes das condições em que estão inseridos (VERMESAN, 2011). Nesse sentido, não só a indústria será beneficiada, mas o desenvolvimento de IoT irá incentivar o desenvolvimento de novas tecnologias para resolver problemas na esfera pública como saúde, meio ambiente, segurança, energia, entre outros.

Encontram-se exemplos na literatura de modelagem de processos de negócios (*Business Process Modeling*, BPNM) para aplicação de IoT:

- Sperner et al., 2011, introduzem o conceito de combinação entre Entidade Física e Entidade Virtual, criando uma Entidade Aumentada, que possui uma identidade única e pode realizar tarefas específicas;
- Chen et al., 2012, propõe a utilização da linguagem de IoT para capacitar três áreas principais: serviço, sequenciamento e variáveis;
- Li et al., 2013, propõe métodos de precificação de IoT de acordo com o processo e resultado que ele gera, a partir do uso de teoria de jogos.

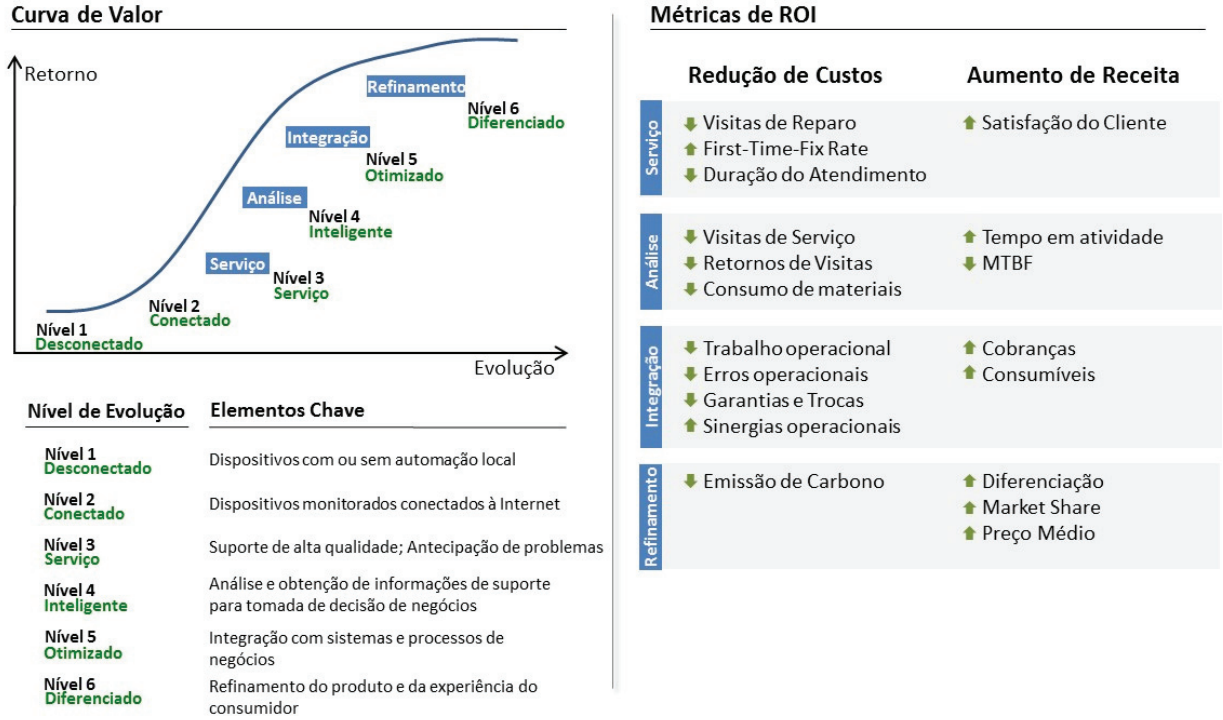

Figura 1: Níveis de evolução de soluções de IoT

Para que uma solução de IoT funcione é preciso invariavelmente unir diversas competências muito distintas uma da outra e em um nível de expertise alto. É preciso ter micro controladores avançados, projeto de eletrônica especializado, programação de software embarcado no produto conectado tornando a "coisa" inteligente, configuração de servidores em nuvem para abrigar a enxurrada de dados, conhecimento profundo da aplicação para tornar o dado uma informação útil e no formato adequado, por exemplo. Estas expertises são raras não só no Brasil, mas em todo o mundo.

A figura 2 apresenta uma visão geral da cadeia de valor envolvida em projetos de IoT, bem como exemplos de atores em cada posição da cadeia de valor.

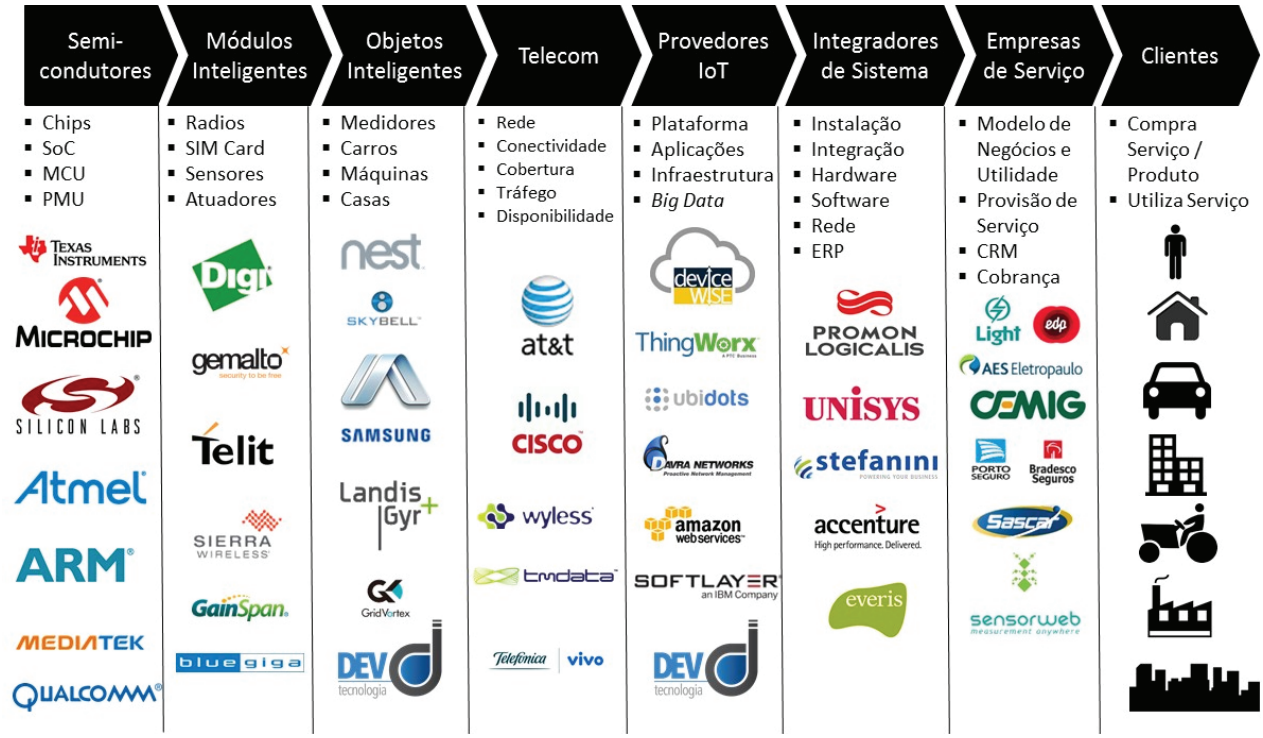

Figura 2 :Cadeia de valor de Internet das Coisas

3 Caso de aplicação de Internet das Coisas em máquina recicladora de solventes

Visando explorar o potencial de aplicação de Internet das Coisas na área industrial, viabilizando novos modelos de negócios como venda de máquinas e equipamentos como serviço ou de acordo com a sua utilização ao invés da transferência do ativo, a DEV Tecnologia propôs um projeto de prova de conceito (chamada de Fase I) no Programa de Pesquisa Inovativa para Pequena Empresa (PIPE) da Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) na terceira chamada de propostas de 2014. Após a aprovação pela diretoria científica e avalistas independentes, o projeto teve início em fevereiro de 2015.

O escopo do projeto foi a aplicação de IoT para viabilização de sistemas produto serviço (PSS) para uma fabricante de máquinas recicladoras de solventes industriais, que possui como objetivo estratégico o aluguel e venda de serviços prestados pela máquina ao invés da transferência do ativo a seus clientes industriais (que são por exemplo fabricantes de cosméticos, indústria química, aeronáutica), tendo em vista tanto a obtenção de maiores margens pela fabricante da máquina de solventes quanto para facilitar as condições comerciais para seu cliente final, que não precisa fazer um alto desembolso no momento inicial, especialmente tendo em vista momentos de recessão em que a capacidade de investimento das empresas é limitada.

