22º Seminário Internacional de Alta Tecnologia

5 OUT 2017
TEATRO UNIMEP
Campus Taquaral · Piracicaba · SP

PRODUÇÃO INTELIGENTE: OS DESAFIOS DA 4ª REVOLUÇÃO INDUSTRIAL

Renomados pesquisadores, especialistas e profissionais apresentarão os desafios, oportunidades e riscos da 4ª Revolução Industrial.

ANAIS

Editado por Klaus Schützer

22° Seminário Internacional de Alta Tecnologia

Produção Inteligente: Os desafios da 4ª Revolução Industrial

Editor

Prof. Dr.-Ing. Klaus Schützer

Lab. de Sistemas Computacionais para Projeto e Manufatura

Faculdade de Engenharia, Arquitetura e Urbanismo

05 de Outubro de 2017

Universidade Metodista de Piracicaba

Teatro UNIMEP – Campus Taquaral, Piracicaba, SP

SCPM

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

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Seminário Internacional de Alta Tecnologia (22. : 2017 : Piracicaba, SP)

S471a Anais do 22. Seminário Internacional de Alta Tecnologia, Piracicaba, SP, Brasil, 5 out., 2017 / editor Klaus Schützer. – Piracicaba: UNIMEP, 2017.
230 p. : il. ; 30 cm.

Tema central: Produção Inteligente: Os desafios da 4ª Revolução Industrial

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 700 instituições presentes em 70 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, 18 colégios, três faculdades integradas e escolas de Educação Básica, de pequeno, médio e grande porte, 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 57 instituições educacionais em 10 estados, além do Distrito Federal, totalizando mais de 50 mil alunos na Educação Básica, Ensino Técnico e Educação Superior nas modalidades presencial e a distância.

A UNIMEP, com aproximadamente 10.000 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, 19 especializações (44 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 2.000 alunos nos cursos de graduação e pós-graduação. Conta também com um corpo docente de 94 professores, sendo cerca de 55% em regime de dedicação integral ou parcial. Cerca de 80% do corpo docente é titulado, sendo que 26 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., Volkswagen 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, Alemanha.

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 Tesa Micro-Hite DCC 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, atuando no 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, bem como em gestão do produto, 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 realimentador 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 DFG.

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

BOSCH

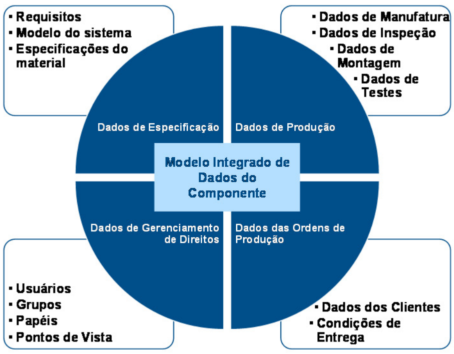
Principais Projetos em desenvolvimento no SCPM

Programa BRAGECRIM
Projeto SCoPE

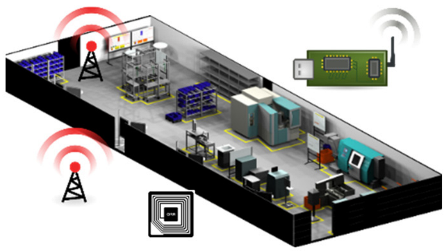
Lab. Sistemas Computacionais para Projeto e Manufatura
Prof. Dr.-Ing. K. Schützer
FEAU - UNIMEP

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

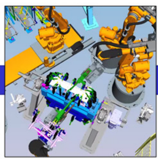


- Transformação de componentes físicos em portadores de informações
- Integração de produtos, informações baseada em internet e tecnologias de comunicação



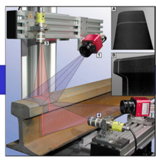
- Incremento das possibilidades de rastreabilidade dos processos de fabricação de componentes individuais
- Utilização dos dados de componentes individuais para formar pares otimizados de componentes em processos de montagem complexos

Modelamento do produto e processo

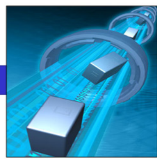


Armazenamento da informação

Reconhecimento do produto



Transmissão de dados



Sistema de produção físico-cibernético

Parceiros

UNIMEP – Universidade Metodista de Piracicaba
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

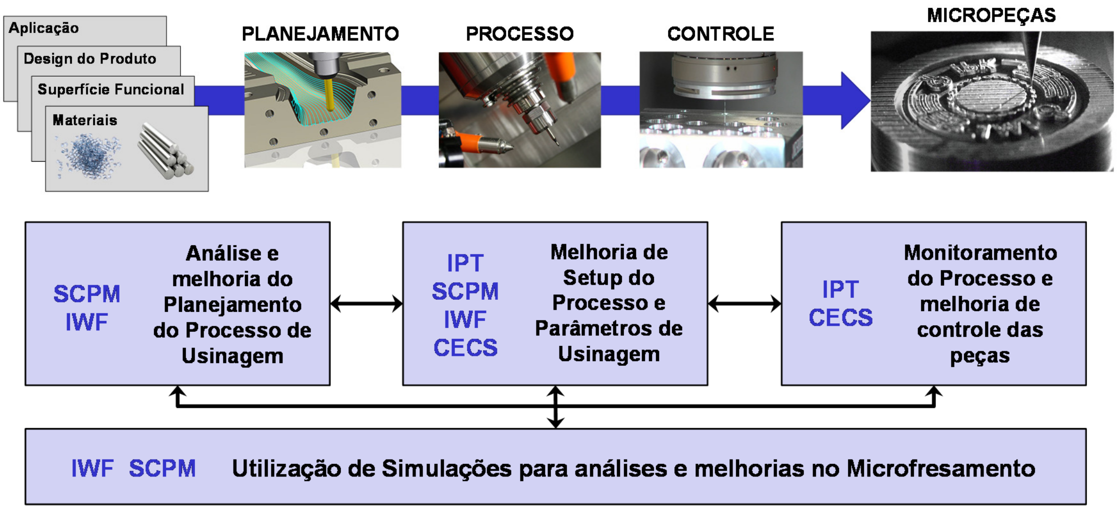
BRASIL DEUTSCHLAND

Micro-O: Micro-milling 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 · TU berlin · Universidade Federal do ABC · ipt Instituto de Pesquisas Tecnológicas · SCPM · IWF · CECS Centro de Engenharia, Modelagem e Ciências Sociais Aplicadas Universidade Federal do ABC

Apoio

CAPES · DFG Deutsche Forschungsgemeinschaft

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Manufatura Inteligente e Fábrica Digital

Lab. Sistemas Computacionais
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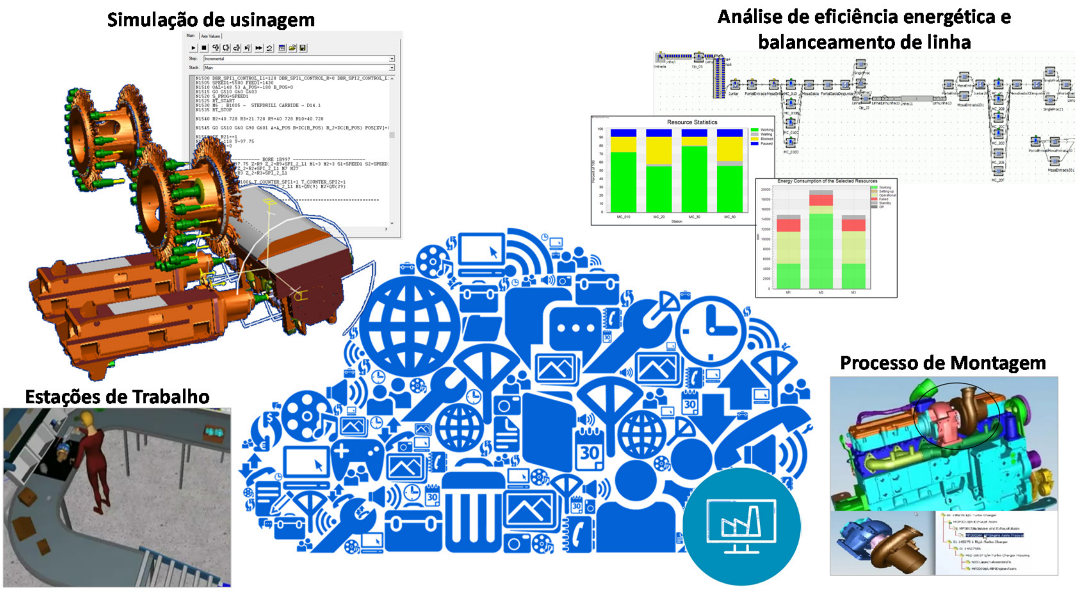
Temas da linha de pesquisa

- Produtos e manufatura inteligente
- Sistemas físico-cibernéticos de produção
- Comunicação componente-componente, componente-máquina e máquina-máquina (M2M)
- Critérios para seleção e implantação de sistemas para representação da Fábrica Digital
- Digitalização e simulação do processo produtivo

Projetos desenvolvidos

- Implementação de ferramentas de simulação no conceito de Fábrica Digital
- Construção de um modelo virtual para simulação e comparação com um processo de manufatura real da indústria
- Otimização da trajetória de ferramenta em processos de usinagem visando ganho de tempo no processo de produção
- Balanceamento de linha visando eliminação de gargalos
- Utilização da simulação visando a otimização de eficiência energética de uma linha de produção



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SCPM UNIMEP Universidade Metodista de Piracicaba Volkswagen GROB SIEMENS

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Fábrica Ensino: Processo de Desenvolvimento do Produto

Lab. Sistemas Computacionais para Projeto e Manufatura
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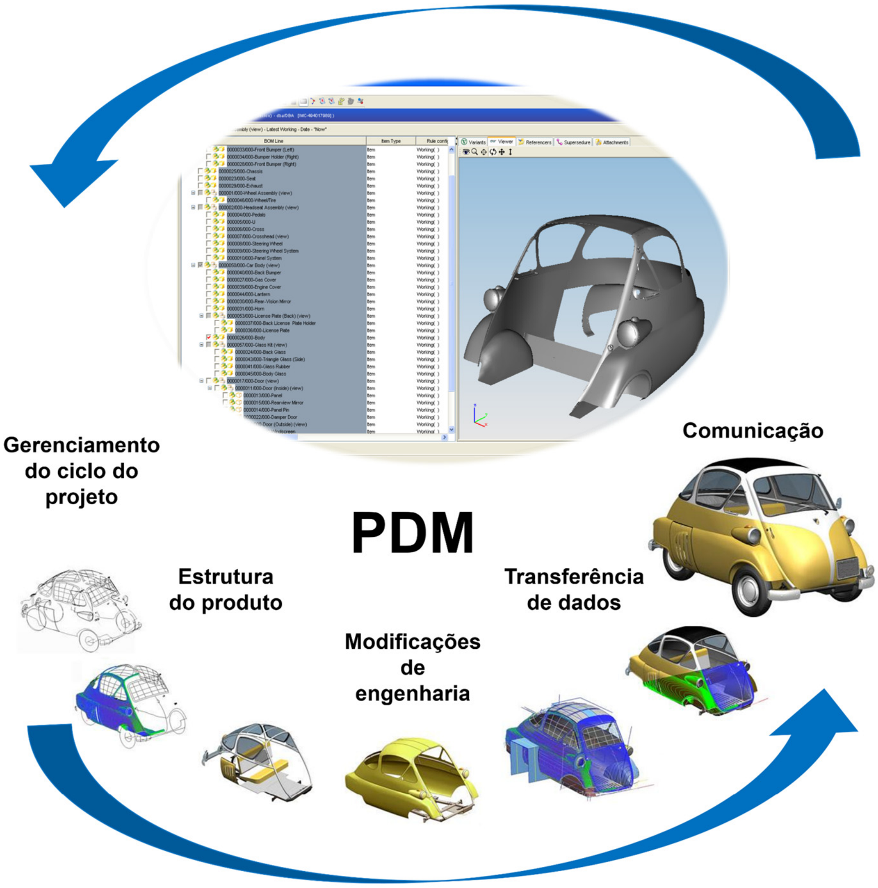
Objetivos

- 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

UNIMEP
Universidade Metodista de Piracicaba

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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, 4ª Revolução Industrial, Produção 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.

Produção Inteligente: Os desafios da 4ª Revolução Industrial

Os períodos de instabilidade política e econômica aumentam a pressão competitiva do mercado impondo grandes desafios para a sociedade e também para as empresas que precisam cada vez mais reduzir custos e aumentar a produtividade para se manterem à frente de seus negócios.

As fábricas precisam ser mais inteligentes, mais enxutas, mais ágeis e muito mais produtivas e devem se apoiar nos avanços da tecnologia de manufatura, na automação e na conectividade digital. Nesse cenário a tomada de decisão rápida e confiável e a gestão inteligente do fluxo de informações são pré-requisitos, uma vez que a produção passa a ser movida pela informação.

A tecnologia de informação e comunicação, os modelos digitais do produto e da produção, em conjunto com a internet e algoritmos inteligentes para tratamento de dados, caracterizam a grande mudança de rumo que vem ocorrendo na manufatura. Os obstáculos a serem vencidos são muitos e exigem uma combinação das mais diversas soluções com destaque para tecnologias inovadoras que conduzem à transformação digital das empresas, um dos principais pilares da chamada 4ª Revolução Industrial.

Essa revolução, também denominada de *Industrie 4.0*, Indústria 4.0, Produção Inteligente, *Data Driven Manufacturing*, Manufatura Digital, entre outros, é uma estratégia que propõe profundas mudanças no modelo de negócios e arquitetura dos processos nas organizações, e que vem se consolidando como uma tendência que oferece oportunidades atrativas para as empresas. Seu foco principal é equipar produtos e sistemas de produção com identificadores únicos, sistemas embarcados com uma base para sensores e atuadores inteligentes para possibilitar a comunicação e interconectividade entre máquinas, produtos, meios de transporte e pessoas, possibilitando um controle inteligente da operação.

O movimento Indústria 4.0 não é um fim em si. Está intimamente ligado a objetivos econômicos claros e oferece potencial para uma diferenciação mais clara na concorrência global.

A introdução da Indústria 4.0 impõe outros desafios e oportunidades também para os recursos humanos das empresas, pois um dos principais requisitos para sua introdução bem-sucedida são os profissionais bem qualificados. Deve também permear questões relacionadas à sustentabilidade e já apresenta, por exemplo, programas que consideram estratégias de eficiência energética que podem ajudar a reduzir custos operacionais gerais da empresa, permitindo que a economia resultante seja investida em outras áreas para promover o crescimento e a inovação.

Considerando esse contexto buscamos identificar as inovações que vêm sendo desenvolvidas em projetos de pesquisa ou que já estão sendo implantadas com sucesso na indústria, e convidamos as comunidades industrial e acadêmica brasileiras para participarem da 22ª edição do Seminário Internacional de Alta Tecnologia. Estes Anais documentam o conteúdo discutido, os benefícios e os desafios que se apresentam na produção nesta 4ª Revolução Industrial com o objetivo de gerar novas ideias e soluções que serão determinantes para o sucesso das empresas.

Os temas aqui discutidos são:

- 4ª Revolução Industrial: Desafios, Oportunidades e Riscos;
- Programa *Industrie 4.0* para a Produção Inteligente;
- Sistemas de Produção Físico-Cibernéticos;
- Estratégias Inovadoras de Produção;
- Organização do Trabalho frente à 4ª Revolução Industrial;
- Eficiência Energética e Sustentabilidade.

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Índice

Artigos Técnicos

Technical Papers

Prof. Dr.-Ing. Eberhard Abele

Prof. Abele was born in 1953 and studied mechanical engineering at the Technische Hochschule Stuttgart, Germany, where he received his diploma in 1977. Afterwards he was a research assistant and department manager at the Fraunhofer Institute for Production Technology and Automation, Stuttgart (IPA). From 1983 to 1999 he held a leading position in the automotive supply industry as main department manager of manufacturing technology and factory manager with stations in Spain and France. The focus of his industrial activities was on automation, increase in productivity and speeding up production. In 1999 Dr. E. Abele accepted the call for the professorship for production engineering at the faculty Mechanical Engineering, Technische Universität Darmstadt, Germany. Since July 2000 he is leading the Institute for Production Management, Technology and Machine Tools (PTW) and contributed to more than 200 publications in the field of manufacturing organisation, machine tool technology and manufacturing processes. The Process Learning Factory (CIP), which he initiated, has shown a novel path in the long-term qualification of university graduates and employees from companies in teaching, but also in further education in the field of production technology and lean management. Prof. Abele led the initiative *Produktionsforschung 2020 for the Bundesministerium für Bildung und Forschung* (BMBF). He is the founder of the European Process Learning Factory initiative as well as chairman of the magazine *Werkstatt und Betrieb* of the Carl Hanser publisher. He initiated the research project eta-Fabrik with 35 partners with a total project sum of 16 million euros.

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The Institute of Production Management, Technology and Machine Tools (PTW) is one of the leading German research institutes for production technology. It is directed by Prof. Dr.-Ing. Eberhard Abele and Prof. Dr.-Ing. Joachim Metternich. Currently about 65 associate researchers focus their work on innovations along the manufacturing value chain. This includes the development of machine components and cutting tools, technologies for high-speed machining, energy efficient machine tools, additive manufacturing processes and production management. As pioneer, the PTW opened in 2007 its own learning factory CiP on the campus of the Technische Universität Darmstadt. In 2016 another Factory ETA opened which addresses the energy efficiency of the machines as well as the storage of energy and the energetic linkage of the machines and the factory building.

Additive Manufacturing – challenges and chances

Abstract

Additive Manufacturing (AM) describes technologies, which build 3D objects by adding layers of material. Different materials can be processed like plastics, ceramics, metals, concrete or even biological tissues.The common principles of AM technologies are that 3D-models designed in the CAD software can be directly used to control the printer without any additional machine setup. Furthermore no parts specific tools are required to make complex parts. New AM processes for different materials have been developed for the recent years. AM processes like laser beam melting of metals are already well developed and several applications for series production can be seen.This talk concentrates on AM technologies, which handle with metal materials. First, the current state of additive manufacturing in industry and science will be shown. Furthermore opportunities for manufacturers in mold and die business and also for small batch producers will discussed.The flaws of metal parts made by AM are explained and possible solutions of post-processing to overcome these flaws are presented. Finally, two example applications for the use of AM, dental implants and cutting tools, are introduced.By the end of the talk the subject Industrie 4.0 will be presented in the field of AM. This includes the idea of company-oriented networks and company-internal networks for the production of components. Finally, the talk closes with a short outlook of the potential in the area of AM and the problems to be solved now.

Keywords

Additive Manufacturing (AM); Hybrid Manufacturing Technologies; Mold and Die; Dental Applications; Costumer Specific Cutting Tools; Industry 4.0; Networks.

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1 Introduction

Additive manufacturing (AM), an emerging field in manufacturing technologies, features the common principle of building solid parts directly from three-dimensional (3D) computer-aided design (CAD) data by adding material layer by layer, whether the material is plastic, metal, concrete or in the future human tissue. According to Wohler's Report, 97 manufacturers produced additive manufacturing systems in 2016 compared to 49 manufacturers in 2014. Nowadays established manufacturers are under pressure due to the huge number of new machines and unprecedented competition in the market of additive production. In the AM segment worldwide sales increased by 17,4% in 2016, compared to the previous year to US $6.063 billion [1]

New AM technologies have been developed in recent decades, to meet the demands of different material and market requirements. The AM technologies which are most commonly used in industry are material extrusion, powder bed fusion, binder jetting, photopolymerization and powder melting. The main applications for metallic AM are in the aerospace, medical and tooling industries (Figure 1).

Significance for mechanical engineering		
Aerospace	●	Lightweight and bionic structures
Medical	●	Lot size 1 and special materials
Tooling	●	Molds with integrated cooling channels
Process engineering	◕	Lot size 1 and function integration
Automation	◑	Special products
Automotive	◔	Prototyping
Electronics	◔	Motors, sockets, heat sinks
General engineering	◔	Parts with complex geometries

Figure 1: Metal AM significance for mechanical engineering [2]

Powder bed fusion-based AM processes use thermal energy to selectively fuse regions of a powder bed [3]. Laser beam melting is a process in which powder is applied in layers, which are then selectively melted using a laser beam to generate 3D parts directly from CAD data. This study focuses on the laser beam melting of metal powders, which is often termed selective laser melting (SLM). SLM typically involves layer thicknesses of 20–100 µm and powders with particle sizes ranging from 20–45 µm [4]. The minimum layer thickness depends on the particle size distribution of the powder being used. To increase the resolution and accuracy of SLM, the process can now use powders with smaller particle sizes, which enables layer thicknesses of less than 20 µm [5, 6]. Powders with mean particle diameters of less than 10 µm tend to agglomerate, which necessitates the use of powder rake systems to process these materials.

2 Opportunities of Additive Manufacturing

AM has great potential in industrial manufacturing, especially in flexible production of individual and near-net-shape parts. In the industrial use the advantages of AM are [2]:

- Design freedom;
- Time to market;
- Individualization;
- Function integration;
- Resource conservation.