Um aspecto fundamental para o sucesso deste modelo de negócios é o oferecimento de um alto nível de serviço e redução de custos de manutenção. Por isso, como primeiro passo para identificar de que forma IoT poderia favorecer este modelo de negócios, realizou-se uma análise FMEA (*failure mode and effect analysis*), apresentada na tabela 1.

Tabela 1: Análise FMEA para avaliação de alavancas de valor da solução de IoT

ITEM/NOME/ FUNÇÃO DO PROJETO/ PROCESSO	MODO DE FALHA POTENCIAL	EFEITO(S) DA FALHA EM POTENCIAL	SEVERIDADE	CAUSA(S) POTENCIAL DA FALHA	OCORRÊNCIA	CONTROLE ATUAL DE PREVEN-ÇÃO	CONTRO LE ATUAL DE DETEC-ÇÃO	DETECÇÃO	RISCO (RPN)	AÇÃO PREVENTI-VA RECOMEN-DADA
Configuração da Máquina (temperatura e tempo de ciclo)	Configuração de temperatura e tempo de ciclos errada	Não destila o suficiente, solvente sem destilar	2	Mudou o solvente e não mudou a configuração	6	Teste, startup *in loco*	Não há como detectar (10% dos casos)	6	72	Formas de limitar a configuração pelo operador (difícil por ser analógico)
		Resíduo ir sujo junto com o solvente destilado, danificar e entupir o equipamento	4	Operador muda a configuração de temperatura e tempo	4	Teste, startup *in loco*	Não há como detectar (90% dos casos)	6	96	Possibilidade de verificar qual a configuração colocada pelo operador
		Carbonizar e grudar o resíduo	6		2			6	72	Formas de alterar a configuração remotamente (difícil por ser analógico)
Tampa da máquina	Abertura da máquina durante operação	Perda de solvente evaporado	6	Esquecimento do operador	2	6 sensores de temperatura e atua como segurança e operação		6	72	Trava pneu-mática, muito cara - não conseguir abrir a tampa, só abrir quan-do temperatu-ra está abai-xo do que x
	Iniciar operação da máquina com tampa aberta	Operador aspira solvente	6	Esquecimento do operador	2			6	72	OBS: Não pode ter coisas elétricas a não ser no painel, longe do vapor. Perto do vapor só coisas pneumáticas

	Abrir a tampa quando conteúdo está quente	Vedação não aguenta temperatura, dilata e não volta ao original	6	Esquecimento do operador	4		Mais frequente	6	144	Sensor ótico (laser) à distância para ver se tampa está aberta ou fechada em determinado instante
Resíduo Contaminante	Acúmulo de resíduo contaminante na máquina	Máquina entope	6	Operador não faz a limpeza com frequência necessária	2	Recomendação, instrução	Em quatro ciclos já não dá para operar mais sem limpeza, e o operador avisa	6	72	Medir o volume de destilado na saída da máquina - regra de três para saber quanto de resíduo tem dentro da máquina (Boia de nível no tambor de saída ou sensor de fluxo)
Partes mecânicas lubrificadas	Desgaste mecânico	Quebra de partes mecânicas	1	Nível de lubrificante abaixo do necessário	1	Mudança de propriedade do óleo (relacionado a horas de utilização)		6	6	Pensar em formas alternativas de dar a informação do horímetro
Óleo térmico dentro da máquina, resistência imersa dentro do óleo nas paredes da máquina	Óleo dilata com a temperatura e tem pulmão, além de visor de nível	Não destila bem, resta solvente não destilado por não atingir temperatura correta	2	Operador não troca o óleo	6	Troca de óleo programada a partir de horímetro (4000 horas)	90% das ocorrências, o operador tem que detectar	6	72	Hoje horímetro é similar a hodômetro analógico, tem que ligar para perguntar quanto estava o horímetro
Temperatura do óleo ligeiramente maior do que o conteúdo		Vazamento de óleo	4	Operador trabalha com temperatura maior do que o especificado, (sobre temperatura) e óleo expande mais do que deveria, ou vedação da resistência desgasta	4	Troca de vedação, limpeza		6	96	Pensar em formas de acessar a informação do nível de óleo
Componente mecânico	Ligar máquina enquanto temperatura está alta	Estragar a guarnição	6		1	Operador não consegue acionar o recarregamento da máquina antes do término ciclo de resfriamento		6	36	
Sensores eletrônicos e atuadores principais	Vibração/Cor-rosão	Leitura errada	6	Fim da vida útil do componente eletrônico	1		Máquina não funciona, detecção de longe	6	36	

Alarme	Falso positivo do sensor sonoro	Irrita o cliente (alarme sonoro que não para de tocar)	4	Sensores de mal especificados para a máquina	1			6	24	Seria interessante saber quando um alarme foi acionado
Vácuo	Falta de vácuo dentro da máquina	Pressão atmosférica - aumenta temperatura, depois vácuo volta e pode danificar a máquina	2	Corta a força no compressor e não tem ar para fazer o vácuo.	2	Vacuômetro analógico com visor para operador, acionamento automático		6	24	Verificar formas de verificar o nível de vácuo dentro da máquina

De maneira geral, todas as falhas são difíceis de detectar (e de fato, a fabricante da máquina de solventes apenas fica ciente do problema quando ele já é irreversível ou quando o cliente já está muito insatisfeito com o funcionamento da máquina). Assim, como o IoT é baseado no controle e monitoramento remoto de diferentes variáveis da máquina, ele tem o potencial de reduzir drasticamente esse problema e poder detectar anteriormente as falhas que acontecem nas máquinas de seus clientes. Com isso, é possível reduzir consideravelmente os custos de manutenção corretiva e diminuir também as reclamações de seus usuários (aumentando o nível de serviço).

Alguns exemplos de como o dispositivo de IoT pode atuar nos fatores identificados pelo FMEA:

Tabela 2: Possíveis soluções para modos de falha utilizando IoT

Modos de Falha	Soluções de IoT	Resultado esperado
Configuração da Máquina (temperatura e tempo de ciclo)	Conexão de n-posições de seletores para medição de temperatura e tempo de ciclo	Saber os parâmetros atuais e poder modificá-los remotamente
	Conexão de um display em que o usuário pode controlar	
Abertura da tampa antes do processo de reciclagem terminar	Conexão de um atuador pneumático com sensor externo	Habilitar o travamento da tampa
	Conexão de atuador pneumático com sensor interno	
	Conexão de uma trava elétrica	
	Sensores infra-vermelho	Saber se a máquina está aberta ou fechada em determinado momento
Acúmulo de resíduos dentro da máquina	Sensores de fluxo e nível	Saber a quantidade de resíduo na máquina antes e após a reciclagem
Óleo não gera calor suficiente para a reciclagem	Sensores de nível de óleo e temperatura	Saber o volume de óleo na máquina e temperatura

Como o número de sensores afeta diretamente os custos da solução de IoT, o risco total calculado com a análise FMEA (penúltima coluna à direita), foi utilizado como fator de priorização para as especificações técnicas. Assim, foi possível identificar as oportunidades mais críticas para o negócio da empresa acessando-o através da criação do mecanismo de IoT.

Para atender aos requisitos resultantes da análise FMEA, propôs-se uma solução de IoT com a arquitetura apresentada na Figura 3. O principal elemento de inovação introduzido pela DEV Tecnologia nesta arquitetura é o DEV FieldConnect.