The layer based production principle allows AM processes to create unique characteristics and geometries for new and innovative parts. Furthermore no product-specific tools are required and the pre-production preparation time is low as the layer geometry is generated directly from the CAD-Data [7]. This encourages the use of AM processes for complex parts and small lot sizes as the preparation time does not increase with higher product complexity (Figure 2).

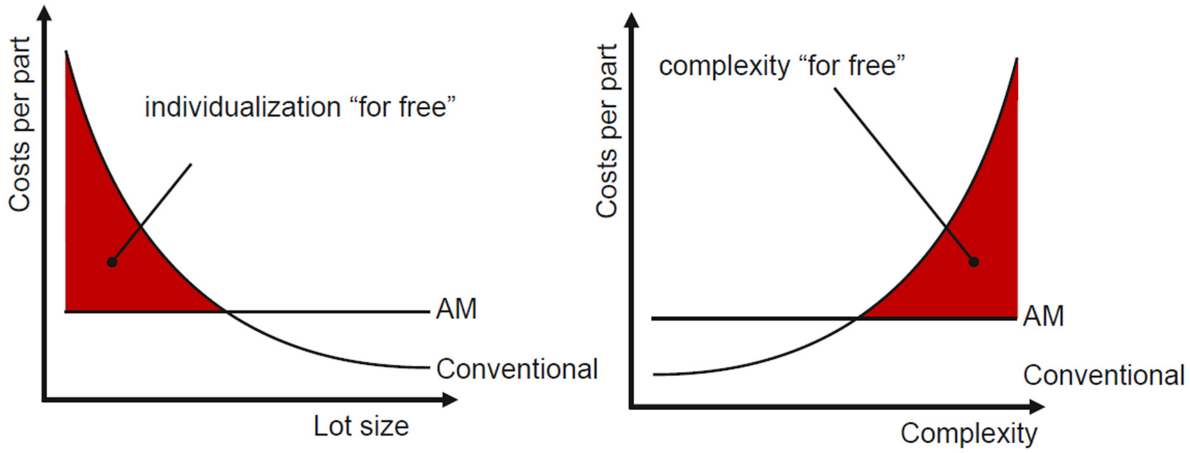

Figure 2: Advantages of AM

In traditional manufacturing processes like casting or milling the production time increases with higher part complexity like light weight structures. For AM processes a contrary cost structure can be seen. Light weight structures use less material thus less volume has to be build up in the production process which reduces the production time and costs.

AM offers accelerated component availability through shortened process chains since machining steps such as die cutting, milling or EDM can be dispensed. Furthermore no part-specific tools and forms are required which also require product development time. Thus a production-on-demand of function patterns or small series can be realized in shorter time.

Another increase in process chain efficiency can be achieved by realizing a resource-saving and material-saving lightweight design processes. In addition to replacing conventional steel with lighter materials such as aluminium or fiber –reinforced composites the optimization of the part geometry offers great chances of reducing component weight and material use. The technical possibilities of additive production processes allow new design and optimization possibilities in this regard since complex structures with comparatively high stiffness's and strengths can be produced with low mass.

The possibility of function integration is another enabler of AM. A distinction is made between integration by design, process-based function and integration of components (Figure 3).

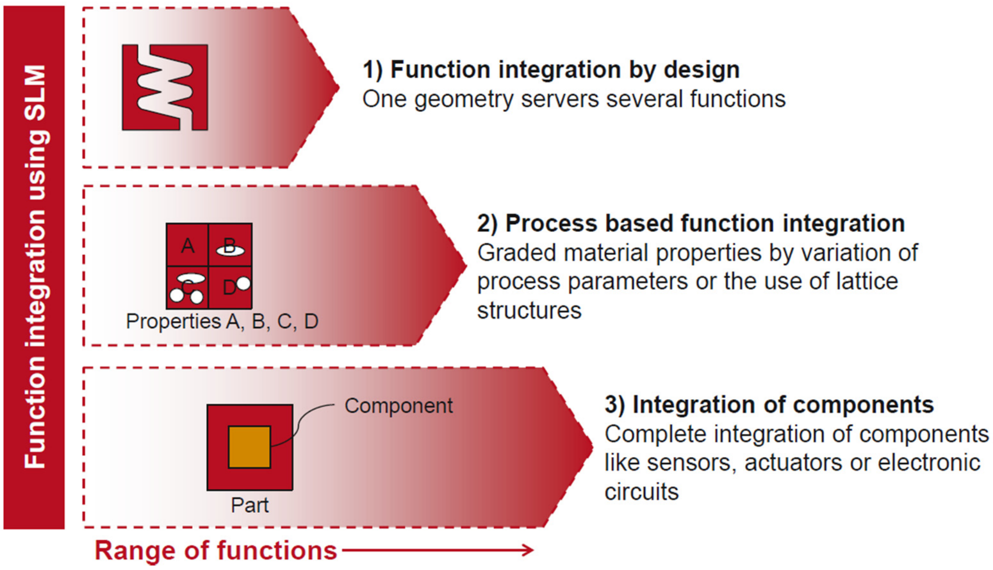

Figure 3: Advantage: Functional integration

Function integration by design is often used for integration of cooling channels in tools. This has the advantage of a high degree of freedom for cooling channels close to the surface and realization of directed temperature control within the tool. This leads to a reduction of cycle times and improved quality due to less part distortion.

For medical applications process based function integration can be used. By adjusting the AM process parameters the part properties like porosity can be influenced without the need of designing them in a CAD software. With the aid of porous structures an improvement during the growth phase of the bone is achieved. Additionally the adjustment of mechanical properties can be used to match the stiffness of the implant to the one of the bone structure to avoid stress shielding. Also function integration by process can be used for internal marking of objects [8]. Destruction free testing methods can be used to identify the parts to prevent product piracy.

By integrating components during the manufacturing process new type of parts with active properties can be made. By integrating actuators or sensors active damping of compact structures [9] or structural health monitoring [10] can be realised while the active elements are completely protected by environmental hazards like corrosive fluids.

3 Hybrid Manufacturing

Powder bed based fusion or SLM is the AM process which is most commonly used to generate metal parts. One major disadvantage of this process compared to traditional production process is the high surface roughness which is critical for many applications. The fatigue performance of additive manufactured parts is dominated by their surface roughness [11, 12] and the high surface roughness is insufficient for fittings with tight tolerances. Those operations increase the total time needed to produce the parts and require part dependant tools which is contrary to the additive manufacturing philosophy. The surface morphology of SLM produced parts is characterised by several effects. These effects are highly depending on the relative orientation of the part to the build direction [13]. On top facing surfaces the morphology is dominated by the stability of a single melt track and the hatch distance between two adjacent tracks [14, 15]. The morphology of side facing surfaces which are parallel to the build direction is dominated by partial melted powder particles. Side facing surfaces are surrounded by loose powder particles during the build process. These particles get drawn into the melt pool but due to insufficient energy on the melt pool edge only partial melting occurs. Additionally to the effects of top and side surfaces, inclined surfaces are characterised by the stair step effect. The stair step effect is a result of the layer wise character of the SLM process. The contour of slope surfaces is approximated in steps represented by the layer height. The influence of the stair case effect on the surface depends on the sloping angle with higher roughness at lower angles. Another disadvantage of the SLM process is that support structures are required during the build process (Figure 4). Support structures are used to connect with the build platform, to support overhanging structures and to prevent part distortion due to residual stress. At the current state of the art SLM requires post processing operations such as grinding, shot peening or machining.

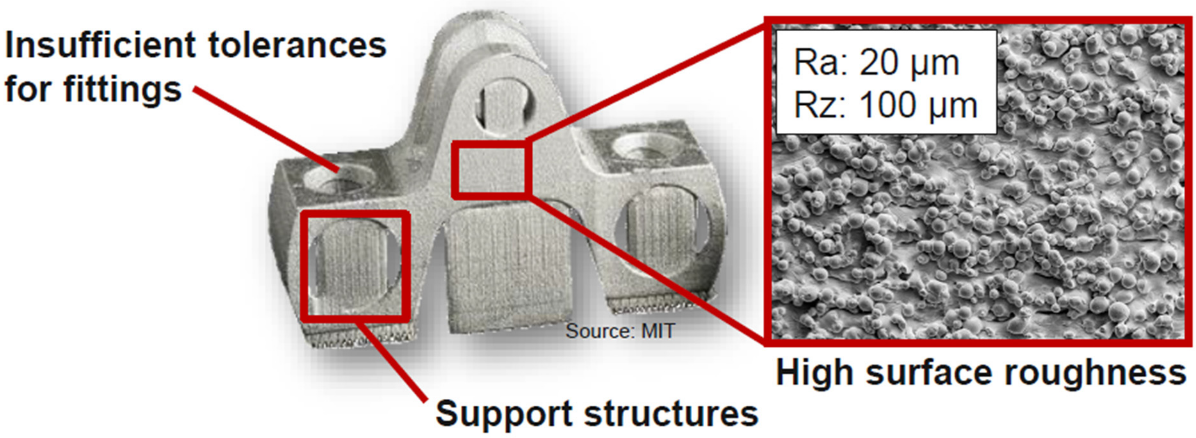

Figure 4: Properties of metal parts made by AM using powder bed based fusion

A significant reduction of the post-processing effort of additive semi-finished products is not to be expected due to the mentioned technical limitations. For these reasons the combination of SLM with milling as post processing or hybrid manufacturing is a common way to finish parts [16].

Different concepts for hybrid manufacturing exists. One way is the serial combination of two for example a SLM machine and a milling machine. In a two machine setup it is necessary to analyse various influencing factors. To achieve reliable post processing results excess material needs to be added to the original CAD geometry. Several factors in both processes need to be considered to select the right amount of excess material. An overview can be seen in Figure 5.

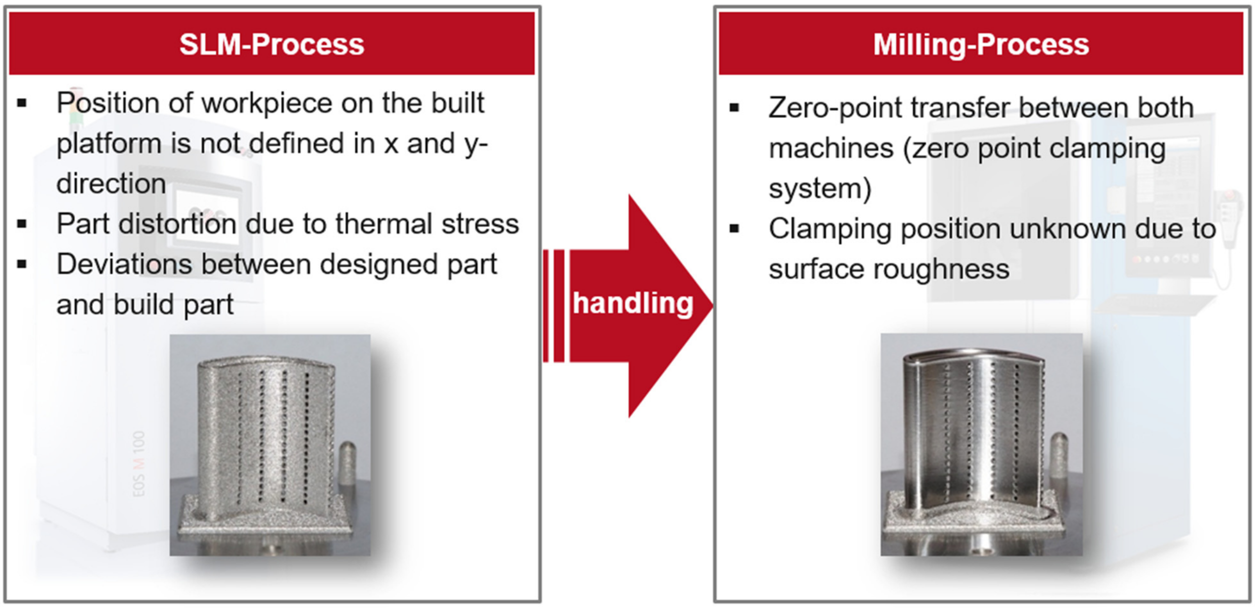

Figure 5: Challenges in a 2-machine hybrid setup

Another way is to integrate both processes into a single machine. This can be realised using SLM or laser cladding machine and adding a spindle to it [17, 18]. The advantages of this setup is that internal structures can be post processes during the build process and that no zero clamping systems are needed. The downside are higher overall system costs. Another hybrid process is the combination of AM and pre-made parts. An AM part is built on a conventional manufactured pre-made part (Figure 6).

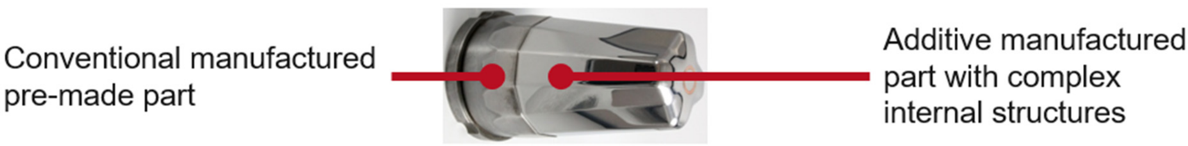

Figure 6: Combination of AM and pre-made parts

3.1 Hybrid Manufacturing in Dental Applications

One application of hybrid manufacturing is the production of dental implants. Medical technology sector is undergoing rapid changes in many areas. Demographic change, new medical materials, increasing cost pressures and the demand for customized medical devices are the main drivers of this trend. Especially in dental technology, these progress have led to a significant change in process technology. In addition there is an increasing shift from manual dental labs to automated industrial processes.

The increasing material diversity and use of Difficult-to-Cut materials in the area of dental technology has an enormous impact on the manufacturing trends. Researches show that 80-90% of all fixed dental prostheses are crowns or pontics. Various materials like Cobalt-chrome alloys, gold alloys and zirconium oxide have been established for the production of dental applications [19]. At the same time a high pressure to decrease production costs is present. Hybrid processes have the potential to further decrease production costs while keeping a high product quality [20]. By utilizing both processes the advantages of both can be exploited while overcoming the disadvantages (Figure 7).

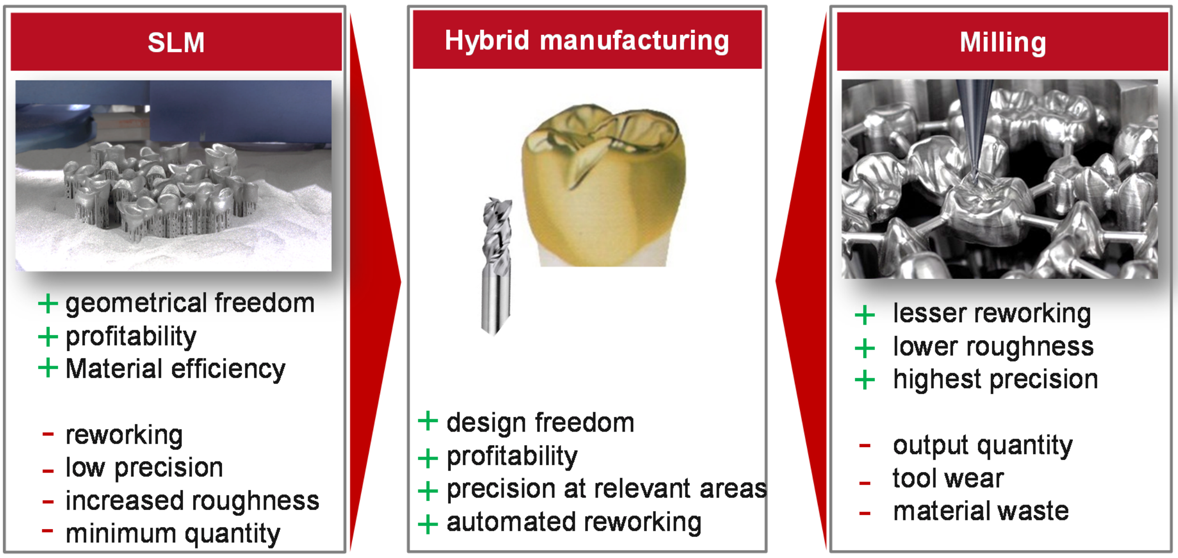

Figure 7: Advantages and disadvantages of hybrid machining processes

3.2 Hybrid Manufacturing in Cutting Tools

Metal parts for automotive, aerospace and other engineering applications become more and more complex. The most common way to make these parts is to use wrought material and shape it by using subtractive processes like drilling or milling. With increased complexity the tools required for the milling operations become also more and more complex. To reduce the manufacturing costs new tool concepts are being developed which require tools with complex internal structures. These internal structures cannot be made using traditional processes for cutting tools. In the recent years the possibilities to make cutting tools using additive manufacturing technologies have been investigated. [21–23]. By using additive manufacturing processes complex internal structures for cooling and lubrication fluids (Figure 8) as well as undercuts for lightweight tools can be made.

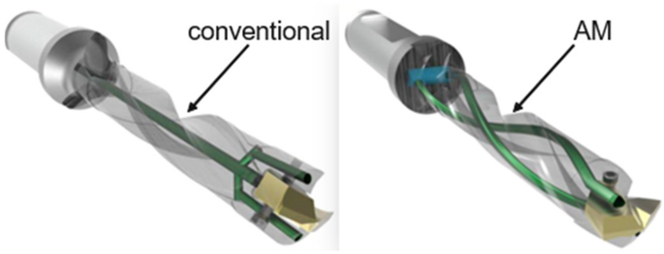

Figure 8: Replaceable head drill [4]

Cutting tools can be differentiated in two categories. Tools with bodies and separate cutting inserts and tools made completely of cutting materials (Figure 9). Cutting tool bodies are traditionally made of steel alloys to decrease costs for large tools. However steel based materials cannot be used for cutting materials like titanium or nickel based alloys due to their limited hardness. Cutting materials like tungsten carbide or ceramics are required for these cutting operations. Those materials can be used in cutting inserts for steel bodies or in tools made completely out of the cutting material. As stated in the introduction section different additive manufacturing processes for different materials exist. Different processes for additive manufacturing of steel alloys like selective laser melting or laser cladding are already being widely used for the industrial production of smaller lot sizes. Additive manufacturing of tungsten carbide or ceramics is still a challenge. Attempts to process cutting materials directly using selective laser melting have been made by several research groups but problems like cracking or delamination occurred [24–26]. Two-step processes using vat. polymerisation or binder jetting to create green parts with a second sintering step in a furnace show more promising results [27, 28].

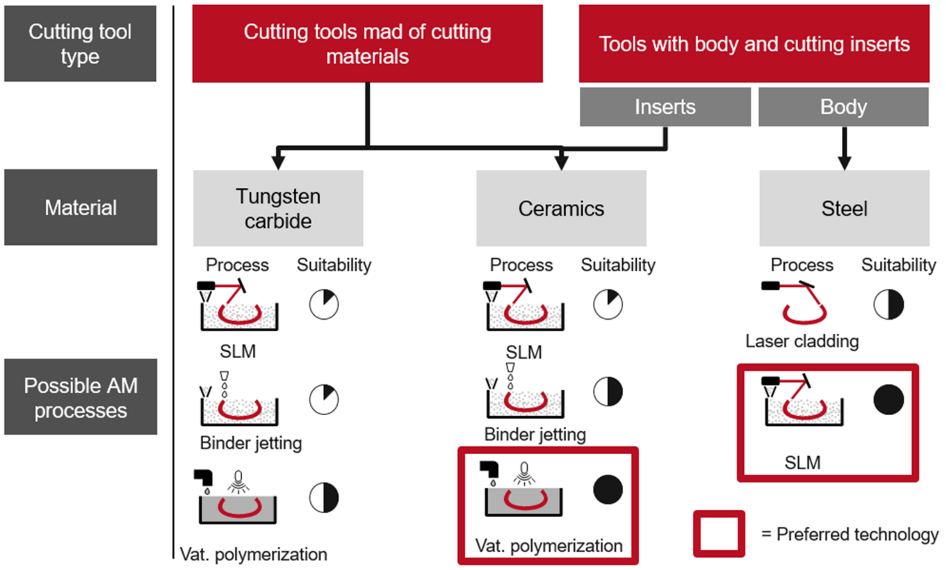

Figure 9: AM processes for cutting tools

The PTW carried out a study using a multi-functional cutting tool from the Austrian company Ceratizit GmbH was used to show the potentials of AM of cutting tools. In a first step test specimens with channels of different diameters ranging from 0.1 to 0.8 mm were build using selective laser melting to investigate fluid throughput and spraying characteristics. The tool body was modified to improve chip removal by integrating a network of 0.2 mm channels into the chip flute. Additionally the cooling channels were modified to realise two different fluid streams for the rake face and the flank. The downside of integrating additional internal structures is a decrease of tool stiffness. Compared to the original tool the body stiffness is decreased by 1542 N/mm after the modifications were applied. This aspect has to be considered when designing new cutting tools using additive manufacturing.