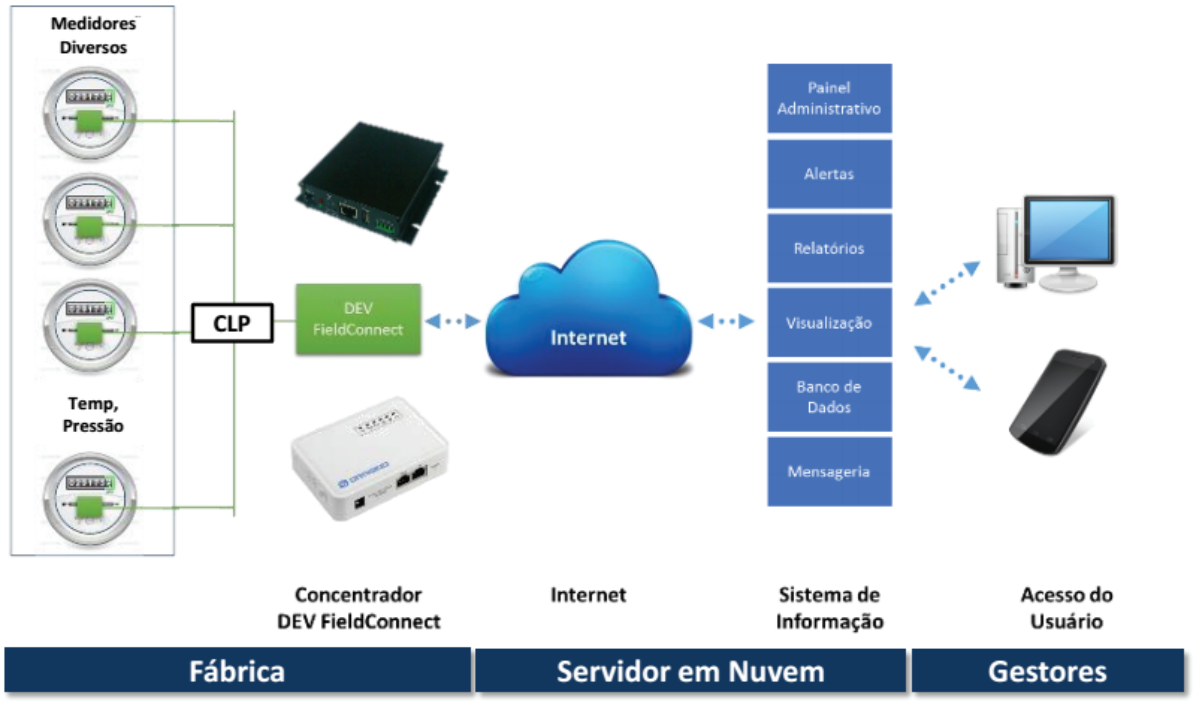

Figura 3: Arquitetura da solução de IoT

Em maior detalhe, os elementos da arquitetura da solução foram:

- Hardware & Firmware
  - CLP da máquina recicladora de solventes;
  - DEV FieldConnect;
  - Rede WiFi local.
- Middleware
  - Cloud server;
  - MQTT protocol;
  - Banco de dados em série de temporal.

- Application Software
  - Web service (acesso através de um navegador);
  - Dashboard.
- Remote Access
  - Computer;
  - Tablet;
  - Smartphone.

As figuras a seguir apresentam os resultados obtidos. A figura 4 apresenta o DEV FieldConnect associado ao CLP do painel da máquina. A figura 5 apresenta o *dashboard* com as variáveis críticas identificadas na análise FMEA. A figura 6 apresenta em detalhes o gráfico de estados da máquina, fundamental para compreender o perfil de utilização da máquina pelo cliente final.

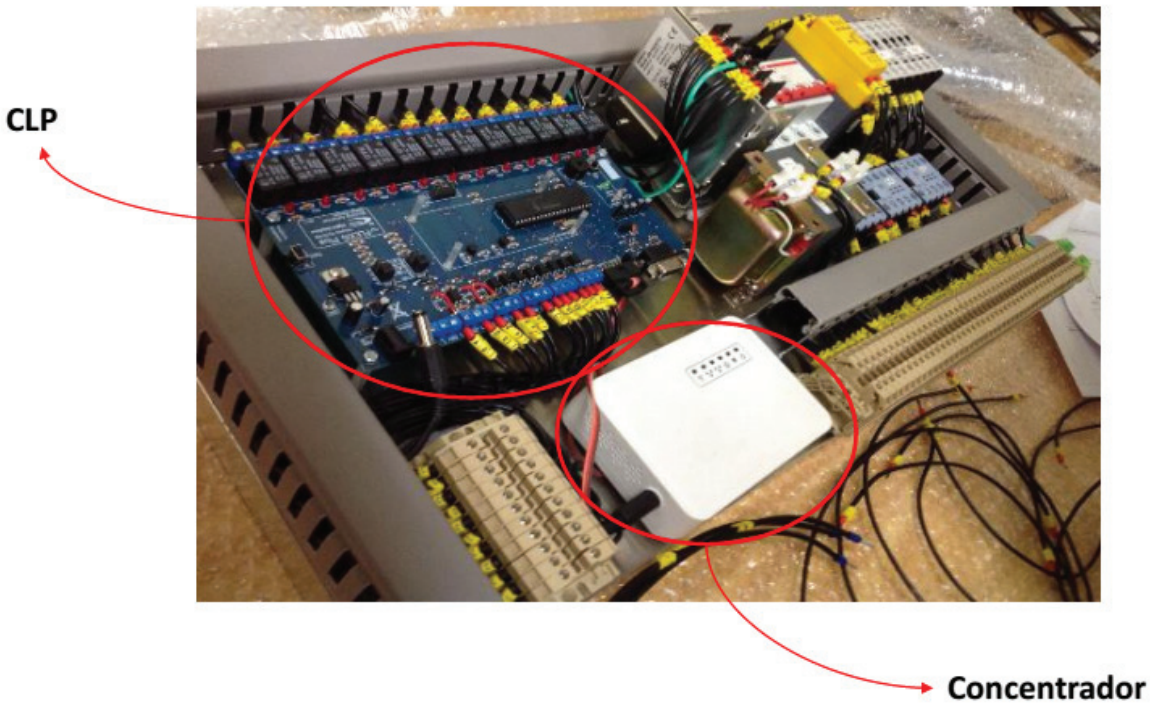

Figura 4: DEV FieldConnect (Concentrador) e CLP da máquina recicladora de solventes

Figura 5: Dashboard IoT da máquina recicladora de solventes

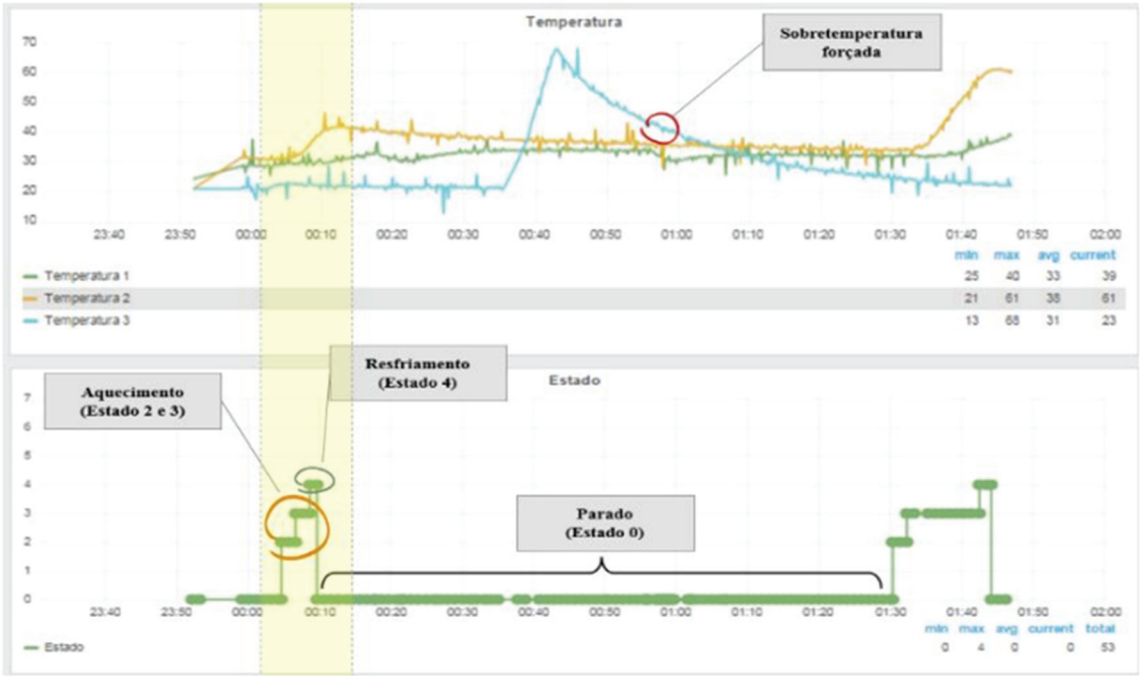

Figura 6: Análise de estados viabilizada pela solução de IoT

4 Resultados de 100 entrevistas com atores da indústria de manufatura no Brasil

Após a conclusão desta primeira etapa, a DEV Tecnologia foi aprovada para participar de um programa de desenvolvimento de startups oferecido FAPESP em parceria com a *George Washington University*. Em decorrência deste programa foram entrevistados mais de 100 atores da indústria de manufatura no Brasil, cujos tipos são apresentados na tabela 3.

Tabela 3: Perfil dos atores da indústria de manufatura entrevistados.

Tipo de ator da indústria	**Entrevistas**
Fabricante de equipamentos de utilidades	28
Fabricante de equipamentos especializados	28
Diretor/Gerente de Produção industrial	21
Integrador	8
Especialista em indústria de manufatura	6
Fornecedor de software industrial	5
Gerente de Utilidades	2
Gerente de Manutenção Industrial	2
Fabricante de equipamentos de linha branca	1
Total	**101**

O objetivo das entrevistas foi entender os problemas enfrentados pelos atores e verificar se e como a solução de IoT proposta na Fase I do programa PIPE poderia ser aplicada para resolvê-los.

Inicialmente hipotetizou-se que os desafios enfrentados pela empresa fabricante de máquinas recicladoras de solvente seriam os mesmos enfrentados por outros fabricantes, como fabricantes de equipamentos altamente especializados (por não serem usados de forma contínua, possuírem valor elevado, favorecendo o modelo de venda como serviço) e fabricantes de equipamentos que provêm utilidades (geradores de ar comprimido, energia, vapor, por exemplo) por serem itens que não são o *core* do processo produtivo e que poderiam ser rentabilizados por quantidade consumida e não adquiridos como ativos pelas indústrias.

Durante as entrevistas, percebeu-se, no entanto, que o número de fabricantes nacionais de equipamentos especializados e utilidades com capacidade financeira de investir em uma mudança de modelo de negócios de venda de produtos para venda de serviços é limitado. A grande maioria dos fabricantes destes equipamentos são empresas internacionais, cujo centro de pesquisa e desenvolvimento localiza-se fora do país. Embora parte dos fabricantes nacionais já possuíssem em seus produtos um nível de automação passível de conexão à Internet principalmente via protocolo Ethernet (nível de maturidade 2 na escala IoT da Figura 1), poucos haviam chegado no nível de serviço (3). Uma exceção foi um fabricante nacional de caldeiras para produção de vapor, que conseguiu de forma bem-sucedida adotar o modelo de negócio de venda de metros cúbicos de vapor ao invés de caldeiras, e que recentemente adotou uma tecnologia de IoT para acesso remoto às informações das máquinas para gestão centralizada, ferramenta considerada fundamental para a sustentabilidade do negócio.

Por outro lado, as entrevistas com diretores e gerentes industriais apontaram diversos pontos de melhoria no processo produtivo em que ter acesso à informação da linha em tempo real fariam grande diferença para a eficiência operacional. Um exemplo foi a checagem se o algoritmo de otimização de balanceamento de velocidades da linha de produção seriada em indústria de bebidas estava funcionando conforme esperado. A partir desta informação a

equipe industrial poderia antecipar problemas de descasamento de velocidades que causam quebras e paradas custosas na linha. Para acessar estas informações de forma gerencial e em tempo real, apesar de já existirem CLPs sofisticados nas máquinas, não seria possível de adaptar de forma rápida e a baixo custo o sistema para atender à demanda, já que se tratava de uma coleta de dados de equipamentos diferentes, com fornecedores diferentes, e cujo software/serviço customizado para esta finalidade seria custoso e com ciclo de compra/integração demasiadamente longo.

Em um outro caso, em uma fábrica de caminhões, veículos de condução automática utilizados no processo produtivo tiveram seu sistema de sensoriamento atualizado de forma a garantir maior precisão nos trajetos realizados e assim maior segurança e produtividade. No entanto, este novo sistema não estava integrado com os demais elementos da rede industrial. Por ser um item móvel, um dispositivo sem fio e inteligente conectado aos sensores e capaz de se conectar com a rede industrial deveria ser utilizado, porém o entrevistado não havia encontrado até o momento nenhuma opção no mercado. Este problema de interoperabilidade entre novos elementos adquiridos com elementos pré-existentes foi citado também por outros dos entrevistados.

Gerentes de manutenção também demonstraram interesse em soluções tanto que facilitariam o inventário de máquinas do parque fabril quanto registro histórico de status e operações realizadas pelas máquinas para fins de manutenção preditiva. A questão do inventário foi apontada por diversas empresas, nas quais a fábrica possui equipamentos de diferentes origens, fornecedores e idades, e que não são propriamente identificados ou facilmente localizados.

Citou-se também como exemplo a análise de vibração para manutenção preditiva de máquinas. No processo atual um técnico fica responsável por levar um equipamento de medição de vibração para amostragem de cinco minutos em cada máquina, que em seguida é levado a um software de análise. Um sensor de vibração de baixo custo associado à máquina e conectado à Internet poderia conectar-se diretamente ao sistema de análise e enviar alertas para manutenção preditiva sem necessidade de alocação de mão de obra e com muito maior assertividade na previsão.

Os gestores de utilidades também se mostraram propensos a adotar tecnologias de fácil instalação e baixo custo para monitoramento do consumo dos insumos de forma mais individualizada, como consumo de energia por máquina, ou consumo de água em partes específicas do processo.

Integradores de automação industrial tradicionais entrevistados declararam utilizar conectividade exclusivamente para atendimentos remotos quando solicitados pelos clientes industriais. Citaram restrições de segurança e acesso restrito a dados da produção dos clientes como um dos motivos para a não prestação de serviços utilizando IoT.

Por fim, identificou-se um novo ator surgindo no cenário de manufatura que é o prestador de serviços de análise de dados especializados em determinados tipos de produção industrial. Utilizando tecnologias de aprendizado de máquina e servidores em nuvem, conseguem adicionar valor nos níveis 3 e 4 da escala de maturidade de IoT. O perfil destas empresas são *startups*, geralmente *spin offs* de universidades.

5 Implicações dos resultados das pesquisas no *design* da solução tecnológica

A partir dos aprendizados obtidos, foi possível compreender de forma mais ampla os requisitos necessários para que a tecnologia de IoT tenha adoção no mercado industrial. Tendo como foco o cliente, gerente industrial de uma fábrica, que está operacional e que necessita de uma transição gradual, porém ágil para a Indústria 4.0, a abordagem deve ser diferente em relação ao foco anterior quando a intenção era prover uma solução para fabricantes interessados em vender ativos como serviços.

Como elementos fundamentais da arquitetura da solução considerou-se com maior peso a interoperabilidade com diferentes protocolos industriais, a flexibilidade para diferentes cenários de aplicação, maior rigidez com segurança da informação e a necessidade de desenvolvimento de um serviço de *backend* que viabilize a gestão dos dispositivos remotamente, incluindo a possibilidade de atualização remota.

A partir desta leitura, realizou-se uma nova concepção para a tecnologia DEV FieldConnect apresentado nas figuras 7 e 8. O FieldConnect será um coletor de dados, controlador multifuncional e *gateway* de sensores, projetado especialmente para aplicações de Internet das Coisas. Será baseado em um processador ARM 32-bits de baixo consumo de energia e possui canais de entrada e saída opto-isolados com nível de confiabilidade industrial. Oferecerá também entrada para diversos sensores externos que podem ser conectados via barramento ou sem-fio. Outras funcionalidades incluem conexão via Ethernet, PoE, Host USB, Wi-Fi, RS-485, ADC, PWM, Contadores de Pulsos, Rádio Sub-GHz, entre outras opções customizáveis. Possuirá gabinete em alumínio com resistência a intempéries podendo ser instalado em campo ou ambientes industriais.

Além disso, tornou-se mais clara a necessidade de estabelecimento de parcerias entre empresas capazes de desenvolver um *gateway* de comunicação flexível (proposta do FieldConnect) com empresas emergentes de *data analytics* para atingir níveis de retorno de investimento mais atrativos para os diretores e gerentes industriais.

Após a validação técnica da etapa 1 e da pesquisa mercadológica realizada com as entrevistas, a DEV Tecnologia agora parte para a fase 2 do projeto PIPE, com financiamento não reembolsável de um milhão de reais oferecido pela FAPESP para desenvolvimento da solução tecnológica e comprovação das hipóteses geradas após a pesquisa de mercado.