A new additive manufacturing process for ceramics was used to make cutting inserts of Al_2O_3 for this study. Green parts were made using a vat. polymerisation process for ceramics developed by the Austrian Lithoz GmbH. In the second step the green part is sintered to remove the binder and to increase the parts density. The result can be seen in Figure 10.

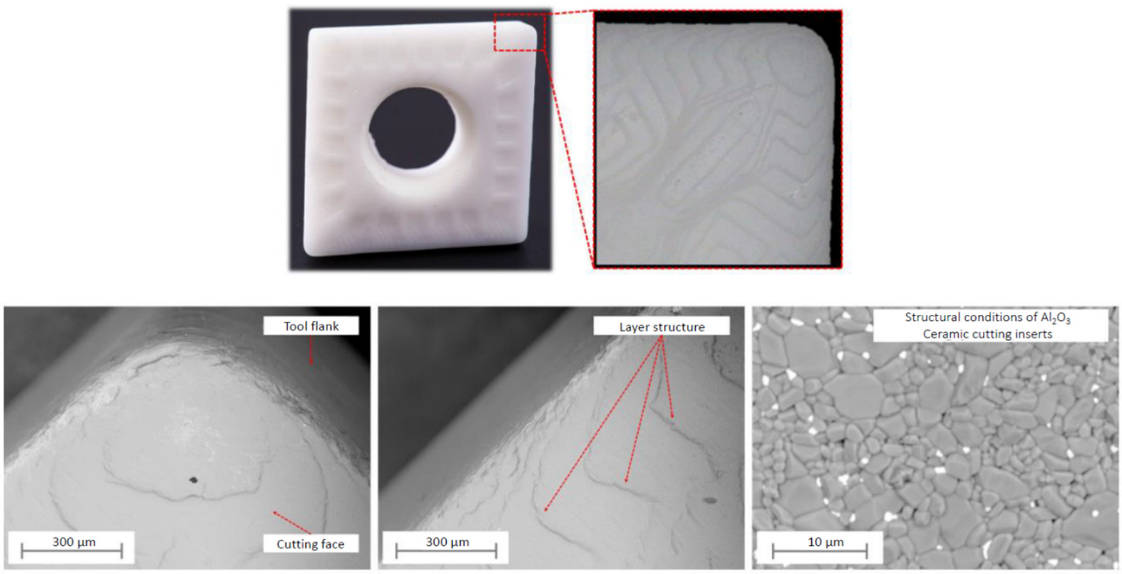

Figure 10: SEM image of a Al2O3-Ceramic cutting insert [29]

After sintering the layer structure can be seen in the SEM images. The cutting inserts were scanned using a 3D optical measurement system. The scanned model was compared to the original CAD file to determine the deviations. Along the cutting edge a maximum deviation of 50 microns can be seen. The cutting edge itself can be considered sharp enough to conduct cutting experiments without any additional post processing. In a cutting experiment grey cast iron GJL-250 was milled in a face turning operation. The cutting forces between using the different tool bodies and cutting inserts were recorded. The result showed no significant influence in the cutting forces between the original and the modified tool body. The cutting experiments revealed up to 50% higher cutting forces using the ceramic insert compared to a conventional made tungsten carbide insert. However the results are still promising and further research will be conducted to address this issue. There is a high potential for this process as complex ceramic tools with internal structures can be made which was not possible before.

4 Additive Process Chains for Industry 4.0

The increasing demand for individualized products and a huge variety of products leads to a rethinking of companies with regard to their manufacturing facility. At the same time lead times and prices of individualized products cannot increase despite maximum flexibility. This requires a cost-neutral flexibility of the process chains which can be achieved by increasing the efficiency or by implementing resource- and material saving products for example. The complete digitalisation of the process chains with a centralized control system and the establishment of a so-called Smart Factory is a solution for this problem. Digital process chains and smart factories are key features of the German High-Tech strategy Industry 4.0 which has been created in 2010 [30].

AM is particularly suitable for the use of Industry 4.0 due to the following properties:

- Mainly digital process chain;
- Individualized products;
- Short delivery time;
- Lightweight products.

Standardized interfaces and processes are required for the digitization of the process chains which are not very pronounced due to the low age of additive production. Furthermore there are only a few supporting processes such as simulation models. These tasks are to be dealt with and managed in the future. The action between end user and service provider is shown in Figure , with the focus on the question of a suitable linkability.

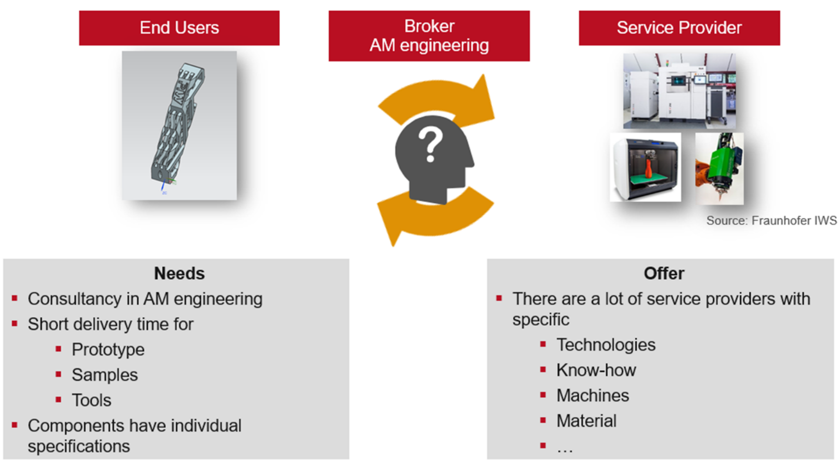

Figure 11: Additive Process Chains for Industry 4.0 - Problem Definition

In addition to the above mentioned points, such as lead times and individual specifications, end users often needs support in AM engineering. On the other hand there is a large number of service providers which can handle different product specifications. One way to connect end users and service providers is to provide cloud-based printing systems. A distinction is made in cross-company networks and internal networks.

For linking end user and AM providers a broker or an AM engineering provider can be used for cross company networks. The end user usually comes from a typical industrial sector such as aerospace, tool manufacturing or the automotive industry. The required parts have branch-specific properties related to constructional dimensions or the material selection. If the product doesn't require any revision the order can be submitted to a web-based broker who selects the appropriate AM provider and takes care of additional steps like data transfer, payment and delivery. If the product still requires an optimization for the AM process, an engineering provider can be used which carries out additional engineering steps.

The topic of cloud based printing at company internal networks is shown by an example of a fictional globally operating company. This company has different business units distributed around the world which require AM manufactured prototypes or spare parts. The information about the required part is forwarded to the global AM centre. This has the expertise to optimize the component for additive production. If the machines are available the component will be manufactured either in the AM centre or at the location of a business unit in which the suitable machine is available.

Network solutions are already implemented on the market like fabberhouse, cross-company networks or stratasys internal networks.

5 References

[1] (2017) Wohlers report 2017: 3D printing and additive manufacturing state of the industry : annual worldwide progress report. Wohlers Associates, Fort Collins, Colorado

[2] LBBW Corporate Research Automobil/Maschinenbau (2017) Beeindruckendes Können: 3D-Druck – Steigende Präzision und Taktzahl

[3] ASTM F2792-12a (2012) Terminology for Additive Manufacturing Technologies, West Conshohocken

[4] Biermann D, Meier H, Haberland C et al. (2013) Einsatz additiv gefertigter Werkzeughalter: Optimierungspotentiale bei der Drehbearbeitung von Titan durch strahlgeschmolzene Werkzeugaufnahmen. Werkstattstechnik online

[5] Abele E et al. (2015) Analysis and optimisation of vertical surface roughness in micro selective laser melting. Surf. Topogr.: Metrol. Prop. 3(3): 34007

[6] Donisi S GG Scheibenfräser und Herstellverfahren(WO 2016/030016 A1)

[7] Gebhardt A (2013) Generative Fertigungsverfahren: Additive Manufacturing und 3D Drucken für Prototyping ; Tooling ; Produktion, 1. Aufl. Carl Hanser Fachbuchverlag, s.l.

[8] Jahnke U et al. (2016) Production-integrated Markings for Traceability of AM Parts in the Context of Industry 4.0. In: Bourell D (ed) 27. Solid Freeform Fabrication Symposium 2016, pp 2394–2406

[9] Stoffregen HA (2015) Strukturintegration piezoelektrischer Vielschichtaktoren mittels selektiven Laserschmelzens. Innovation Fertigungstechnik. Shaker, Herzogenrath, Herzogenrath

[10] Li X et al. (2003) Embedded Fiber Bragg Grating Sensors in Polymer Structures Fabricated by Layered Manufacturing. Journal of Manufacturing Processes 5(1): 78–86

[11] Stoffregen HA et al. (2014) Fatigue Analysis in Selective Laser Melting: Review and Investigation of Thin-walled Actuator Housings. In: Bourell D (ed) 25. Solid Freeform Fabrication Symposium, pp 635–650

[12] Greitemeier D et al. (2015) Effect of surface roughness on fatigue performance of additive manufactured Ti–6Al–4V. Mater. Sci. Technol.: 1743284715Y.000

[13] Strano G et al. (2013) Surface roughness analysis, modelling and prediction in selective laser melting. Journal of Materials Processing Technology 213(4): 589–597

[14] Pupo Y et al. (2014) Surface Quality Analysis in Selective Laser Melting with CoCrMo Powders. MSF 797: 157–162

[15] Yadroitsev I et al. (2011) Surface Morphology in Selective Laser Melting of Metal Powders. Physics Procedia 12: 264–270

[16] Schürmann H (2014) 3-D-Druck ist auf dem Weg in die industrielle Praxis. VDI Nachrichten(Nr. 41): 7

[17] Frazier WE (2014) Metal Additive Manufacturing: A Review. J. of Materi Eng and Perform 23(6): 1917–1928

[18] Lell F et al. (2016) Generative Fertigung von 3-D-Bauteilen in Fertigteilqualität. Lightweight Des 9(S2): 28–31

[19] Schmalz G et al. (2009) Biocompatibility of Dental Materials. Springer Berlin Heidelberg, Berlin, Heidelberg

[20] Abele E (2015) Rechnerunterstützte Entwicklung und Fertigung dentaler Produkte: [Ergebnisbericht des BMBF Verbundprojektes COMMANDD]. Berichte aus der Medizintechnik. Shaker, Aachen

[21] Donisi S, Graf, Gregor (27. August) Scheibenfräser und Herstellverfahren(WO 2016/030016 A1)

[22] Andreas Enzenbach (2014) IMPULSE - Ausgabe 55: Mapal Technologie-Magazin, Aalen

[23] Biermann D et al. (2013) Einsatz additiv gefertigter Werkzeughalter: Optimierungspotentiale bei der Drehbearbeitung von Titan durch strahlgeschmolzene Werkzeugaufnahmen. Werkstattstechnik online(6): 481–484

[24] Khmyrov RS et al. (2016) Obtaining Crack-free WC-Co Alloys by Selective Laser Melting. Physics Procedia 83: 874–881

[25] Gläser T (2010) Untersuchungen zum Lasersintern von Wolframkarbi-Kobalt. Dissertation, RWTH Aachen

[26] Liu Q et al. (2015) Effect of high-temperature preheating on the selective laser melting of yttria-stabilized zirconia ceramic. Journal of Materials Processing Technology

[27] Kernan BD et al. (2007) Three-dimensional printing of tungsten carbide–10wt% cobalt using a cobalt oxide precursor. International Journal of Refractory Metals and Hard Materials 25(1): 82–94

[28] Schwentenwein M et al. (2014) Additive Manufacturing of Dense Alumina Ceramics. Int. J. Appl. Ceram. Technol.: n/a

[29] Abele E et al. (2016) Mit SLM-Technologie hergestellte Zerspanungswerkzeuge – Potentiale und Grenzen

[30] N.N. (2015) Industry 4.0. http://www.hightech-strategie.de/de/Industrie-4-0-59.php

22nd International Seminar on High Technology: Additive Manufacturing – Challenges and Chances

Prof. Dr.-Ing. Eberhard Abele, Michael Kniepkamp M.Sc., Martin Link M.Sc.
Piracicaba | October 5, 2017, Piracicaba, Brazil

TECHNISCHE UNIVERSITÄT DARMSTADT
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Institute of Production Management, Technology and Machine Tools | Prof. Dr.-Ing. E. Abele / Prof. Dr.-Ing. J. Metternich

Agenda

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- **Current State of the Art of Additive Manufacturing**
- **Opportunities of Additive Manufacturing**
- **Hybrid Manufacturing**
- **Example: Dental Applications**
- **Example: Cutting Tools**
- **Additive Process Chains for Industry 4.0**

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What is Additive Manufacturing?

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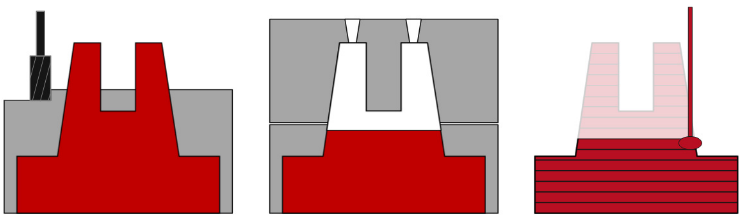
Subtractive Processes	Casting	Additive Manufacturing



Subtractive Processes	Casting	Additive Manufacturing
• Removal of material • „top down" principle • From semi finished products • Part specific tools required	• Casting in one Step • Liquefied materials • Molds required	• „bottom up" principle layer by layer • No part specific tools required

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Economic Situation of Additive Manufacturing

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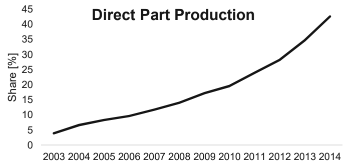
Industry Growth

- CAGR: ~ 30 % every year
- 12850 professional systems sold in 2014
- In 2014: 543 metal systems sold
- In 2016: 2000 metal systems sold
- 44 % of all parts are "direct parts"
- Main drivers:
  - -U.S. >GE, Stratasys
  - - Germany >EOS, Trumpf
  - - Japan

Sold consumer printers for < 5000$ in 2014: ~ 140000



Quelle: Wohlers Associates, Inc.

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Not a Disruptive Technology for all Applications but Complementary to Traditional Systems

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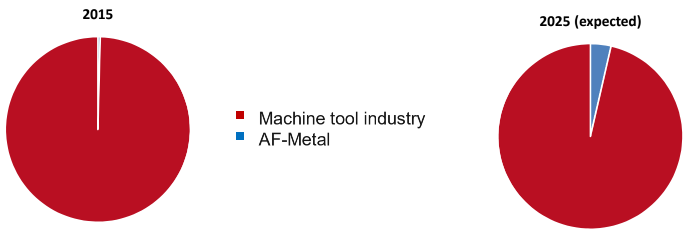
Scenario: AM metal systems compared to the global machine tool industry (2015: ca. 68 bill. EUR)*



Source: VDW, LBBW Research *Szenario 2025: AM-Metallsysteme CAGR 30%, Werkzeugmaschinen CAGR 3%

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Applications of Additive Manufacturing

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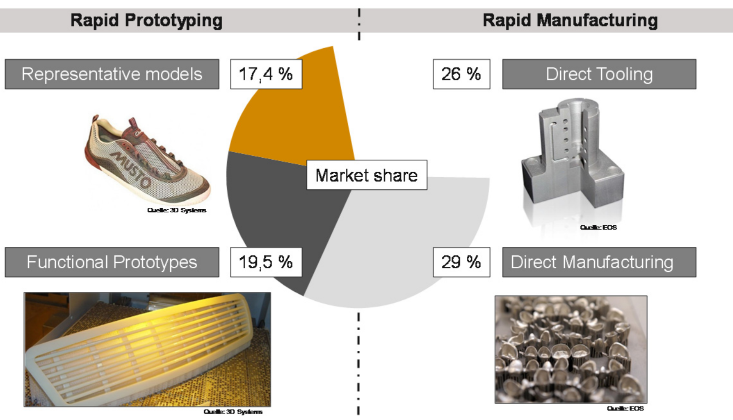

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Additive Manufacturing Processes 1/3

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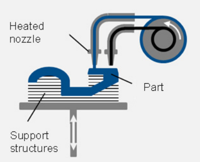
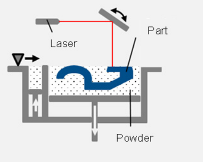
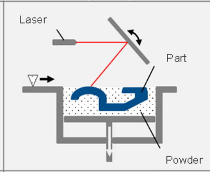
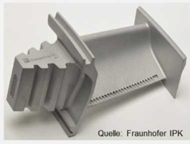
	Material extrusion (FLM/FDM)	Powder bed Fusion (SLS)	Powder bed Fusion (SLM)
Principle			
Materials	ABS and PLA	Polyamide	Metals
Sample parts			

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Additive Manufacturing Processes 2/3

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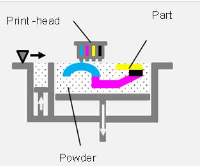
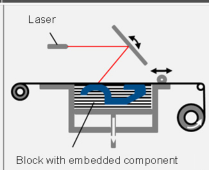
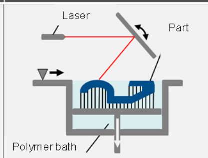
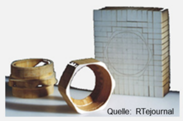
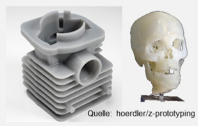
	Binder jetting	Sheet lamination	Photopolymerization
Principle			
Materials	Gypsum, ceramic or starch powder	Paper-, polyester- and glass fiber foils	Epoxy resin and acrylates
Sample parts			

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Additive Manufacturing Processes 3/3
Laser Cladding

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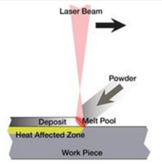
Powder melting

Principle:



Materials: Metal

Sample parts:

- The laser beam is defocused on the workpiece with a selected spot size.
- The powder coating material is carried by an inert gas through a powder nozzle into the melt pool.
- The laser optics and powder nozzle are moved across the workpiece surface to deposit single tracks,.

Typical laser power	1 – 6 kW
Typical build up rate	0.1 to 12 kg
Typical coating thickness	0.2 to 4 mm (or more)
Coating materials	Weldable powders (metals, metallic alloys, carbide blends)

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Laser Cladding and Milling Using Robots

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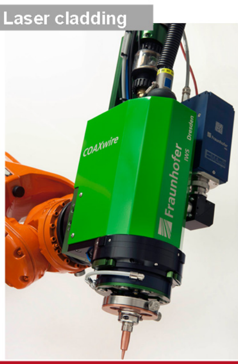
Laser cladding



Milling

High flexibility of robots for large parts

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Main Applications for Additive Manufacturing

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Significance for mechanical engineering		
Aerospace	●	Lightweight and bionic structures
Medical	●	Lot size 1 and special materials
Tooling	●	Molds with integrated cooling channels
Process engineering	◕	Lot size 1 and function integration
Automation	◑	Special products
Automotive	◔	Prototyping
Electronics	◔	Motors, sockets, heat sinks
General engineering	◔	Parts with complex geometries

Quelle: LBBW Research

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Examples of Additive Manufactured Components

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medical engineering – dental crowns

- cost-effective manufacturing of individualized medical products

tool making & mold making – tool inserts

- conformal cooling channels enable shorter cycle times

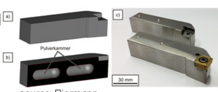
aerospace – supporting elements

- conformal production of expensive materials
- weight savings due to bionic design

automotive industry – prototypes

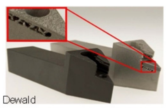
- production of prototypes

vibration damping



source: Biermann

indirect cooling with LN_2



source: Dewald

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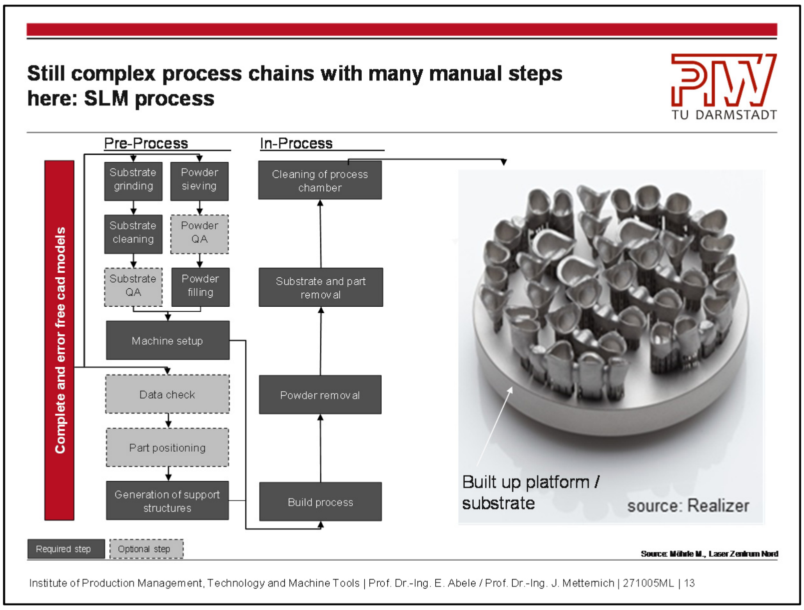
Still complex process chains with many manual steps
here: SLM process
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Pre-Process
In-Process
Complete and error free cad models
Substrate grinding
Powder sieving
Substrate cleaning
Powder QA
Substrate QA
Powder filling
Machine setup
Data check
Part positioning
Generation of support structures
Cleaning of process chamber
Substrate and part removal
Powder removal
Build process
Built up platform / substrate
source: Realizer
Required step
Optional step
Source: Möhrle M., Laser Zentrum Nord
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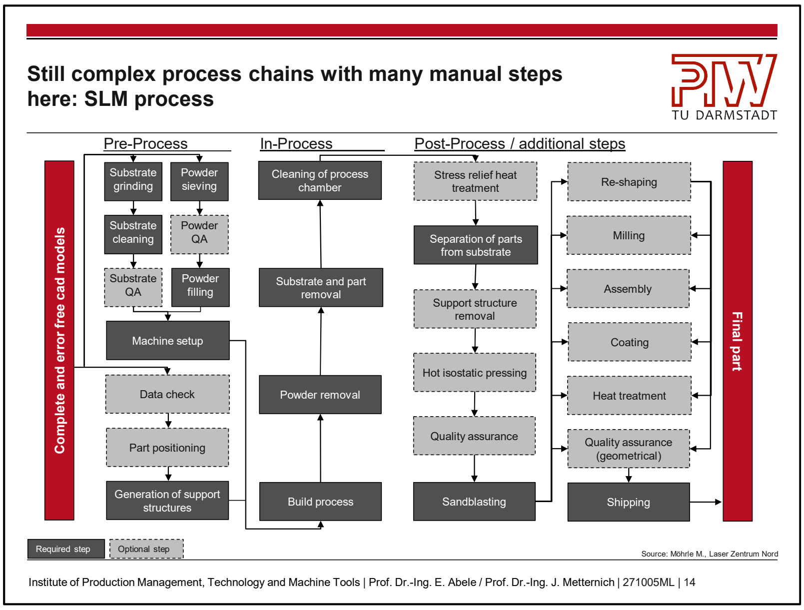
Still complex process chains with many manual steps
here: SLM process
TU DARMSTADT
Pre-Process
In-Process
Post-Process / additional steps
Complete and error free cad models
Substrate grinding
Powder sieving
Substrate cleaning
Powder QA
Substrate QA
Powder filling
Machine setup
Data check
Part positioning
Generation of support structures
Cleaning of process chamber
Substrate and part removal
Powder removal
Build process
Stress relief heat treatment
Separation of parts from substrate
Support structure removal
Hot isostatic pressing
Quality assurance
Sandblasting
Re-shaping
Milling
Assembly
Coating
Heat treatment
Quality assurance (geometrical)
Shipping
Final part
Required step
Optional step
Source: Möhrle M., Laser Zentrum Nord
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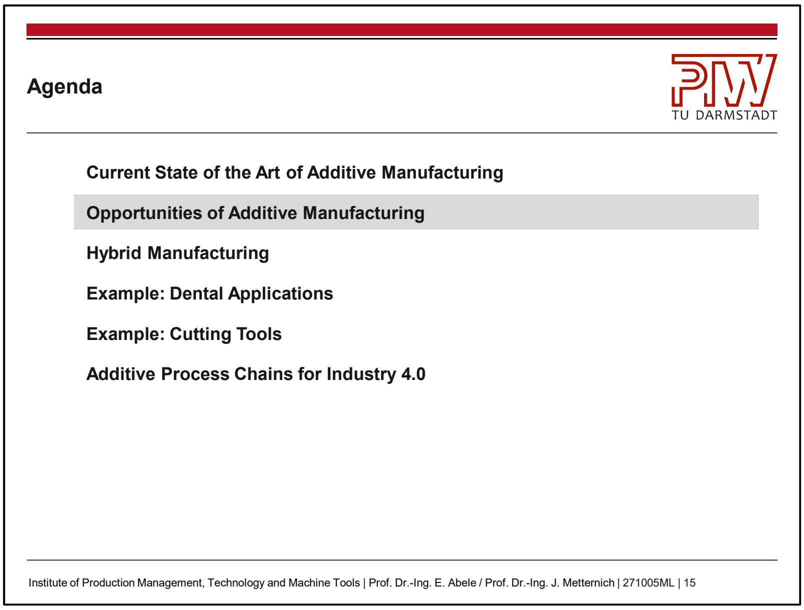
Agenda
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Current State of the Art of Additive Manufacturing
Opportunities of Additive Manufacturing
Hybrid Manufacturing
Example: Dental Applications
Example: Cutting Tools
Additive Process Chains for Industry 4.0
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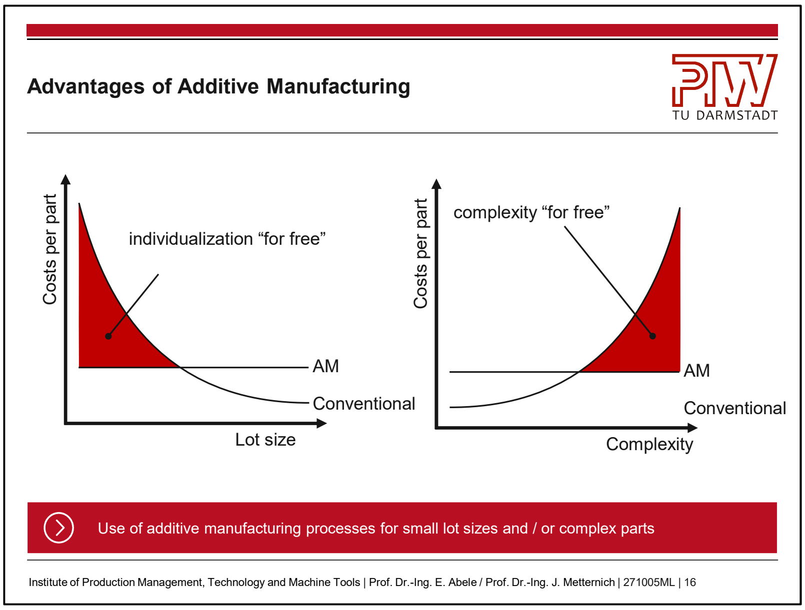
Advantages of Additive Manufacturing
PTW
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Costs per part
individualization "for free"
AM
Conventional
Lot size
Costs per part
complexity "for free"
AM
Conventional
Complexity
Use of additive manufacturing processes for small lot sizes and / or complex parts
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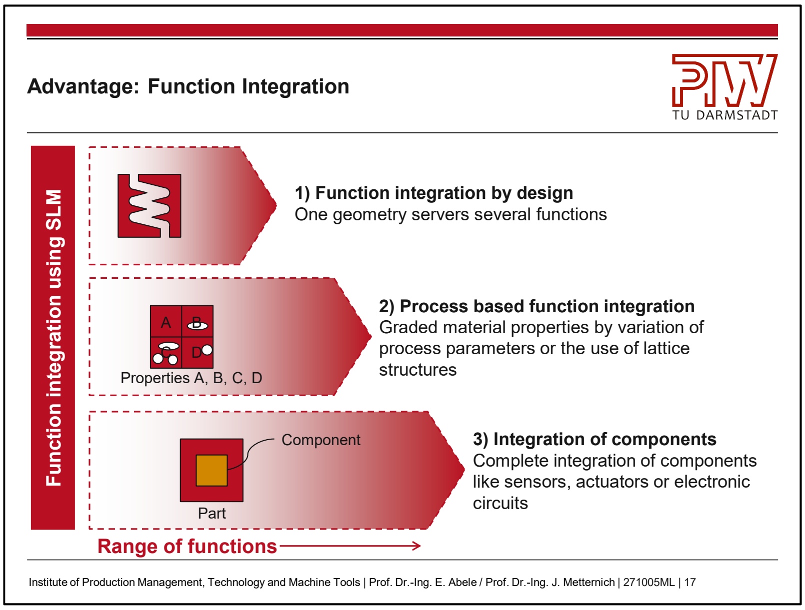
Advantage: Function Integration
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Function integration using SLM
1) Function integration by design
One geometry servers several functions
A
B
D
Properties A, B, C, D
2) Process based function integration
Graded material properties by variation of process parameters or the use of lattice structures
Component
Part
3) Integration of components
Complete integration of components like sensors, actuators or electronic circuits
Range of functions
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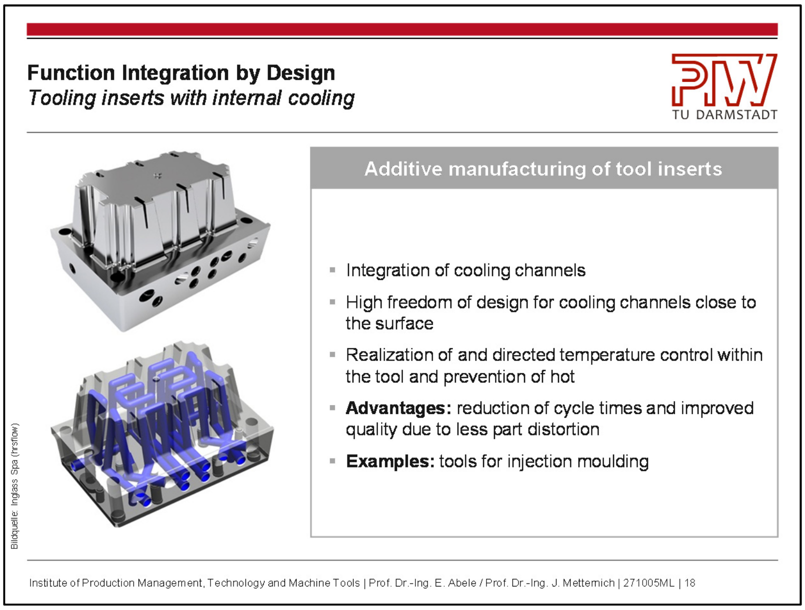
Function Integration by Design
Tooling inserts with internal cooling
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Additive manufacturing of tool inserts
Integration of cooling channels
High freedom of design for cooling channels close to the surface
Realization of and directed temperature control within the tool and prevention of hot
Advantages: reduction of cycle times and improved quality due to less part distortion
Examples: tools for injection moulding
Bildquelle: Inglass Spa (hrsflow)
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Function Integration by Process
Medical implants

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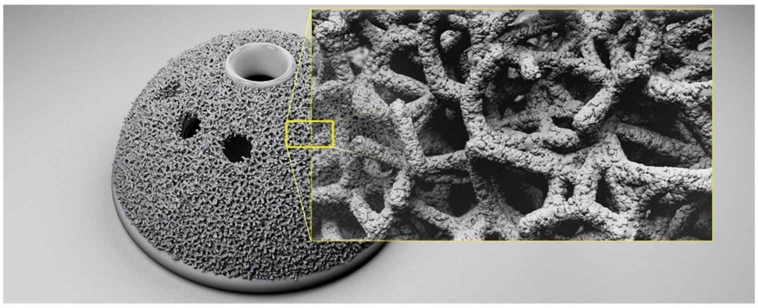

Bildquelle: Within lab

- Improvement of bone in-growth due to porous
- Adjustment of mechanical properties to match the stiffness of the bone structure to avoid "stress shielding".

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Function Integration by Process
Internal marking of objects

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Part: high density process parameters
Text: porous process parameters (15 %)

Source: Patent DE102009043597 A1.

- Marking of by variation of process parameters
- Identification of objects using destruction free testing
- Protection from product piracy
- In-part balancing

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Function Integration by Integrating Components

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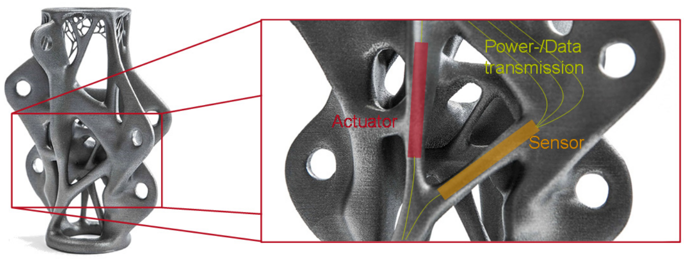

Img. source: www.arup.com

- Part specific adaptability (stiffness, geometry, material)
- Increased reliability (monolithic enclosure, protection from hazardous environments)
- Optimal positioning (inside the flow of forces)
- Direct manufacturing and assembly process without the need of specific tools

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Property's of Metal Parts Made by Additive Manufacturing Using Powder Bed Based Fusion (SLM)

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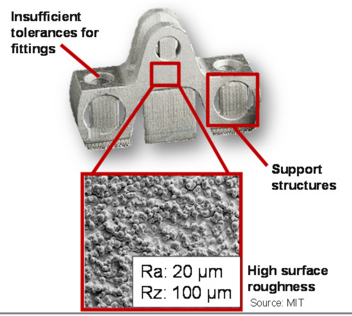
Surface quality



Material data – EOS StainlessSteel 316L

	As built
Ultimate tensile strength [5]	
- in horizontal direction (XY)	640 ± 50 MPa
- in vertical direction (Z)	540 ± 55 MPa
Yield strength, Rp0.2% [5]	
- in horizontal direction (XY)	530 ± 60 MPa
- in vertical direction (Z)	470 ± 90 MPa
Young's modulus [5]	
- in horizontal direction (XY)	typ. 185 GPa
- in vertical direction (Z)	typ. 180 GPa
Elongation at break [5]	
- in horizontal direction (XY)	40 ± 15 %
- in vertical direction (Z)	50 ± 20 %
Hardness [6]	typ. 89 HRB

Source: EOS

Parts made by additive manufacturing are not ready to use. Post processing is required

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Hybrid Processes – Combination of Additive and Cutting Processes

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2 machine setup

Hybrid machine

Combination of additive manufacturing and pre-made parts

Bilder: DMG, Datron, Concept Laser, EOS

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Challenges in a 2-Machine Hybrid Setup

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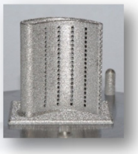
SLM-Process

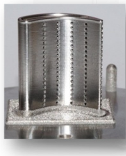
- Position of workpiece on the built platform is not defined in x- and y-direction
- Part distortion due to thermal stress
- Deviations between designed part and build part



handling

Milling-Process

- Zero-point transfer between both machines (zero point clamping system)
- Clamping position unknown due to surface roughness



The sum of all these errors define the required excess material required for post processing

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Hybrid Machine: Powder Bed Fusion and 2.5 Axis Cutting

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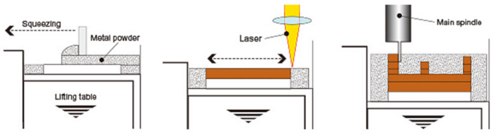
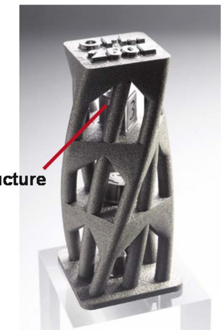
Hybrid SLM process





Milled internal structure

Image source: Matsuura, Sodick

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Current State of the Art of Additive Manufacturing

Opportunities of Additive Manufacturing

Hybrid Manufacturing

Example: Dental Applications

Example: Cutting Tools

Additive Process Chains for Industry 4.0

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Manufacturing Trends within the Dental Sector
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Source: ExoCad
Source: Straumann
CAD/CAM-process-chain enables industrial manufacturing
TiAl
Steel
NiTi
NiCr
Ti
CoCr
Difficult-to-Cut materials
Main Drivers
▪ Shift from manual dental labs to automated industrial processes
▪ Increasing material diversity and number of Difficult-to-Cut (DTC) materials
▪ Increasing CNC based manufacturing
▪ Competition cutting vs. additive
Source: EOS
Additive manufacturing
Source: Datron
CNC machining
Hybrid manufacturing by combining additive manufacturing and cnc machining offers new possibilities
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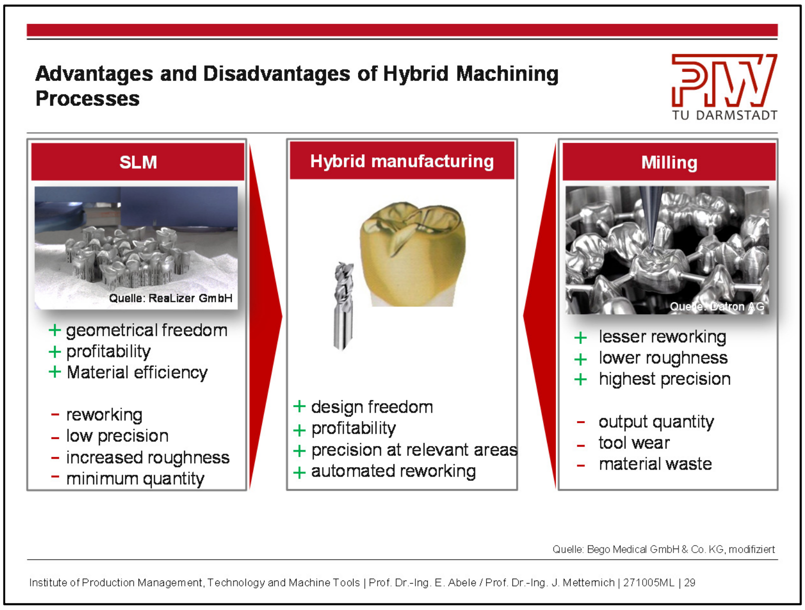
Advantages and Disadvantages of Hybrid Machining Processes
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SLM
Quelle: ReaLizer GmbH
+ geometrical freedom
+ profitability
+ Material efficiency
– reworking
– low precision
– increased roughness
– minimum quantity
Hybrid manufacturing
+ design freedom
+ profitability
+ precision at relevant areas
+ automated reworking
Milling
Quelle: Datron AG
+ lesser reworking
+ lower roughness
+ highest precision
– output quantity
– tool wear
– material waste
Quelle: Bego Medical GmbH & Co. KG, modifiziert
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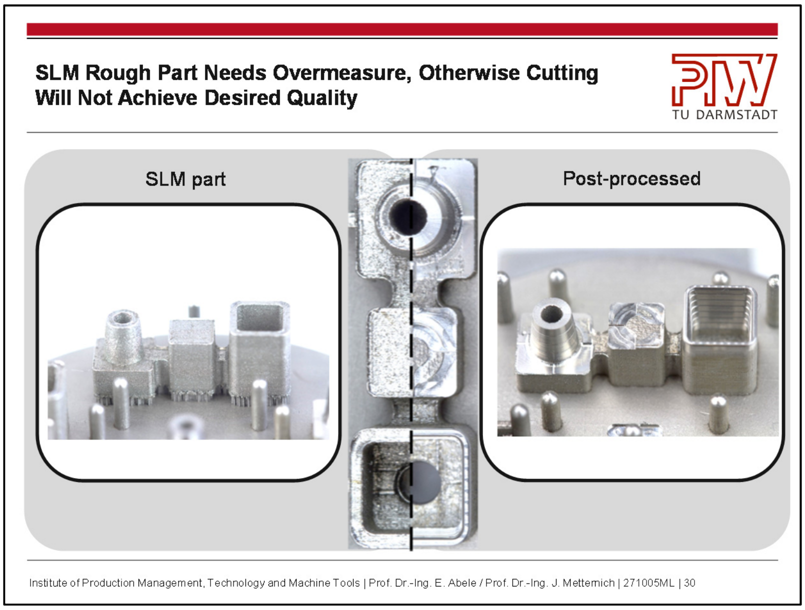
SLM Rough Part Needs Overmeasure, Otherwise Cutting Will Not Achieve Desired Quality
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SLM part
Post-processed
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Real Implant Testing

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- Current State of the Art of Additive Manufacturing
- Opportunities of Additive Manufacturing
- Hybrid Manufacturing
- Example: Dental Applications
- **Example: Cutting Tools**
- Additive Process Chains for Industry 4.0

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AM Processes for Cutting Tools

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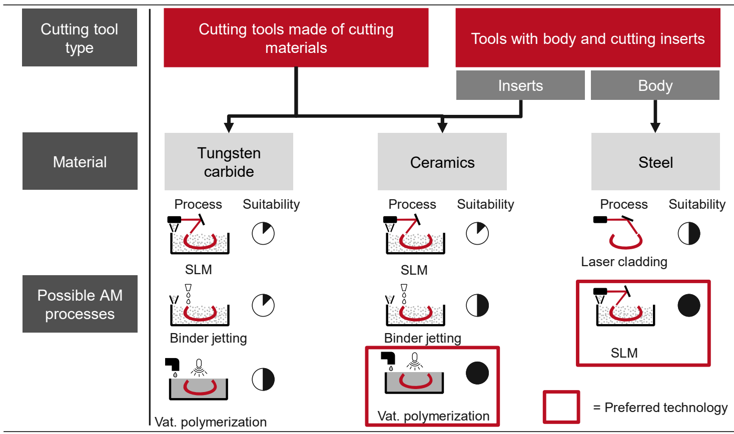