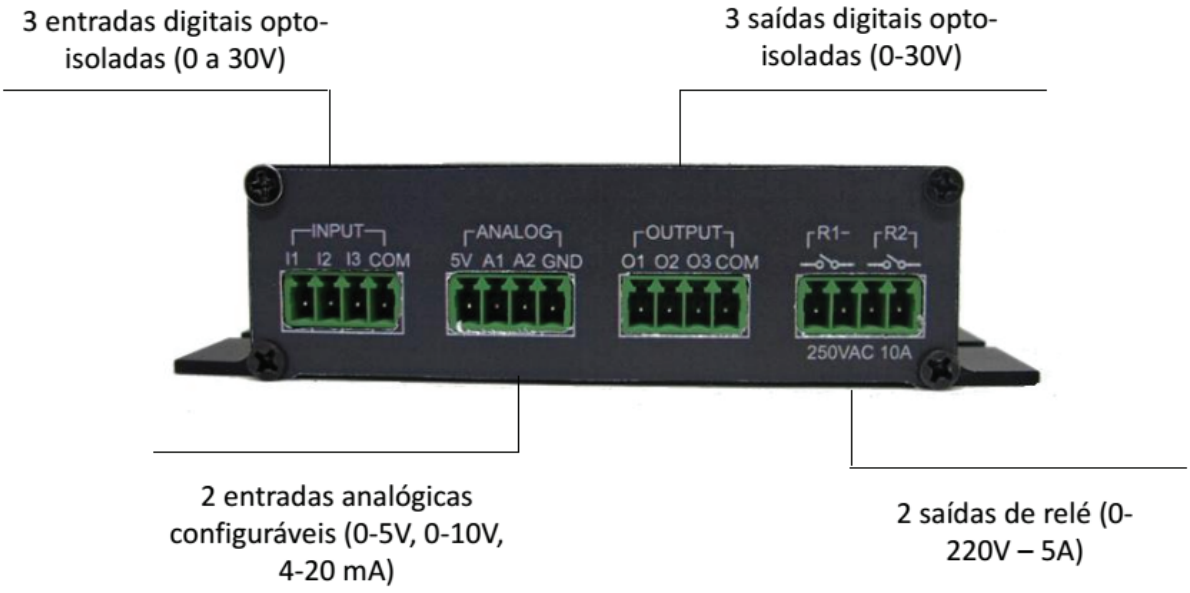

Figura 7: DEV FieldConnect

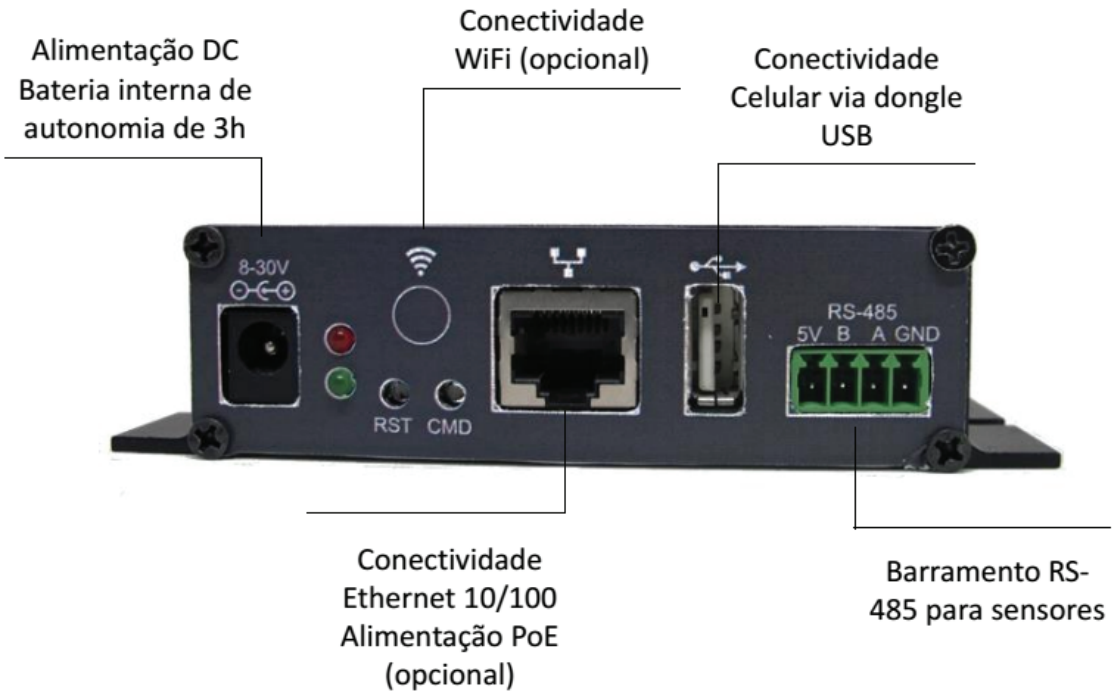

Figura 8: DEV FieldConnect

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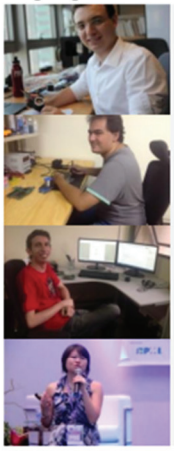

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Time: de 2 para 20 em menos de 3 anos

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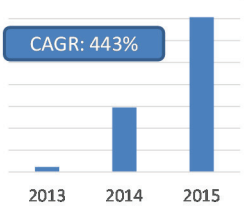

DEV Tecnologia

O que é a Internet of Things (IoT)?

A Internet das Coisas ou *Internet of Things (IoT)*, em inglês, é um termo utilizado para descrever um paradigma tecnológico no qual os objetos físicos estão conectados em rede e são acessados através da Internet.

Esses objetos são capazes de interagir entre eles ou com o ambiente externo, alterando como e onde as decisões são tomadas, assim como quem as toma

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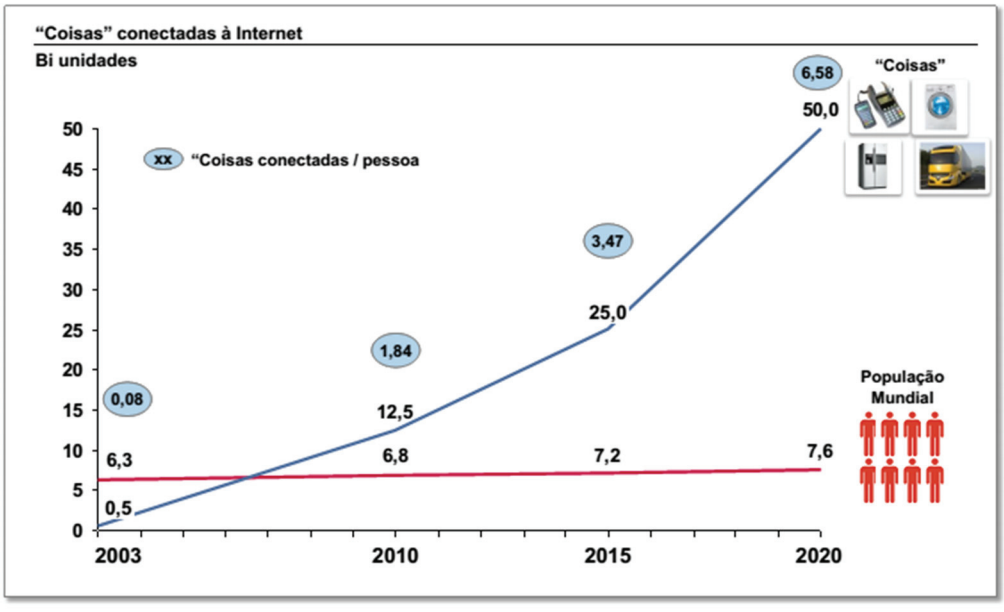
Existe controvérsia com relação à previsão de "coisas" conectadas, mas estimativas apontam ~50 bilhões em 2020 e US$ 14.4 Trilhões



Fonte: CISCO Internet of Everything White Paper

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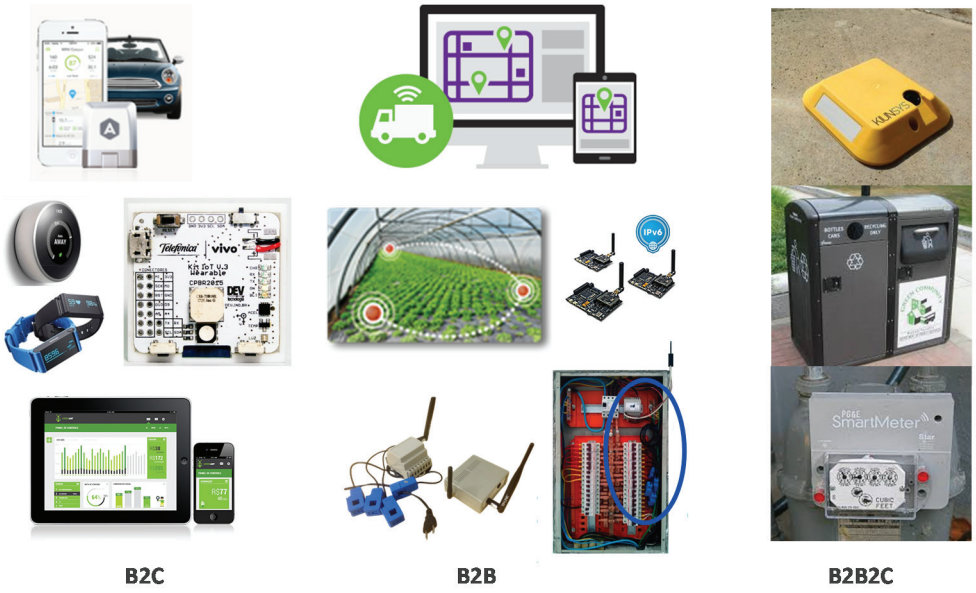
Mercados de IoT podem ser classificados em B2C, B2B e B2B2C