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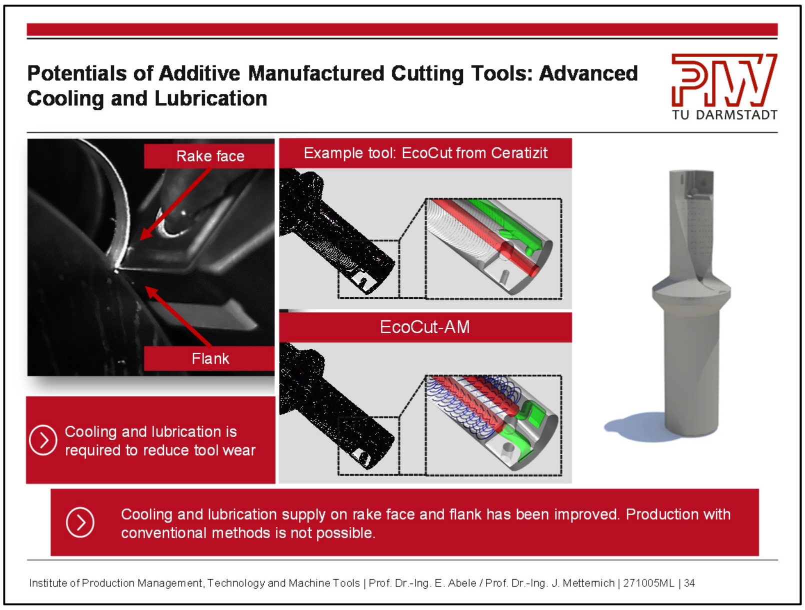
Potentials of Additive Manufactured Cutting Tools: Advanced Cooling and Lubrication
TU DARMSTADT
Rake face
Flank
Example tool: EcoCut from Ceratizit
EcoCut-AM
Cooling and lubrication is required to reduce tool wear
Cooling and lubrication supply on rake face and flank has been improved. Production with conventional methods is not possible.
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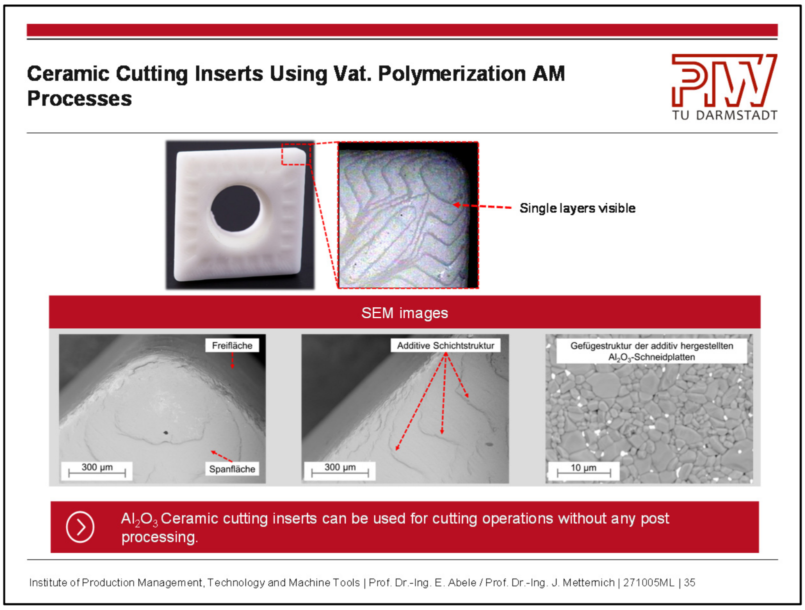
Ceramic Cutting Inserts Using Vat. Polymerization AM Processes
TU DARMSTADT
Single layers visible
SEM images
Freifläche
Spanfläche
300 µm
Additive Schichtstruktur
300 µm
Gefügestruktur der additiv hergestellten Al_2O_3-Schneidplatten
10 µm
Al_2O_3 Ceramic cutting inserts can be used for cutting operations without any post processing.
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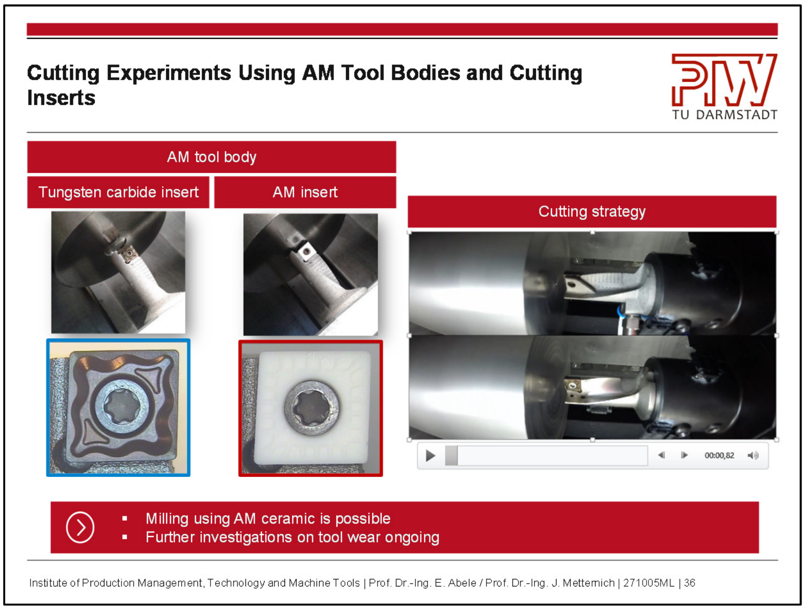
Cutting Experiments Using AM Tool Bodies and Cutting Inserts
TU DARMSTADT
AM tool body
Tungsten carbide insert
AM insert
Cutting strategy
Milling using AM ceramic is possible
Further investigations on tool wear ongoing
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Agenda

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Potentials of AM Technologies for Industry 4.0

TU DARMSTADT

Industry 4.0 - Objectives

- Full digitalization of process chains
- Decentralized control
- Smart Factory

Potentials of AM Technologies

- Mainly digital process chain
- Individualized products
- Short delivery time

Source: Kärcher

- Standardization of processes
- Standardization of interfaces
- Processes online
- Simulation models

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Additive Process Chains for Industry 4.0 – Problem Definition

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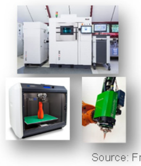
End Users

Broker
AM engineering

Service Provider



Source: Fraunhofer IWS

Needs

- Consultancy in AM engineering
- Short delivery time for
  - Prototype
  - Samples
  - Tools
- Components have individual specifications

Offer

- There are a lot of service providers with specific
  - Technologies
  - Know-how
  - Machines
  - Material
  - ...

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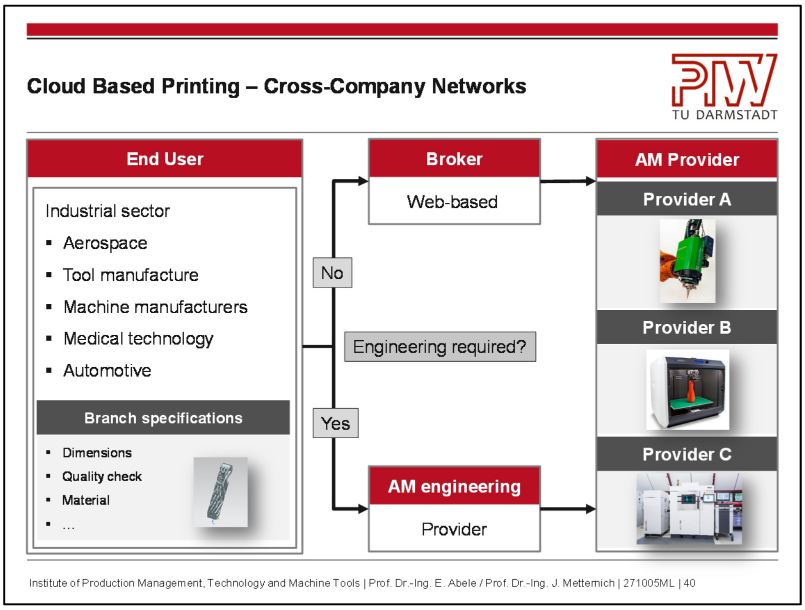
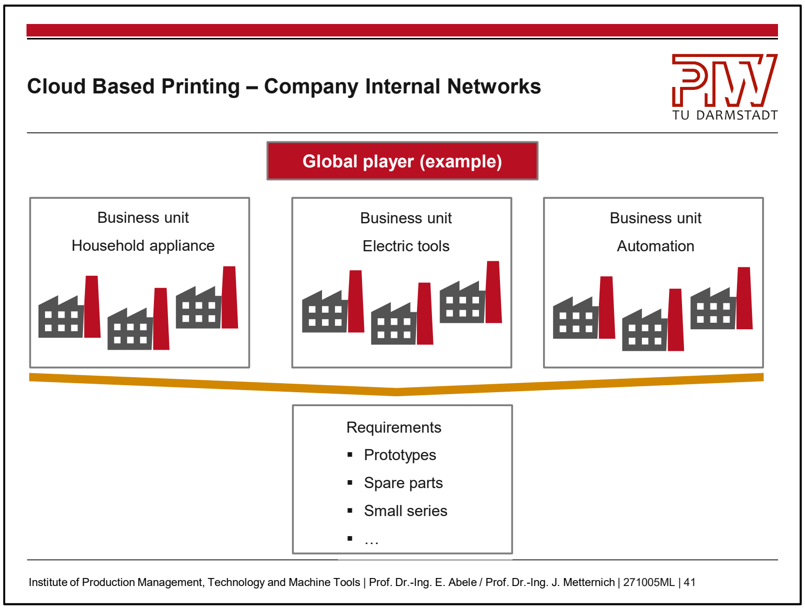

Cloud Based Printing – Cross-Company Networks
TU DARMSTADT
End User
Industrial sector
Aerospace
Tool manufacture
Machine manufacturers
Medical technology
Automotive
Branch specifications
Dimensions
Quality check
Material
...
No
Yes
Engineering required?
Broker
Web-based
AM engineering
Provider
AM Provider
Provider A
Provider B
Provider C
Institute of Production Management, Technology and Machine Tools | Prof. Dr.-Ing. E. Abele / Prof. Dr.-Ing. J. Metternich | 271005ML | 40


Cloud Based Printing – Company Internal Networks
TU DARMSTADT
Global player (example)
Business unit
Household appliance
Business unit
Electric tools
Business unit
Automation
Requirements
Prototypes
Spare parts
Small series
...
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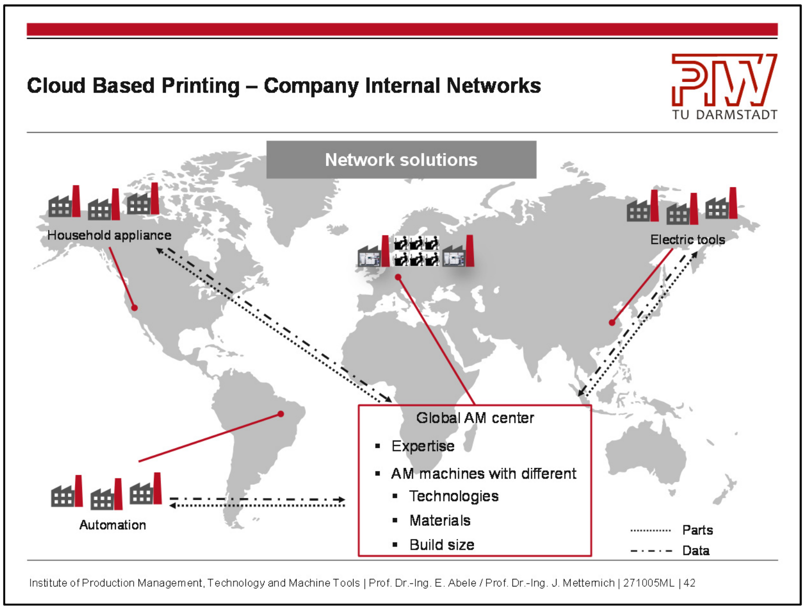
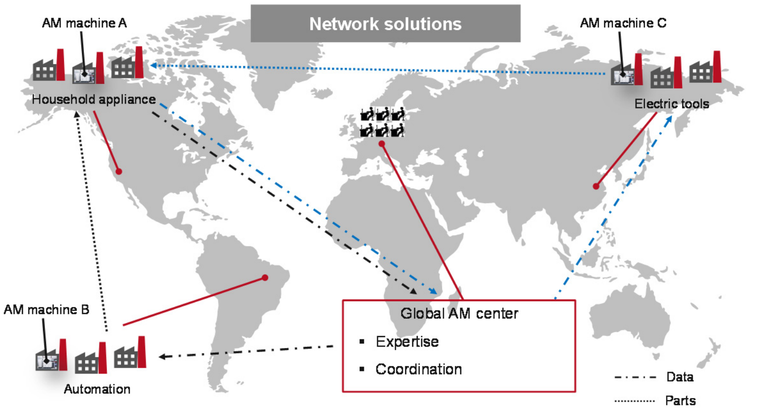

Cloud Based Printing – Company Internal Networks
TU DARMSTADT
Network solutions
Household appliance
Electric tools
Automation
Global AM center
Expertise
AM machines with different
Technologies
Materials
Build size
Parts
Data
Institute of Production Management, Technology and Machine Tools | Prof. Dr.-Ing. E. Abele / Prof. Dr.-Ing. J. Metternich | 271005ML | 42

Cloud Based Printing – Company Internal Networks

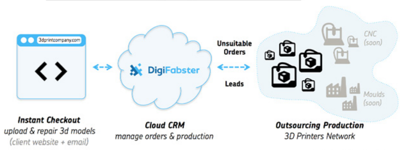
PTW TU DARMSTADT



Cloud Based Printing - Examples

PTW TU DARMSTADT

Cross-Company Networks



Source: DigiFabster

Internal Networks

Source: Stratasys

Network solutions are already implemented on the market

Thank you for your kind attention!!

If you have any questions, do not hesitate to contact us.

TECHNISCHE UNIVERSITÄT DARMSTADT

PTW TU DARMSTADT

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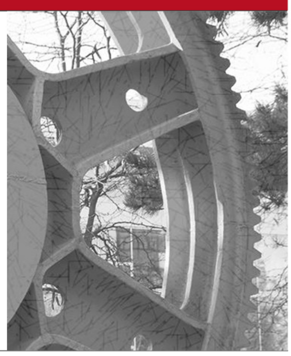

Prof. Dr.-Ing. Berend Denkena

Prof. Dr.-Ing. Denkena was born in 1959 and studied mechanical engineering at the University of Hannover, where he received his Diploma in 1987. He worked as a research engineer at the Institute of Production Engineering and Machine Tools of the University of Hannover from 1987 until 1992. In 1992 he received his doctorate in engineering. From 1992 until 1996 Prof. Denkena worked at Thyssen Production Systems as Design Engineer in Essen, Germany, and later on a as Head of Standards Engineering and Systems Analysis in Auburn Hills, USA, before he held the position as Head of Machining Center Development at Hüller Hille GmbH in Ludwigsburg, Germany. In 1996 he became Head of Engineering and Turning Machine Development at Gildemeister Drehmaschinen GmbH. Since 2001 Prof. Denkena holds a professorship (W3) of Production Engineering and Machine Tools at the Leibniz Universität Hannover. He is member of the German Academic Society for Production Engineering (WGP), the International Academy of Production Engineering (CIRP) and the German Academy of Science and Engineering (Acatech). From 2009 until 2012 Prof. Denkena was elected chairman of CIRP STC Cutting and member of the CIRP council. Since 2012 he serves a member of the supervisory board of DMG MORI AG.

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IFW, Leibniz Universität Hannover

The Institute of Production Engineering and Machine Tools (IFW) is focused on all aspects of production engineering. Currently, 90 researchers work in the fields of machining processes, the development of machines as well as production planning and organization. Moreover, the institute has a leading role in the area of Industry 4.0. The IFW combines experimental, theoretical and simulation-based methods, covering both basic and applied research and offering services and consulting. An intermediary between research and practice, keeping the close links between university and industry alive is an important aspect of the work at IFW. In addition to R&D, educating students is another focal point and the curriculum covers all research areas in which scientists at IFW are actively engaged.

IFW
Institut für Fertigungstechnik
und Werkzeugmaschinen
Prof. Dr.-Ing. Berend Denkena

Metal Cutting meets Industry 4.0

Abstract

The last 250 years of technological development in manufacturing have been driven by innovative ideas and have been characterized by a continuous increase of performance. Important milestones of this development were the mechanization of production, the assembly line and the automated production. The upcoming 4th Industrial Revolution is ignited by the demand for highly adaptable and connected process chains, which are able to produce individualized products in an efficient, reliable and sustainable manner. The presentation highlights recent developments in sensor and actuator integrated components and strategies for adaptive process control. Examples for machine integrated cyber-physical systems and results of online compensation strategies are given. Moreover, an approach for a self-optimizing process planning is presented. The approach combines actual machine data with process data from a simultaneous material removal simulation. Using machine learning the aggregated data is transferred to deployable information for process planning. Finally, an outlook is given on how machine data cannot only support process planning on a machine level but also scheduling for entire production systems.

Keywords

Self-optimization; Cyber-physical Systems; Adaptive Process Control; Machining; Process Planning.

1 Introduction

Developments in metal cutting have always been closely connected to progress in other fields of science and technology. Soon after their invention, steam machines were used to power multiple spindles in factories. Later on, individual electric motors replaced belt-driven metal cutting machines. The pursuit of more powerful motors resulted in higher cutting speeds and higher material removal rates. Thus, larger process forces acted on machine components and cutting tools were exposed to higher temperatures. As consequence, the machine design needed to be adapted. Moreover, novel cutting tools like tungsten carbide were introduced to cope with higher mechanical and thermal loads. The invention of numerical control systems marks another milestone in the history of metal cutting. Machines could be controlled precisely by flexible programs.

Today, production faces an increasing competitive pressure and rising demands with respect to small lot production. Thus, companies need to combine the flexibility of a workshop production and the efficiency of a high-volume production. Intelligent manufacturing systems and adaptive production planning may offer solutions to cope with these challenges. Focusing on the feedback of process information, this article demonstrates how intelligent manufacturing systems can be used as a key to optimize production processes. Machine tools and components are being equipped with integrated sensors and communication systems distributed in the machine in a way which is similar to human nerves and nerve tracts. Inspired by a human who holds a tool in one hand and a component in the other the machine "feels" the conditions of the process, the component, and the tool. The information can be retraced, which makes it possible for the production to react autonomously to events which require the individual rescheduling and adaptation of procedures and work processes. Retracing information has an enormous potential to increase the quality and safety of production processes while increasing productivity at the same time. The "feeling" machines developed in CRC 653 ''Gentelligent Components in Their Lifecycle'' provide detailed information about the condition of the machine and the process. With that, the "feeling" machines enable an independent adaption of production parameters. Data exchange between machines, tools, and components are made possible by communication technologies. The information gained from the manufacturing process of the "feeling" machine is processed directly. These data flow into a self-learning regression model aimed at minimizing the rejection rate at consistent maximum productivity.

2 Feeling machine

In order to achieve an intelligent manufacturing system machines and their components must be capable of sensing their own condition and provide online information about the current machining process. Moreover, the entities of the intelligent manufacturing system need to be enabled to control and even optimize the machining steps on their own. Aiming for such systems, process signals are indispensable. Whereas humans have the natural ability to detect process conditions, like forces, and react accordingly, machine tools need additional sensors for data acquisition (see figure 1). In the following, it will be shown how components of a machine tool (spindle slide and clamping system) are enabled to “feel” and how this technology can be used in production processes.

Figure 1: Sensory components enable machines to "feel"

2.1 Sensory spindle slide

In milling, the spindle slide, that carries the working spindle, is well suited for the integration of sensory machine components, since it is closely located to the cutting process and directly guides the flux of force. Because the spindle is used for all processes in a machine tool, sensor positioning at the spindle slide offers a high flexibility with respect to different cutting operations. The load detection is realized by strain measurements on the structure of the component. However, structural components, like the spindle slide, are crucial parts with respect to the machining accuracy and the process stability. Thus, they generally possess a high stiffness. Consequently, strains in the structure are very low and can hardly be used for process monitoring. Finite element analyses with an applied load of 1 kN at the TCP support this statement. As shown in figure 2, the strain values are mostly smaller than 10 µm/m. Therefore, modifications of the component’s design that increase the sensitivity without lowering the stiffness need to be considered.

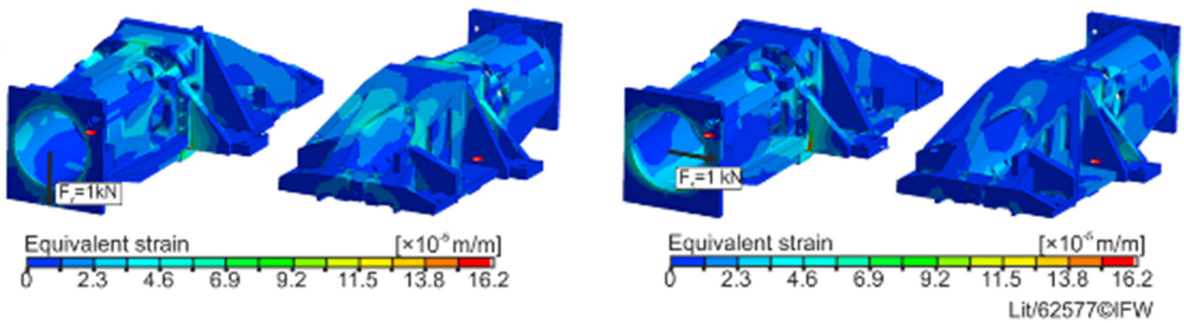

Figure 2: Strain state in spindle slide structure

Aiming for a higher sensitivity the force flux in the component is locally altered by notches [1, 2]. The notch results in a local strain intensification in the notch ground. Due to novel extremely small sensors, which have been developed within in the CRC 653, the size of the notch can be reduced (chamfer angle 90–120 degree, depth 2–4 mm). Because of the negligible dimensions of the notch in comparison to the size of the component, the stiffness is only reduced in the range of 0.1 %.

A prototype of the sensory spindle slide is realized an integrated into a milling center DMG HSC55 linear [1, 2] (figure 3). Commercially available strain gauges and two different kinds of miniature strain gauges are tested. The first kind of the miniature strain gauges is directly sputtered on the component's surface and subsequently structured using a laser beam (L-SG) [3]. The second type of micro strain gauges is based on a flexible polymer substrate (µ-SG) [4]. Based on the results of the FE-analyses the strain gauges are applied on twelve positions across the spindle slide.

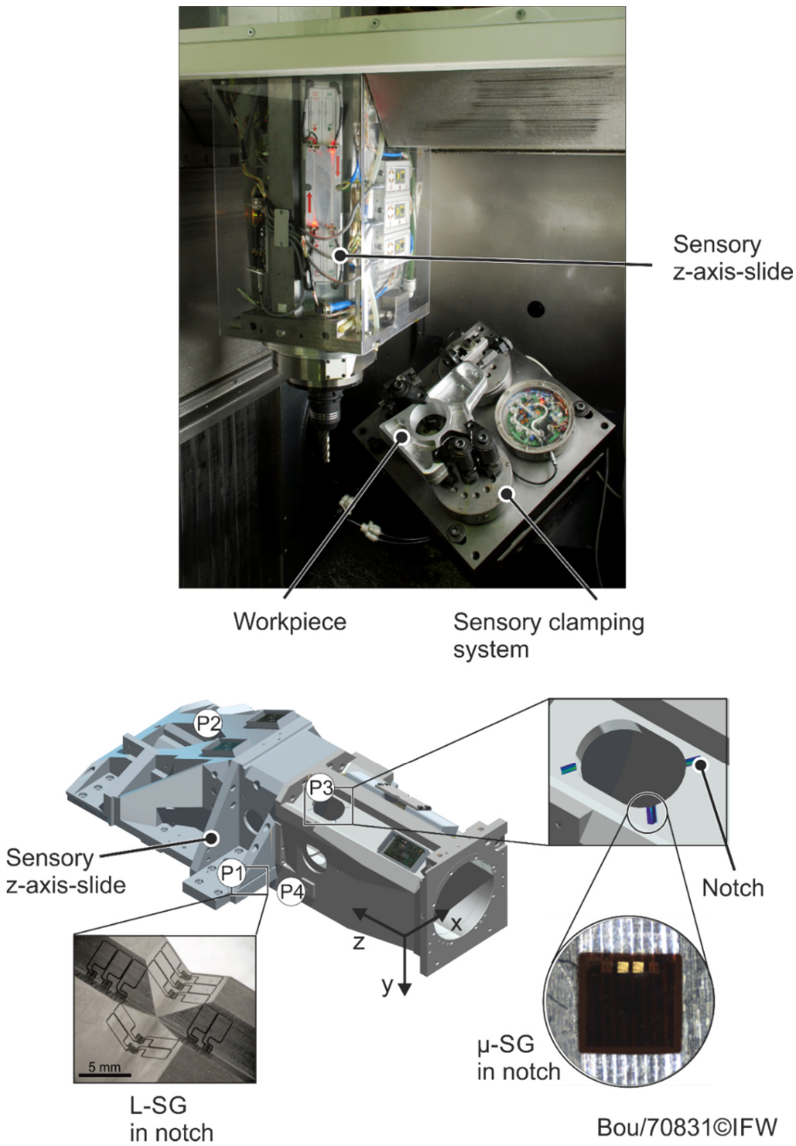

Figure 3: Integrated sensory components and sensor positions across the spindle slide

The sensor types L-SG and µ-SG are integrated in notches, whereas the references strain gauges (Ref.) are applied closely to the respective positions, but not in notches. Figure 4 compares the sensitivities of the strain gauges at the positions P1, P2, P3 and P4 under a static load at the TCP. It can be clearly seen that integrating the strain gauges in notches increases the sensitivity. Compared to the x- and y-directions, the spindle slide is not very sensitive in z-direction. This can be explained with the higher stiffness of the component in the z-direction.

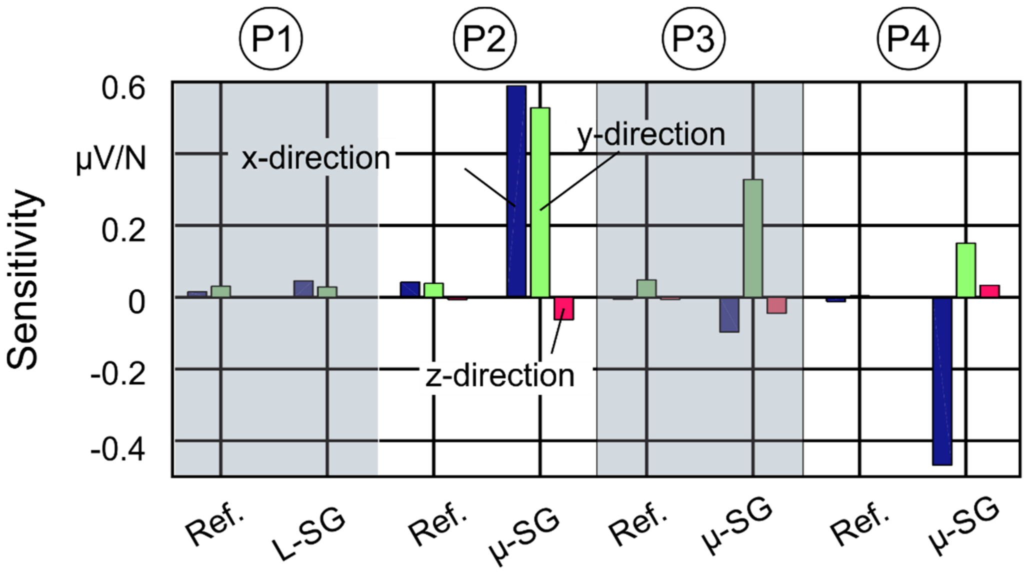

Figure 4: Influence of the notches on the sensitivity of different sensor types with respect to direction

Using calibration matrices the strain signals are converted into process forces. A comparison to reference forces measured by a dynamometer shows a maximum deviation of 40 N in up and down milling processes of aluminum. Consequently, the presented method provides a sufficient signal quality for process monitoring and control.

2.2 Sensory clamping system

Clamping systems are the interface between the workpiece and the machine tool. Comparable to the spindle slide, the clamping system guides the forces flux and is in close proximity to the cutting process. Thus, clamping systems with integrated sensors offer a promising option for monitoring of machining processes. Additionally, a sensory clamping system allows to detect clamping failures and costly malfunctions of the clamping system itself. However, several challenges, like sufficient sensor sensitivity, harsh environmental conditions and power transfer, must be overcome to ensure a reliable system.

The development of the sensory clamping system is based on an example from the automotive industry. The concept of the sensory clamping system and the required auxiliary systems is shown in figure 5. Similar to the spindle slide, the pistons of the clamping system are equipped with strain gauges. Moreover, temperature sensors are applied to the clamping elements. Every clamping element possesses its own microcontroller. Thus, additional elements can be added easily. The obtained data is transferred via radio link to an IPC. An inductive energy transmission of up to 100 W ensures a stable power supply of the individual clamping elements.

Aiming to find optimal positions for the strain gauges the strain distribution of the clamping housing is calculated and subsequently analyzed. For this purpose, the simulation software ANSYS is coupled with MATLAB via a programmed interface. Suitable sensor positions are characterized by two criteria. First, the desired measurand causes high strains at the position (high sensitivity for desired measurands). Second, unwanted interaction affect the strain at the position as little as possible (low unwanted interaction). The identified optimal sensors positons are shown in figure 6 a.

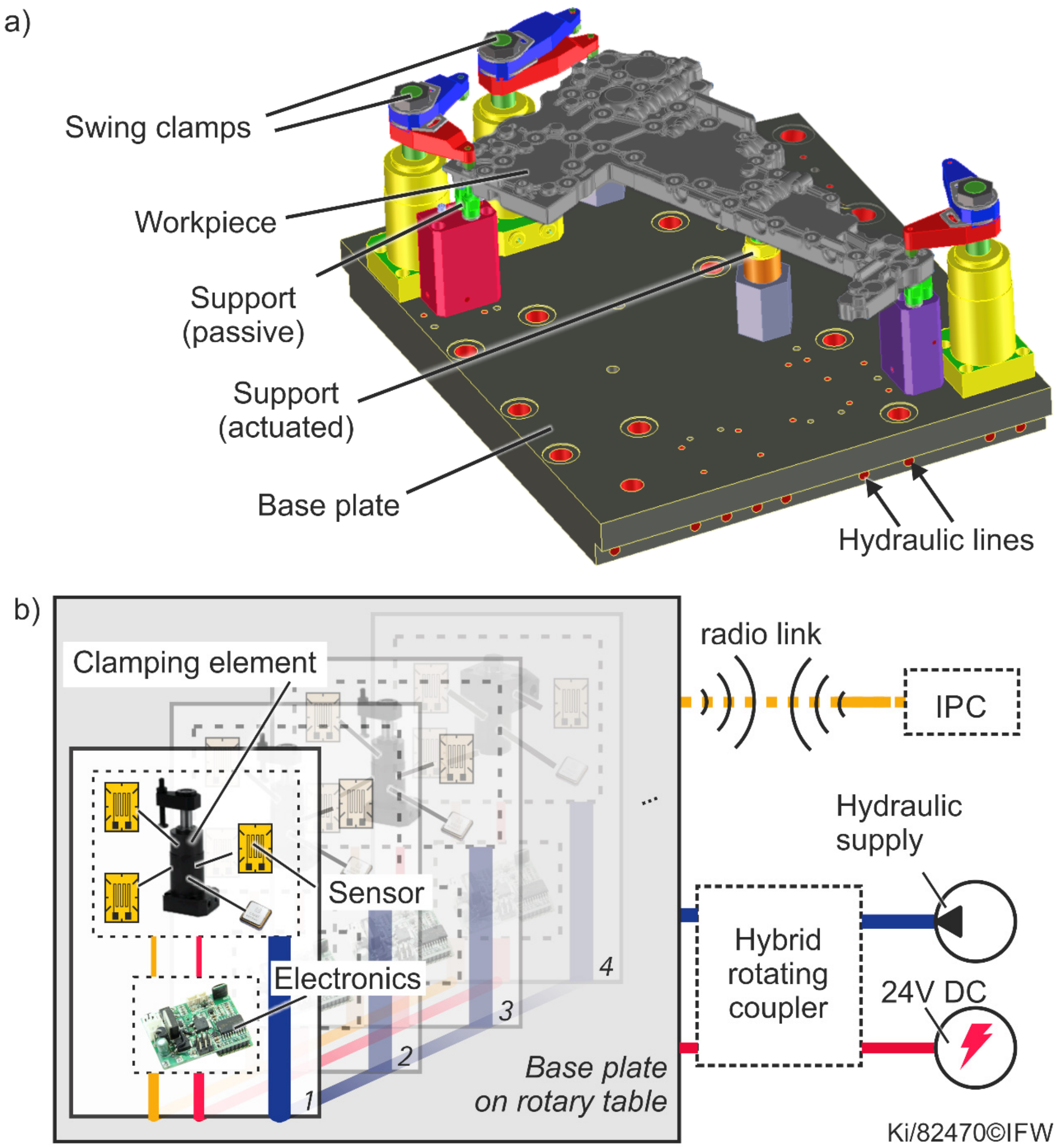

Figure 5: (a) Hydraulic clamping fixture; (b) overall concept of the 'feeling' clamping system

As presented in chapter 2.1, applying sensors in notches increases the sensitivity. In case of the presented clamping system, this approach results in an improved sensitivity of 71% while the stiffness is reduced by 1.3% [5]. However, to avoid stress concentration and interior fatigue of the clamping piston the integration of notches is not considered here.

As presented by Hoffmann [6], it is desirable to interconnect four strain gauges to form a Wheatstone Bridge aiming to maximize the measurement signal. The axial strain gauges are connected to full bridges. Hence, temperatures drifts can be compensated. The tangential strain gauges form a two quarter-bridge (figure 6 b). Thereby, the influence of bending forces on the pressure measurement is compensated [7]. The applied sensors and wiring are protected with a Roemheld protection tube against environmental influences. A detailed presentation of the energy and data transmission as well as the signal processing is given in [8].

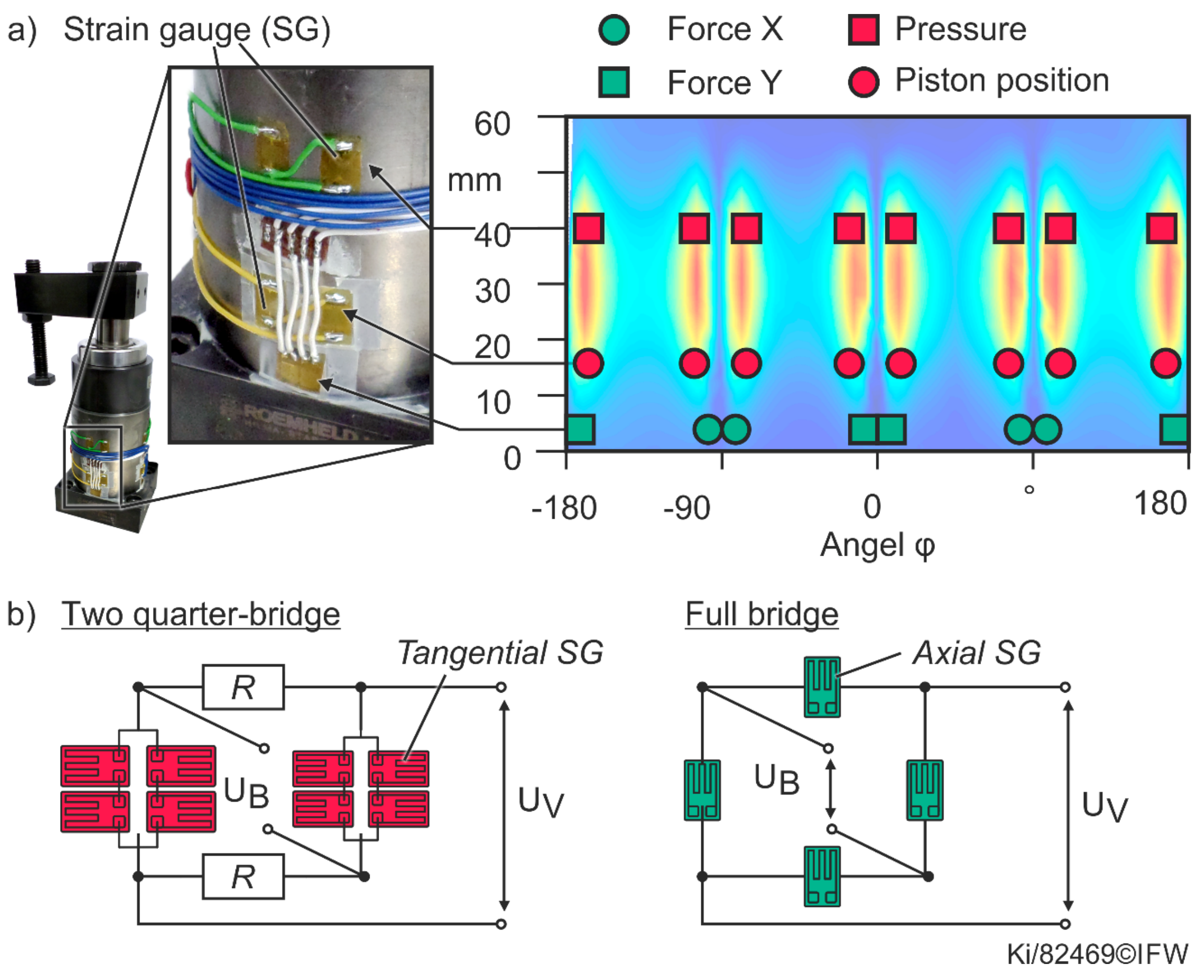

Figure 6: (a) Determined positions for strain gauges; (b) strain gauge interconnections

In order to determine the acting forces on the clamping element the measured strains need to be converted. The system of the swing clamp can be simplified into a bending beam. With the known lever arm *L* the force *F* can be calculated from the measured strain (figure 7 a). The diagrams in figure 7 b) present a comparison between a conventional force sensor and the integrated sensors. It becomes clear that the integrated strain gauge-based sensors are able to detect the applied forces in x- and y-direction. The sensory clamping systems allows to measure forces with a variation of less than ±4 N.

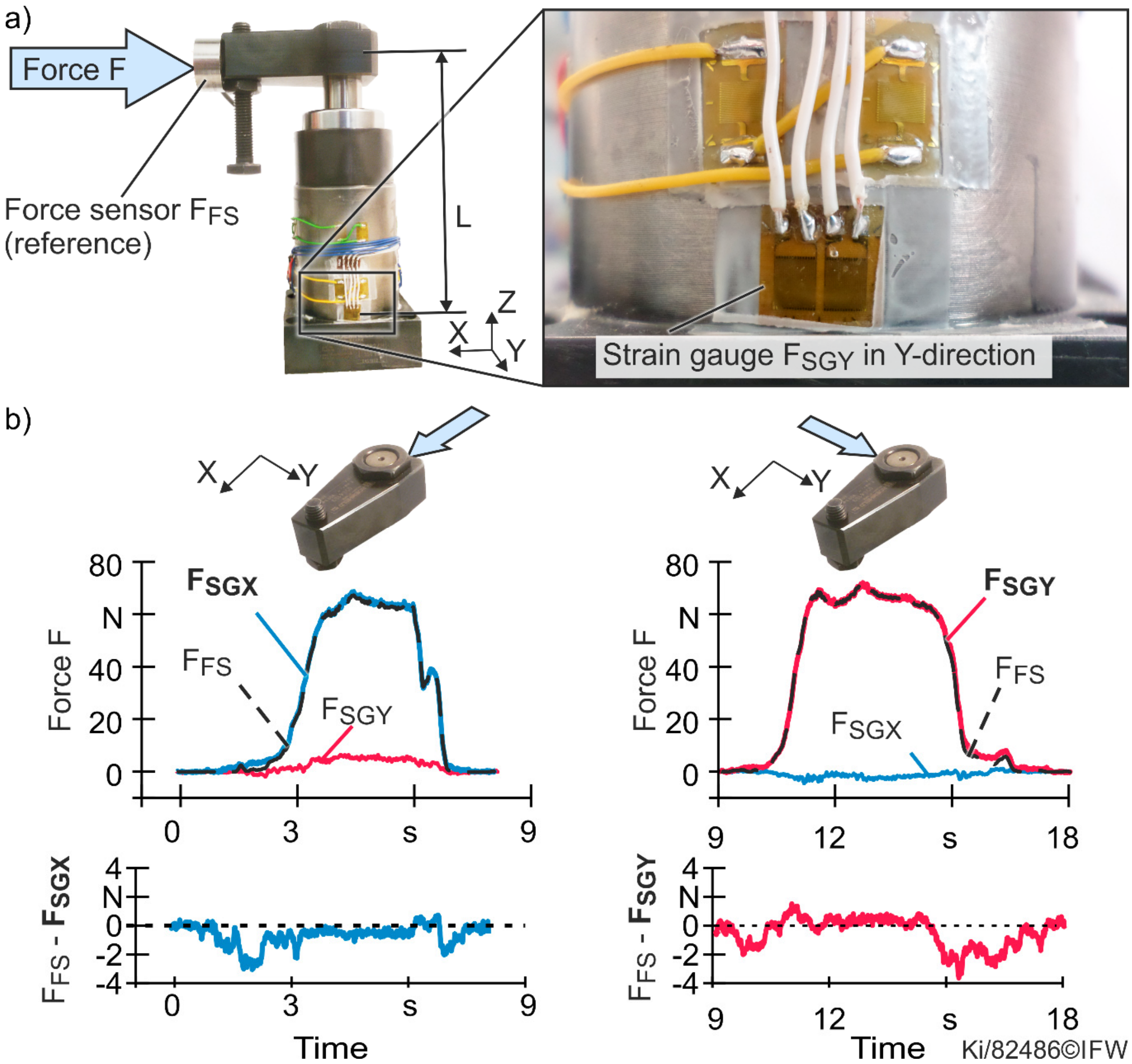

Figure 7: (a) Set-up for force application; (b) comparison between a conventional force sensor and the integrated sensors for force measurement

2.3 Process monitoring and control

The presented sensory machine components offer high potential for process monitoring and control. In the following, the use of the sensory clamping system for process monitoring and the sensory spindle slide for process control is demonstrated.