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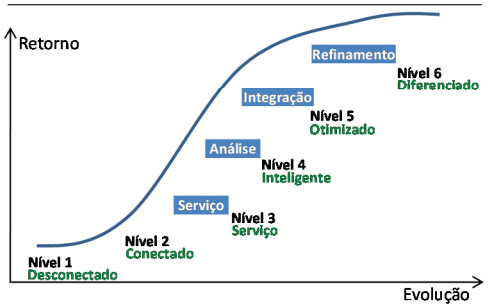
O retorno sobre o investimento em IoT é proporcional ao nível de maturidade

Curva de Valor



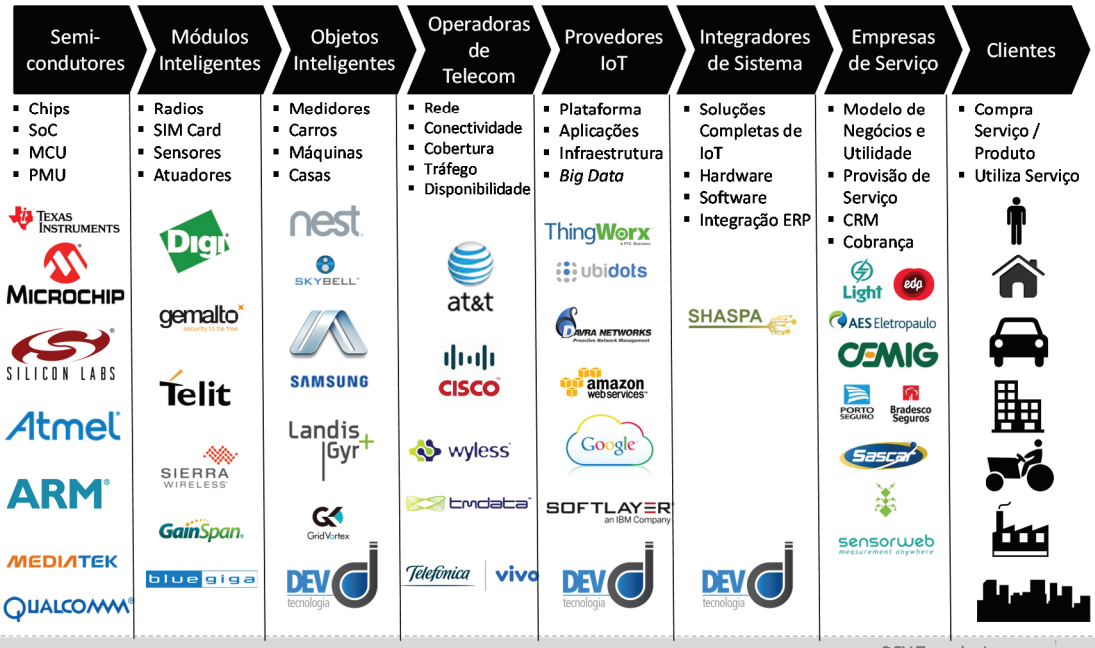
Nível de Evolução	Elementos Chave
Nível 1 Desconectado	Dispositivos com ou sem automação local
Nível 2 Conectado	Dispositivos monitorados conectados à Internet
Nível 3 Serviço	Suporte de alta qualidade; Antecipação de problemas
Nível 4 Inteligente	Análise e obtenção de informações de suporte para tomada de decisão de negócios
Nível 5 Otimizado	Integração com sistemas e processos de negócios
Nível 6 Diferenciado	Refinamento do produto e da experiência do consumidor

Métricas de ROI

	Redução de Custos	Aumento de Receita
Serviço	⬇ Visitas de Reparo ⬆ First-Time-Fix Rate ⬇ Duração do Atendimento	⬆ Satisfação do Cliente
Análise	⬇ Visitas de Serviço ⬇ Retornos de Visitas ⬇ Consumo de materiais	⬆ Tempo em atividade ⬇ MTBF
Integração	⬇ Trabalho operacional ⬇ Erros operacionais ⬇ Garantias e Trocas ⬆ Sinergias operacionais	⬆ Cobranças ⬆ Consumíveis
Refinamento	⬇ Emissão de Carbono	⬆ Diferenciação ⬆ Market Share ⬆ Preço Médio

DEV Tecnologia

Cadeia de Valor



Caso aplicado à indústria

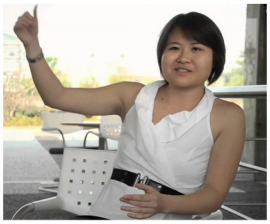
- **Reciclador de solventes industriais** para fabricantes de produtos químicos
- **Tecnologia nacional** desenvolvida pela Rochmam na incubadora CIETEC – USP
- **Modelo de negócios desejado:** locação com pagamentos mensais como um percentual das economias geradas
- **Processo químico**: destilação
- **Diferenciais:** segurança e durabilidade
- **Controle:** circuito de intertravamento baseado em sensores e contatores com configuração manual

rochmam

FAPESP

DEV Tecnologia

Time do projeto – PIPE Fase 1



Sílvia Takey
Pesquisadora responsável

Prof. E. Zancul
Pesquisador Associado

Prof. P. Cauchick
Pesquisador Associado

DEV Tecnologia

Desafios – Análise FMEA

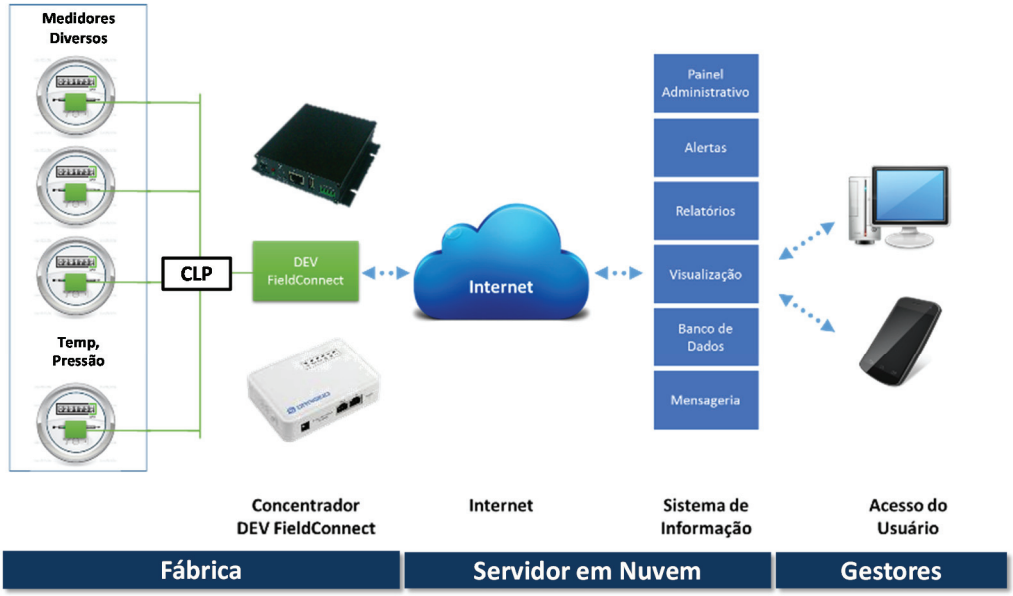
ITEM/NOME/FUNÇÃO DO PROJETO/ PROCESSO	MODO DE FALHA POTENCIAL	EFEITO (S) DA FALHA EM POTENCIAL	SEVERIDADE	CAUSA (S) POTENCIAL DA FALHA	OCORRÊNCIA	CONTROLE ATUAL DE PREVENÇÃO	CONTROLE ATUAL DE DETECÇÃO	DETECÇÃO	RISCO (RPN)	AÇÃO PREVENTIVA RECOMENDADA
Configuração da Máquina (temperatura e tempo de ciclo)	Configuração de temperatura e tempo de ciclos errada	Não destila o suficiente, solvente sem destilar	2	Mudou o solvente e não mudou a configuração	6	Teste, startup in loco	Não há como detectar (10% dos casos)	6	72	Formas de limitar a configuração pelo operador (difícil por ser analógico)
		Resíduo ir sujo junto com o solvente destilado, danificar e entupir o equipamento	4	Operador muda a configuração de temperatura e tempo	4	Teste, startup in loco	Não há como detectar (90% dos casos)	6	96	Possibilidade de verificar qual a configuração colocada pelo operador
		Carbonizar e grudar o resíduo	6		2			6	72	Formas de alterar a configuração remotamente (difícil por

- Detectar mau uso do operador
- Setup remote em caso de substituição de fluido a ser reciclado
- Avaliar o status atual da máquina
- Checar parâmetros operacionais
- Monitoramento de utilização
- Detecção precoce de falhas

DEV Tecnologia

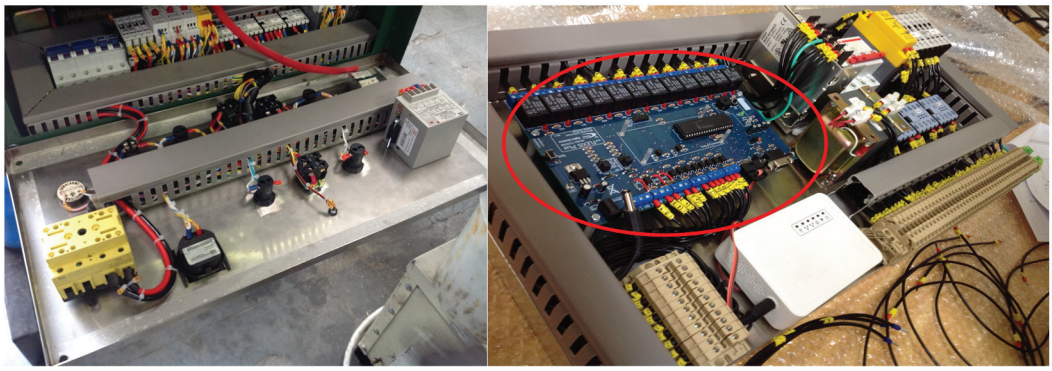
Para superar os desafios foi concebida uma arquitetura ligando o CLP a um concentrador, que com encriptação envia os dados para a Internet

Solução DEV Tecnologia - Visão Geral



DEV Tecnologia

Resultados

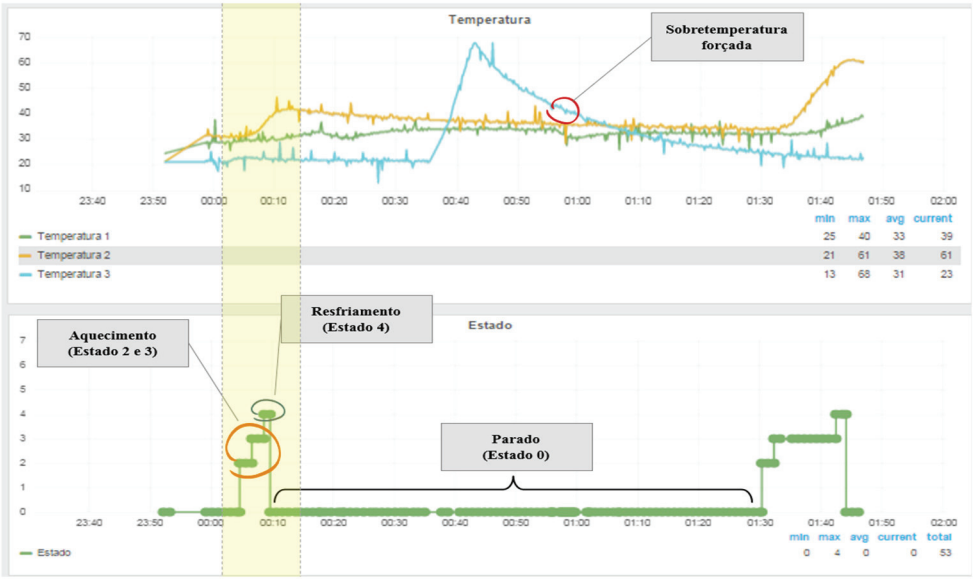


DEV Tecnologia

Resultados

DEV Tecnologia

Resultados



DEV Tecnologia

Resultados

Input remote de parâmetros da máquina

Exportação de dados de um período determinado para outras análises

DEV Tecnologia

Modelo de negócios para PSS IoT – Fim da Fase 1

ODM	Integrador/VAR	Manufatura	Cliente
IoT Gateway "DEV FieldConnect" Plataforma de alto volume	Integradores de tecnologia e automação industrial *Value added resellers*	Offering of services instead of sales of goods gaining higher margins Automatic billing based on usage Maintenance at affordable costs Faster assessment of customer needs	Online monitoring of usage of service provided Environmental impact data Monitoring of SLA
	Complementor Provedor de data analytics/big data Provedores de sistemas supervisórios		

DEV Tecnologia

Resultados: aprovação do financiamento - fase 2 na FAPESP e novos parceiros interessados

Financiamento não reembolsável (R$1 mi)

Inovação Tecnológica PIPE

FAPESP

Parceria DOW DuPont para a fase 2

DOW

DUPONT

DEV Tecnologia

PIPE High-Tech Entrepreneurial Training

FAPESP

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

+100 entrevistas com potenciais clientes no segmento industrial

DEV Tecnologia 20

Arquétipos de clientes

Fabricante de equipamentos

Diretor da indústria de equipamentos de utilidades industriais: Nosso cliente não quer comprar uma máquina de HVAC, ele quer ter sempre o clima certo para a produção! E eu preciso fornecê-lo como um serviço. Mas sem acesso em tempo real para minhas máquinas, não vou ser capaz de proporcionar uma elevada qualidade e eficiência do serviço. Conectividade e software não são nosso núcleo, precisamos contar com terceiros com soluções competitivas.

Dono de equipamentos industriais especializados para nicho de mercado: Fabricamos um cortador de laser de alta tecnologia que atende às necessidades de diversos segmentos. Eu posso rentabilizar o meu ativo alugando ou vendendo-o como serviço para lotes de diferentes clientes, sendo capaz de cobrá-los de acordo com seu uso e garantir que a máquina está funcionando (e sendo operado) bem. Nossos clientes valorizam um serviço personalizado.

Indústrias

Gerente industrial: eu preciso aumentar de 10% da eficiência global. Perdemos eficiência quando há um evento na linha que não é esperado e o tomador de decisão não é imediatamente alertado. Conseguir um PLC, um computador, integração com o software de automação apenas para obter este aviso seria muito caro ou fisicamente difícil (que envolve as estruturas móveis, como prateleiras em movimento).

Gerente de Utilities: Eu preciso para reduzir 20% da nossa conta de energia e eu não sei todas as fontes de resíduos para tomar as medidas apropriadas. Eu também quero saber se a melhoria que eu fiz teve o efeito esperado. Automação sofisticada é muito cara e não vale a pena.

Gerente de manutenção: Eu preciso manter as máquinas operando 24/7. Se eu detectar uma potencial falha e corrigi-la antes que aconteça é ideal. Mas hoje eu tenho que enviar um cara para medir cada vibração da máquina durante 5 minutos e depois colocar de volta em um software para analisar para tentar prever uma falha com esses dados.