In the application scenario the sensory clamping system is used to monitor a milling process of AL7075. Process failures are provoked by two intentionally placed defects in the aluminum workpiece. Figure 8 summarizes the measured monitoring signals of 24 milling operations. The monitoring limits are taught using statistical limit curves [9]. With each additional data set the monitoring limits tighten more around the expected value. The confidence interval is set to 98%. The provoked process failures are identified reliably after only four learning processes. Consequently, it can be summarized that the sensory clamping system offers high potential for process monitoring.

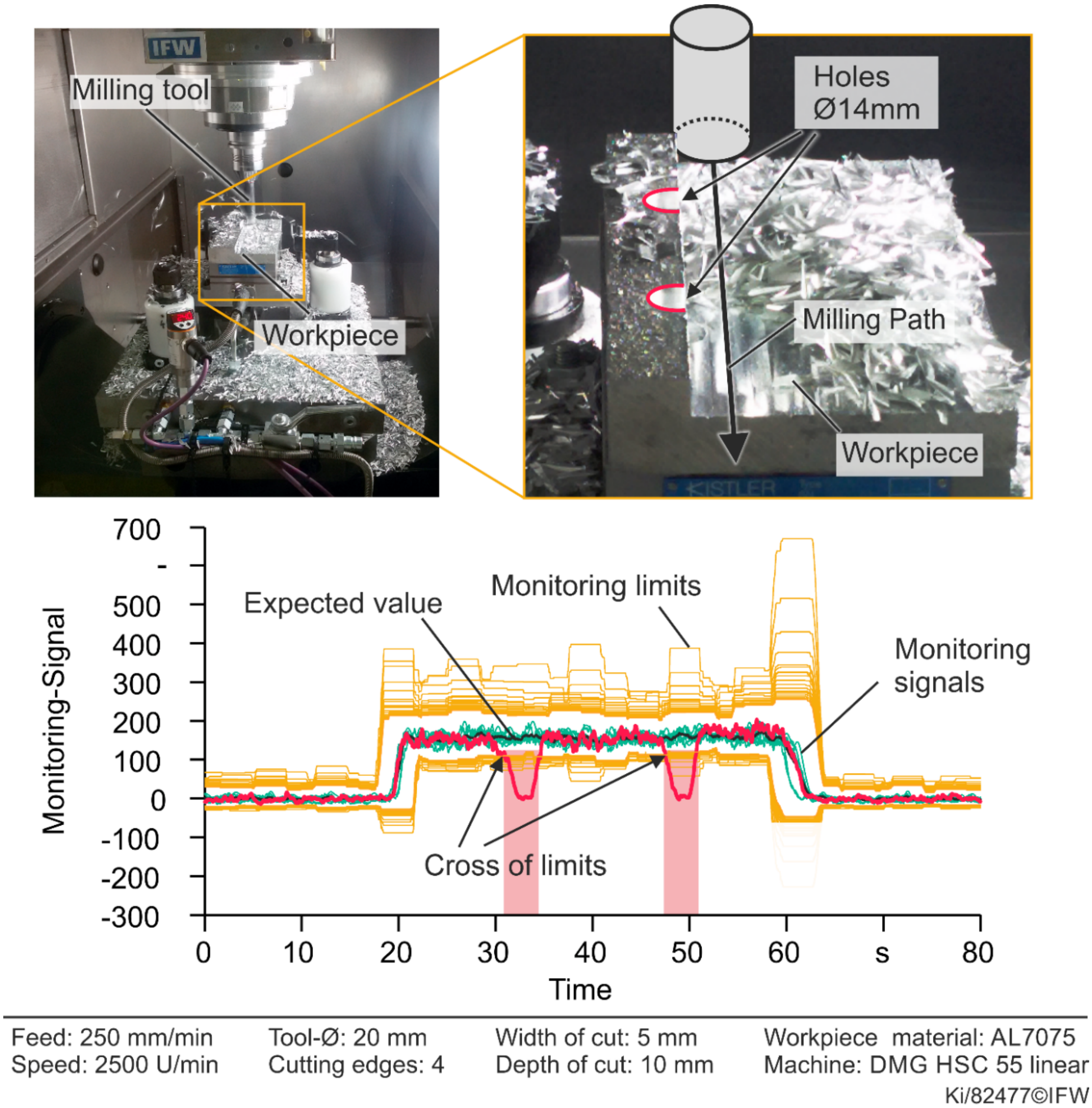

Figure 8: Process monitoring

The tool deflection represents one of the most quality-degrading effects in machining. Generally, it occurs due to process forces acting on the tool resulting in a deviation between the actual and the desired shape of the workpiece. For online monitoring and subsequent control of the deflection the process force signal and the stiffness need to be known. The process forces can be measured using the presented sensory components, e.g. the spindle slide. Based on the integrated force-sensing system the author's working group has developed a measuring cycle to identify the stiffness of the tool within the machine [1, 2].

In order to achieve the desired geometrical accuracy of the workpiece, the tool deflection has to be controlled while machining. For this purpose, the actual tool deflection d_{Act} is controlled to the reference deflection d_{Ref} by adjusting the axis feed of the machine. Consequently, as soon as disturbance occur, like changes in the depth of cut a_p or the cutting width a_e, the feed rate is adjusted. The established control loop for this task is depicted in figure 9.

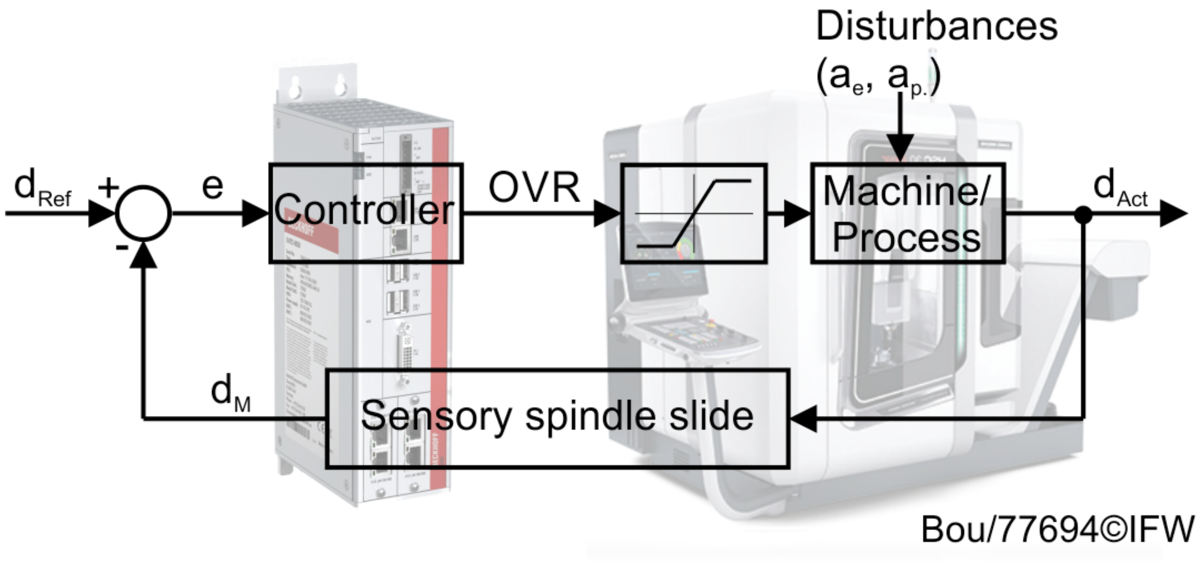

Figure 9: Control loop for tool deflection

The current deflection d_M is calculated using force data from the sensory spindle slide. A comparison of the current tool deflection d_M to the reference tool deflection d_{Ref} results in the residual error *e* that is handed over to the controller. The controller adjusts the feed rate via the feed override OVR. For safety reasons the override can only be varied between 0% and 120%. The entire control loop is implemented on an industrial PC and programmed with the programming environment TwinCAT3 from Beckhoff. The control loop can achieve a maximum sampling rate of 250 Hz.

In order to assess the developed control approach with respect to the geometrical accuracy and the cutting time, milling tests are performed with varying cutting widths and depths. In the first step of the test setup, a ramp is milled. In the second step, milling of a straight path is performed. Without the control loop, the increasing width of cut over the milling path results in an increased tool deflection and a higher geometrical deviation. With the implemented control loop, the feed rate is reduced over the milling path and the tool deviation is controlled to the reference value. Using the developed tool deflection control the geometrical error is reduced by 80%. However, due to the decreased feed rate, the process time increases about 60%. To avoid the higher process time further approaches, like controlling the width of cut instead of the feed rate, are currently investigated.

3 Process planning and control in crosslinked manufacturing systems

Developments in the field of information and communication technology have changed our world entirely over the recent years. This is also reflected in the way customers interact with companies and in an increasing number of individualized products. As a consequence, production processes and process chains have become more complex. In addition to these challenges, companies face cyclic demands, stochastic disturbances and an increased quality awareness [10]. In order to cope with these challenges, an integrated platform for adaptive process planning, control, monitoring and modelling, called Virtual Planner, has been developed within the CRC 653 (figure 10). Key elements of the Virtual Planner are presented in this chapter.

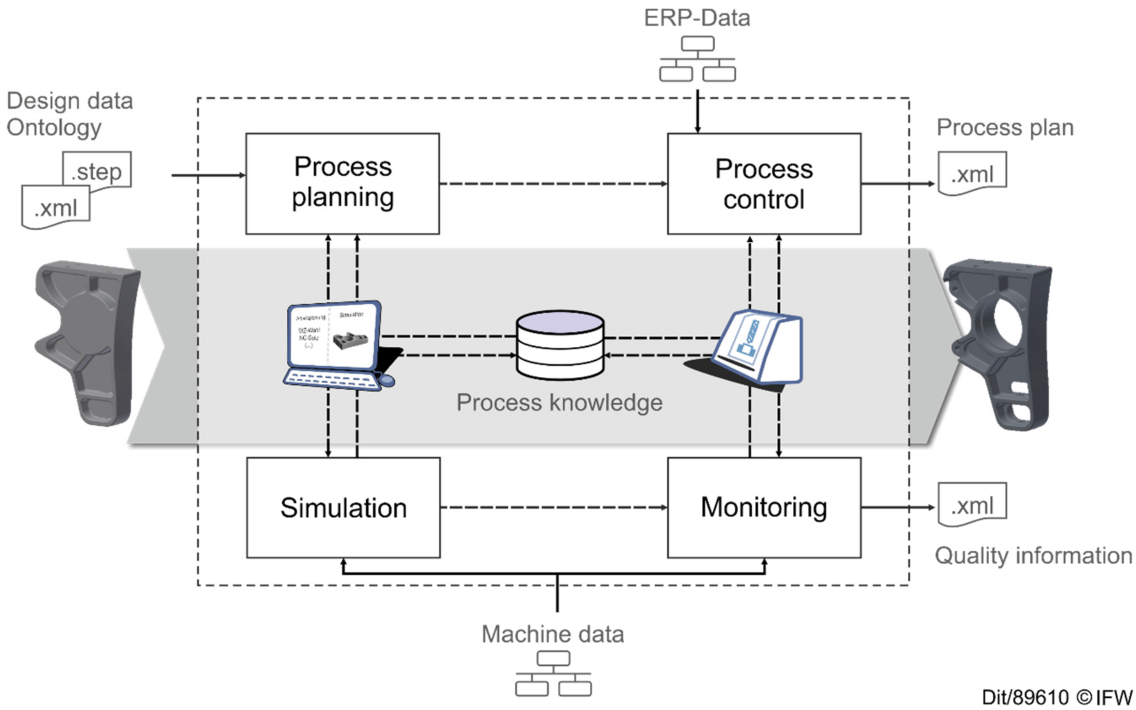

Figure 10: Elements of the Virtual Planner

3.1 Adaptive process planning and control

The *Virtual Planner* is based on an adaptive process planning and control approach, since conventional concepts of production process planning do not exhibit the necessary flexibility for the mentioned challenges. The conventional hierarchic process planning offers the lowest flexibility. Main parts are the rough planning and the detailed planning stage. Within the rough planning stage, the sequence of production operations is determined whereas the operations are assigned to the production resources during the detailed planning. No alternative operations are planned before the start of the production process, consequently the flexibility of this method is low. If an interruption in the process appears, the complete planning process will be executed again. As a result, there is little effort necessary at the beginning of the production process. However, the approach offers a low flexibility and requires high efforts in case of disturbances [11].

In contrast to the hierarchic approach, non-linear process planning considers alternative operations and process sequences via a process plan network. The allocation of the resources to the process step is executed shortly before the process is about to start. Consequently, the actual availability of resources and their current utilization is considered resulting. Though, changes in the production route require an additional step of detailed planning [11, 12].

Dynamic process planning offers an even higher flexibility. No planning activities are executed before the start of the production process. The resources are allocated directly before the process step starts with respect to the availability and utilization of the resources. For this reason, the ability to react is very high. However, the planning effort is also very high [11].

All three approaches display different preferences between planning effort and flexibility. The hierarchic approach which divides rough and detailed planning enables a low planning effort along with low flexibility. For standardized processes with mass goods, high availability and low utilization of production resources the hierarchic planning is well suited. Higher flexibility and higher efforts compared to the hierarchic planning are characteristics of the non-linear process planning. Moreover, the dynamic planning ensures maximum flexibility with high efforts. Combining the beneficial characteristics of these three approaches, namely, the distinction between rough and detailed planning, the use of alternative process plans and the use of dynamic and actual state information, results in the concept of adaptive process planning (Figure 11).

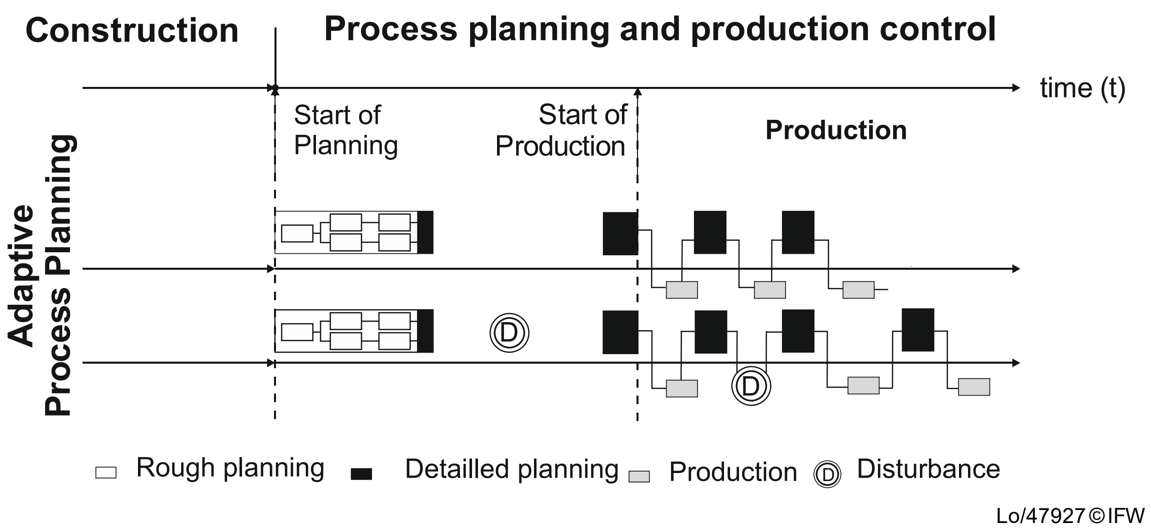

Figure 11: Novel approach for adaptive process planning [11]

Before start of production the rough planning including generating all possible process plans and production step sequences is executed. In order to reduce the effort in identifying alternative process plans Lorenzen proposed a method to derive the required process steps from design features, as defined in the ISO 14649-10 [11]. In combination with the ontology concept company-specific alternative process plans can be determined. Based on defined and prioritized criteria (e.g. processing time, cost, quality) all sequences of process steps are evaluated by the analytical hierarchy process (AHP). The main aspect to be highlighted is the continuous detailed planning parallel to manufacturing. As a consequence, the actual state of the production system regarding machine availability and actual process parameters is considered [13]. As soon as disturbance occur in the production the production plan is automatically reevaluated and the workpieces rerouted.

The processing of the workpieces requires in case of machining processes detailed information on process parameters. Aiming to reduce the manual planning effort Schmidt [10] developed a method for data-based parameter selection and evaluation. All process parameters (e.g. cutting speed, feed rate) and resulting targets (e.g. surface roughness) are saved directly in a structured data base in order to create and extend the planning basis for future evaluations and detailed process planning. A transformation from former process results to the actual planning activity is enabled by four steps (data selection, data transformation, data mining and data interpretation), see figure 12 [10, 14]. Subsequent simulation studies demonstrated the high potential of the adaptive planning approach with respect to lead time and production costs.

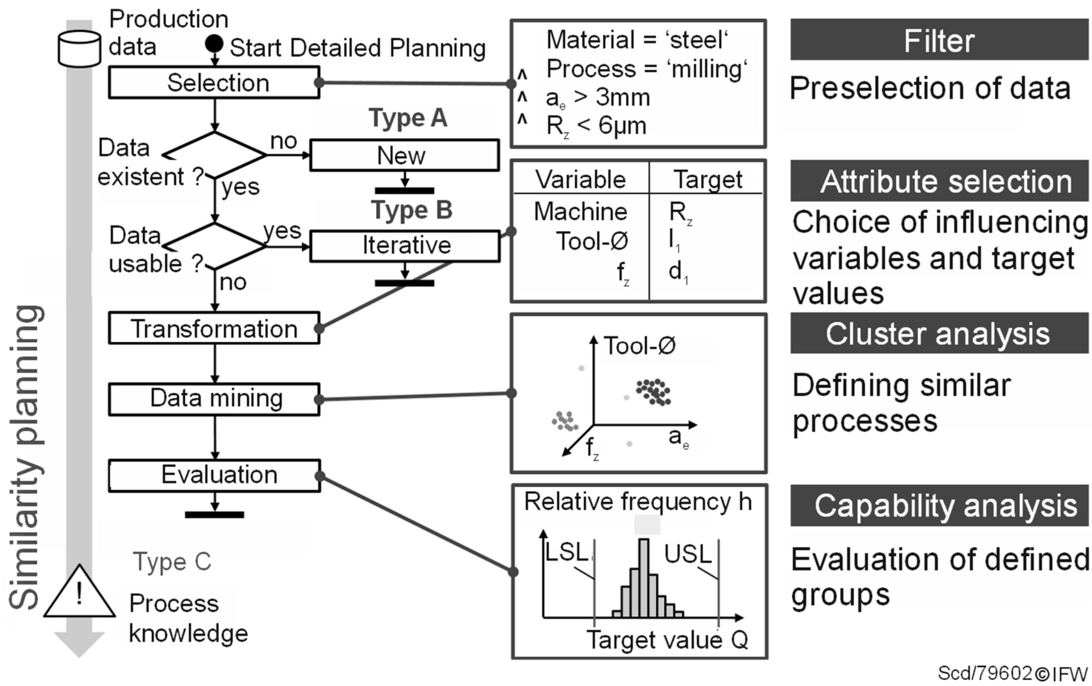

Figure 12: Procedure of data evaluation [10]

Within the *Virtual Planner* the process simulation has two tasks. First, it enables a virtual quality control of every process. Second, the simulation supports the detailed process planning. In the following, it is shown how a parallel process simulation can be used to enrich machine data and utilize the combined data for process planning.

For this purpose a machine center is connected to the *Virtual Planner*. The machine control provides drive information, which were originally used for internal control tasks. However, the information give also insight into the machining processes itself. The information of interest are the axis positions, feeds and currents as well as the spindle speed and the spindle load factor. Drive currents and the spindle load are monitored continuously and transmitted to the *Virtual Planner* at a frequency of 25 Hz. Process forces are transferred at a frequency of 100 Hz. The shape error of the workpiece, which is measured directly after machining with an integrated machine probe, is transferred by an NC-based communication routine. The system setup and the information flows are depicted in figure 13.