DEV Tecnologia

Sumário de entrevistas com clientes

	Validation							
	DON'T CARE		NTH		MUST HAVE		Total Percentage	Total #
Segment	Percentage	#	Percentage	#	Percentage	#		
Channel								
Integrator	38%	3	0%		63%	5	100%	8
Software provider	0%		20%	1	80%	4	100%	5
Customer								
Owner utilities equipment	54%	15	11%	3	36%	10	100%	28
Owner specialized equipment	64%	18	7%	2	29%	8	100%	28
Industrial Manager	**29%**	**6**	**5%**	**1**	**67%**	**14**	**100%**	**21**
Industry specialist	33%	2	17%	1	50%	3	100%	6
Utilities Manager	0%		50%	1	50%	1	100%	2
Maintenance manager	0%		0%		100%	2	100%	2
Durable goods manufacturer	100%	1	0%		0%		100%	1
Grand Total	45%	45	9%	9	47%	47	100%	101

DEV Tecnologia

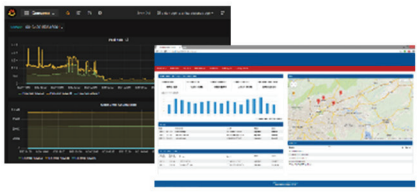
Desenvolvemos a plataforma DEV FieldConnect®, para tornar equipamentos conectados a baixo custo e fácil implantação

Equipamento Conectado + **Informações em Nuvem**

DEV FieldConnect®

Coleta e Envio de **Dados Para Internet**
Altamente **Otimizado em Função e Custo**
Comunicação **Sem Fio** com Sensores

Viabilidade Técnica e Econômica



DEV Dashboard®

Monitoramento Online no PC ou Celular
Análise de Dados e **Relatórios**
Altamente **Customizado para Aplicação**

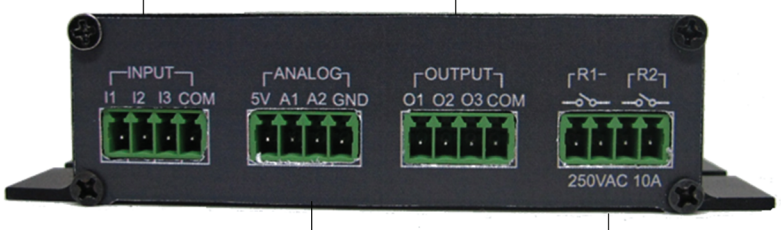
Valor Agregado na Informação

DEV Tecnologia

Desenvolvemos a plataforma DEV FieldConnect®, para tornar equipamentos conectados a baixo custo e fácil implantação

3 entradas digitais opto-isoladas (0 a 30V)

3 saídas digitais opto-isoladas (0-30V)

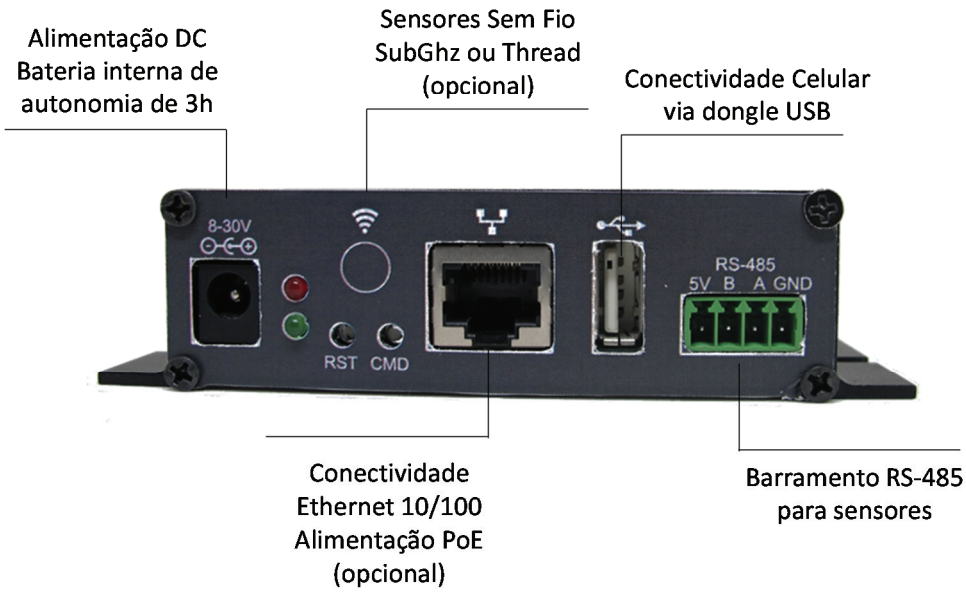


2 entradas analógicas configuráveis (0-5V, 0-10V, 4-20 mA)

2 saídas de relé (0-250VAC – 10A)

DEV Tecnologia

Desenvolvemos a plataforma DEV FieldConnect®, para tornar equipamentos conectados a baixo custo e fácil implantação



DEV Tecnologia

Casos de usos para utilização da tecnologia DEV FieldConnect

Exemplos de Aplicações	Casos em andamento/prospecção
• Gerenciamento remoto de ativos fixos • Monitoramento remoto de utilização (ciclos de operação, horas) • Monitoramento e Detecção de mau uso por operador • Checagem e configuração dinâmica de parâmetros operacionais • Detecção precoce de falhas • Automação local atualizável via nuvem	ambev brf Albert Einstein Hospital Israelita Telefônica vivo CPS Centro Paula Souza Governo do Estado São Paulo Secretaria de Desenvolvimento Econômico, Ciência, Tecnologia e Inovação

DEV Tecnologia

Caso aplicado: Controle de luminárias com comunicação Sem Fio Thread

- **Controlador Sem Fio** integrável com driver para luminária LED
- Rede sem fio com tecnologia **Thread 2.4 GHz**
- **Concentrador DEV FieldConnect** comunicando com a Internet ou rede privada
- Monitoramento e/ou Acionamento remoto via **Painel de Gerenciamento** online
- **Comunicação segura** de ponta a ponta

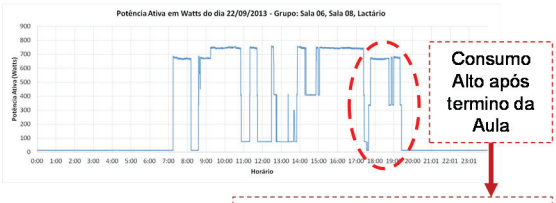
DEV Tecnologia

Caso aplicado: Medição online de economia de energia com troca de lâmpadas por LED e hábitos de consumo em escola pública

1ª Geração da Tecnologia

Testes incluindo **Iluminação Eficiente**

Dados reais do monitoramento



Economia **+40%** na conta de luz com a troca de lâmpadas e **+20% com hábitos**

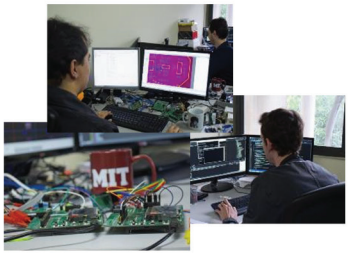
DEV Tecnologia

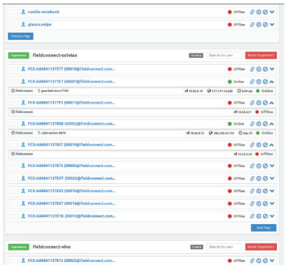
Caso aplicado: Coleta remota de dados de sensors de temperatura, umidade, luminosidade e nível de bateria

DEV Tecnologia

Nosso modelo de negócios é de design house de hw/fw/sw/app, venda OEM de dispositivos e licenciamento de tecnologia

Serviços de Design House | **Venda OEM de dispositivos** | **Licenciamento de Tecnologia**

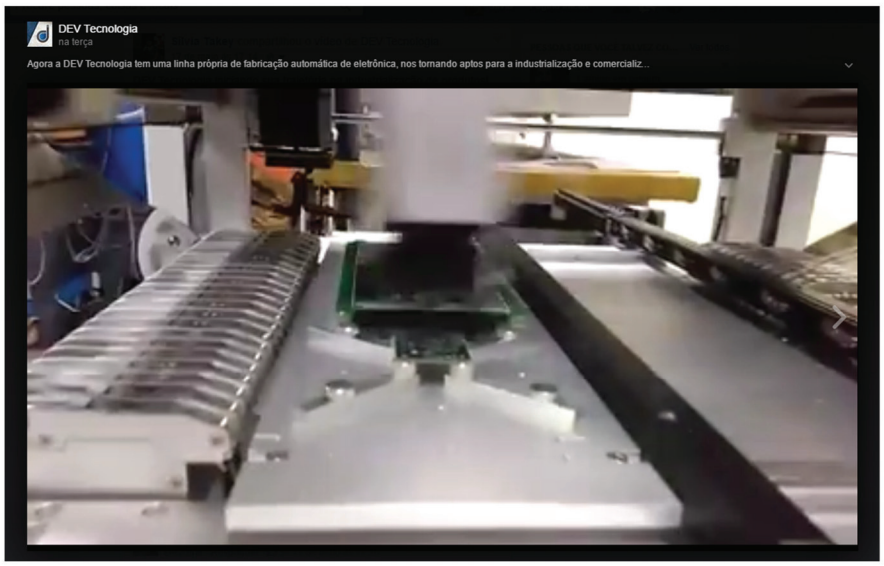




DEV FieldConnect
Previsão de lançamento em mercado no primeiro semestre de 2017

DEV Tecnologia

Para venda OEM possuímos uma linha para fabricação própria para pequenos volumes e parceiros para alto volume



DEV Tecnologia

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Patrocínio

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ISSN 2175-9960