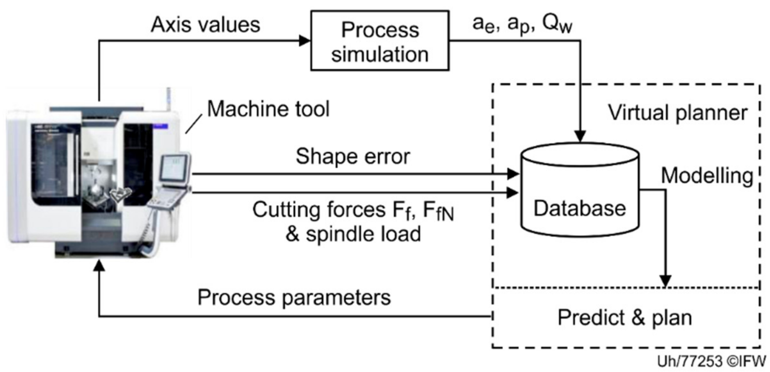

Figure 13: Information flow between machine tool, process simulation and Virtual Planner

The data types described so far include process forces and machine internal states. Though, the system is lacking geometrical information about the actual process in terms of the geometric process conditions that describe the interaction of the tool and the workpiece in the course of the process. This information is indispensable to build up correlations between sensor information and the cutting process. To gain geometrical process conditions, a simultaneous process simulation is developed, that mirrors the machine tool and the workpiece with the actual shape including the removed material (figure 14).

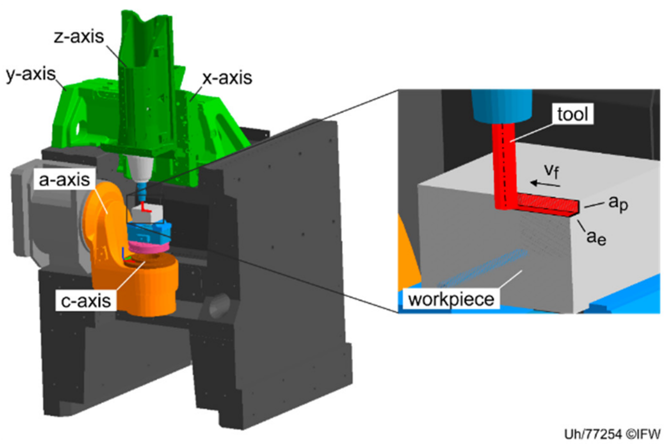

Figure 14: Machine and process simulation

For that purpose, the material removal simulation CutS, which is developed at the Institute of Production Engineering and Machine Tools, is extended such that the axis positions of the machine tool are directly assigned to the axis of the virtual machine model. By this means, the process is available digitally, which allows to perform calculations and to analyze the process. The simulation describes the tool and workpiece interaction in terms of width of cut, depth of cut and the material removal rate and also mirrors the actual feed rate.

Using a Support Vector Machine as machine learning approach correlations between the process parameters and the resulting shape error are obtained. Subsequently, the model is used to predict the shape error of the next workpiece and adapt the tool path locally. Thus, a lower shape deviation is obtained in machining of the next workpiece. Using this self-optimizing compensation strategy the shape error can be reduced by up to 70% (see figure 15).

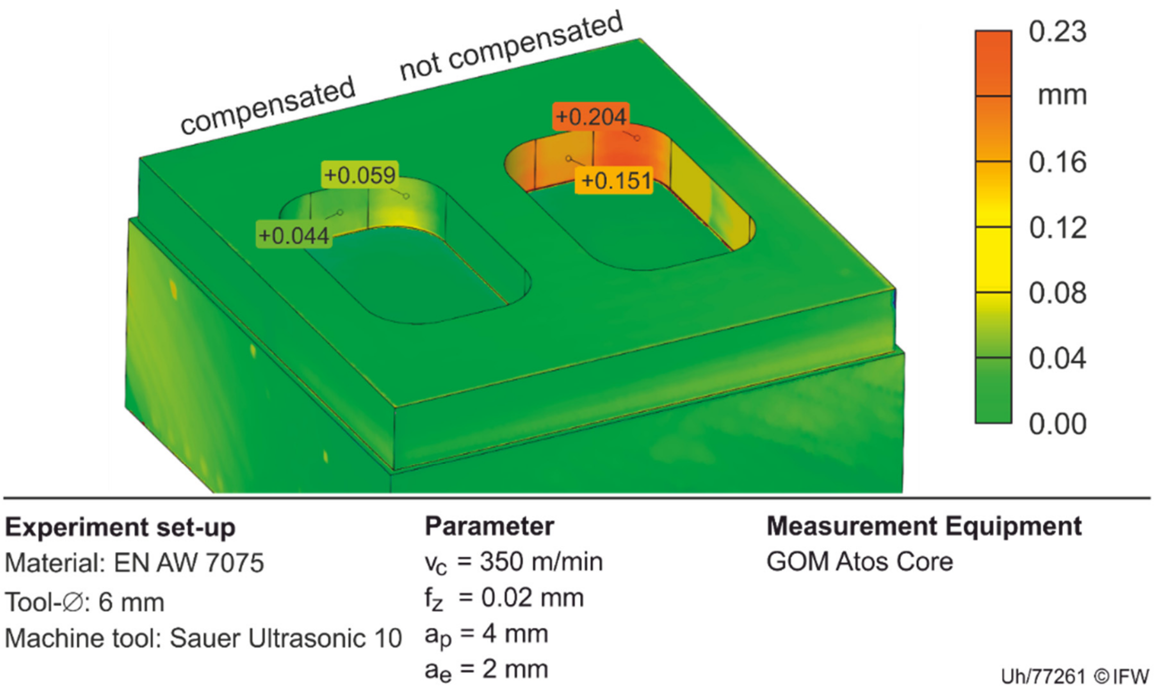

Figure 15: Results of the developed a self-optimizing compensation strategy

4 Summary

Increasing customer demands and the trend toward individualized products affect every aspect of manufacturing including metal cutting. The efficient planning and controlling of manufacturing processes require – with an increasing emphasis on economics – more information about the production stage. Especially when manufacturing lot size one, the planning of manufacturing processes is costly and requires lots of data due to the constantly changing product portfolio. High productivity and product quality are crucial in order to survive in international competition. A challenge for some companies is the increasing individualization of production. In the single-item and small-lot production, it leads to a very large variety of versions and to a high number of possible processes and process chains. Retracing current status information from the tool machines into the monitoring of the process, for example, enables a teachless observation process when manufacturing single components.

This article has highlighted developments in the area of machine tools and production planning. It has been shown that feeling components, like clamping systems or spindle slides, enable an embedded process monitoring and control. With respect to process planning, an integrated platform for planning, control, monitoring and simulation has been presented. The demonstrated approaches show that the digitization offers a solution for the metal cutting industry to cope with the ever rising demands.

5 Acknowledgements

The results presented in this paper obtained within the Collaborative Research Center 653 ‘‘Gentelligent Components in Their Lifecycle’’. The authors thanks the German Research Foundation (DFG) for its financial and organizational support.

6 References

[1] B. Denkena, K.M. Litwinski, D. Brouwer, H. Boujnah: Design and analysis of a prototypical sensory Z-slide for machine tools, Prod. Eng. Res. Dev., 7 (1) (2013), pp. 9–14

[2] B. Denkena, K.M. Litwinski, H. Boujnah: Detection of tool deflection in milling by a sensory axis slide for machine tools, Mechatronics 34 (2016), pp. 95–99

[3] L. Overmeyer, J.F. Duesing, O. Suttmann, U. Stute: Laser patterning of thin film sensors on 3-D surfaces, CIRP Ann. Manuf. Technol. 61 (2012), pp. 215–218

[4] T. Griesbach, M.C. Wurz, L. Rissing: Application of sacrificial layer for the modular micro sensor fabrication on a flexible polymer substrate, in: Sensor+Test Conference, 2011 pp. 355-360

[5] B. Denkena, D. Dahlmann, J. Kiesner, Sensor integration for a hydraulic clamping system, in: Proc. 2nd International Conference on System-Integrated Intelligence: Challenges for Product and Production Engineering, SysInt 2014, July 2nd–4th, Bremen, Germany, 2014, pp. 465–473

[6] K. Hoffmann: Applying the Wheatstone Bridge Circuit, HBM, 1986

[7] B. Denkena, J. Kiesner: Strain gauge based sensing hydraulic fixtures. Mechatronics 34 (2016), pp. 111–118

[8] B. Denkena, T. Mörke: Cyber-Physical and Gentelligent Systems in Manufacturing and Life Cycle, Academic Press, 2017, pp. 332–353

[9] J. W. Brinkhaus: Statistische Verfahren zur selbstlernenden Überwachung spanender Bearbeitungen in Werkzeugmaschinen, Dr.-Ing. Dissertation Leibniz Universität Hannover, 2009

[10] J. Schmidt, Integrierte Arbeitsplanung und Fertigungssteuerung auf Basis von Zustandsinformationen, Dr.-Ing. Dissertation, Leibniz Universität Hannover, 2015

[11] B. Denkena, J. Schmidt, M. Krüger, A quality-oriented approach to product-driven production, in: B. Denkena, J. Gausemeier, B. Scholz-Reiter (Eds.), System-Intergrated Intelligence: New Challenges for Product and Production Engineering. Proceedings of the 1st Joint International Symposium on System-Integrated Intelligence 2012 (SYSINT2012), Garbsen, 27th–29th June 2012, pp. 6–8

[12] S. Kim, J. Woo, S. Park, B. Jung, H. Cho, Integrated development of nonlinear process planning and simulation-based shop floor control, in: E. Yücesan, C.-H. Chen, J.L. Snowden, J.M. Charnes (Eds.), Proceedings of the Winter Simulation Conference, San Diego, 2002, pp: 1465–1468

[13] L.-E. Lorenzen, Entwicklung einer Methode zur gentelligenten Arbeitsplanung, Dr.-Ing. Dissertation, Leibniz Universität Hannover, 2011

[14] T.L. Saaty, L.G. Vargas, Models, Methods, Concepts & Applications of the Analytical Hierarchy Process, vol. 2. International Series in Operations Research & Management Science, vol. 175, Springer, New York, 2012


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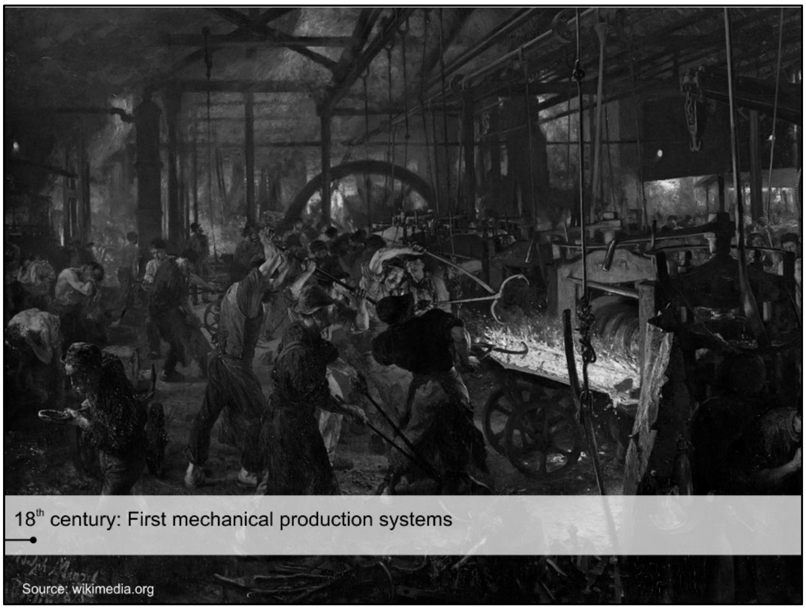
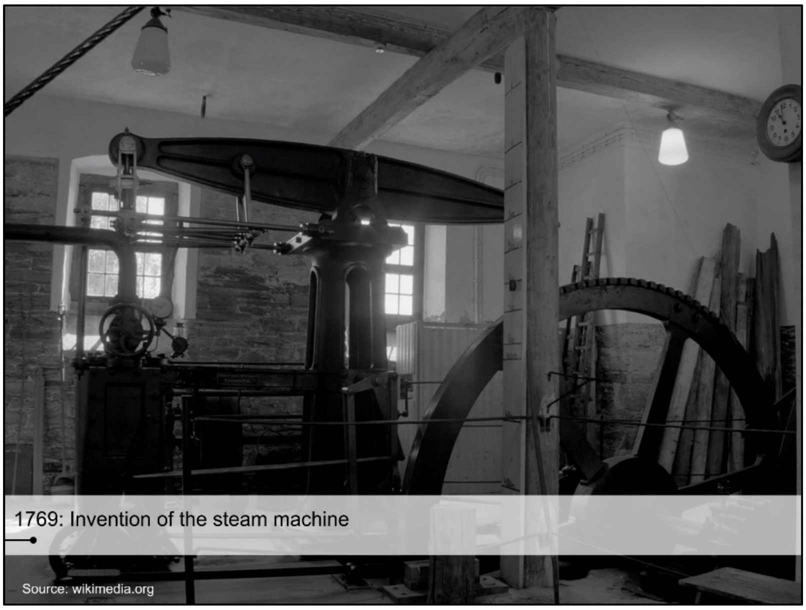

18th century: First mechanical production systems
Source: wikimedia.org


1769: Invention of the steam machine
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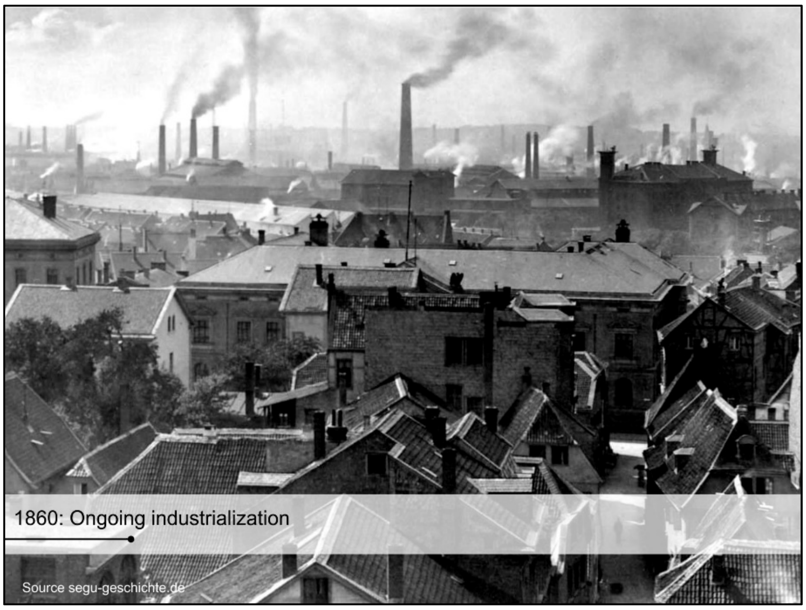
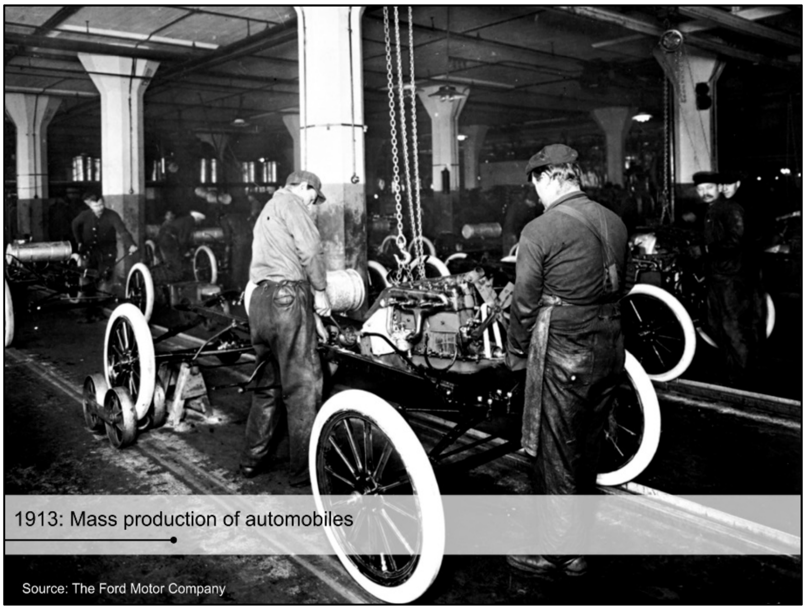
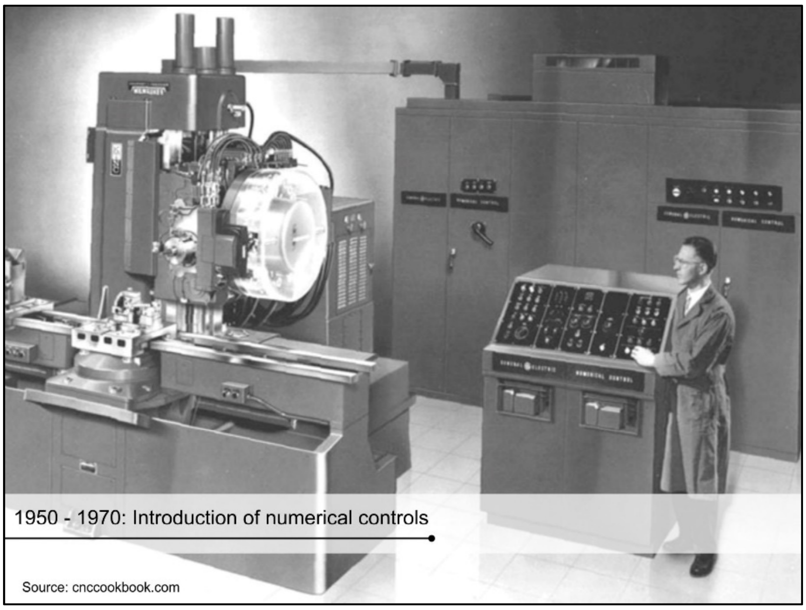
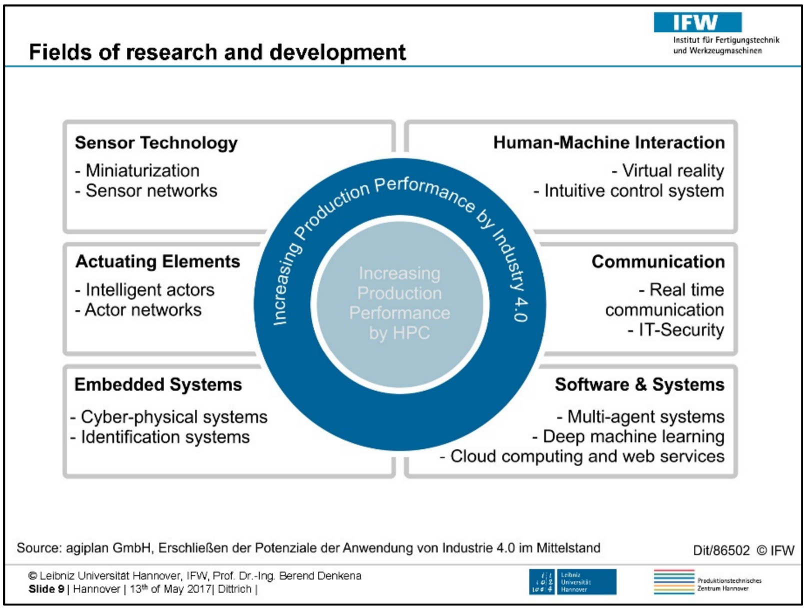

1860: Ongoing industrialization
Source segu-geschichte.de


1866: First electric motors
Source: siemens.de


1913: Mass production of automobiles
Source: The Ford Motor Company


1950 - 1970: Introduction of numerical controls
Source: cnccookbook.com


Today: Next revolution?
Source: Huffington Post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Communication
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- IT-Security
Embedded Systems
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- Identification systems
Software & Systems
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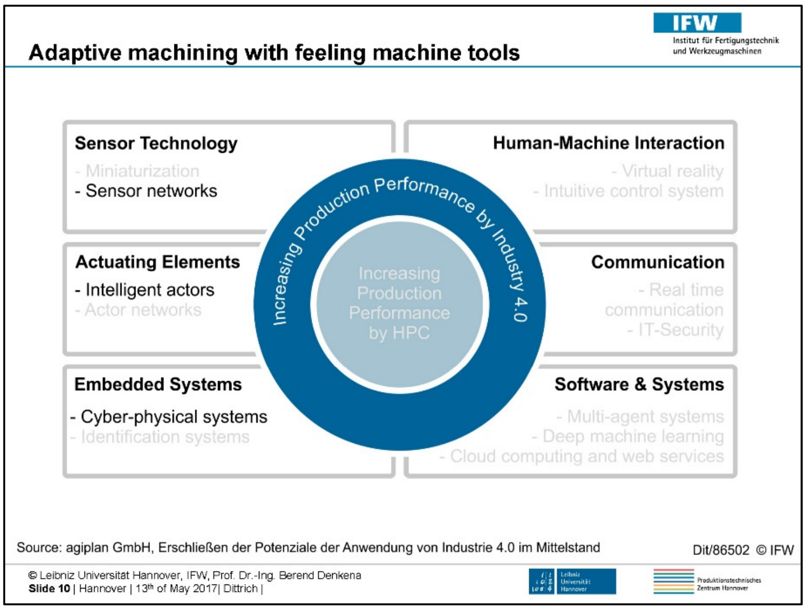
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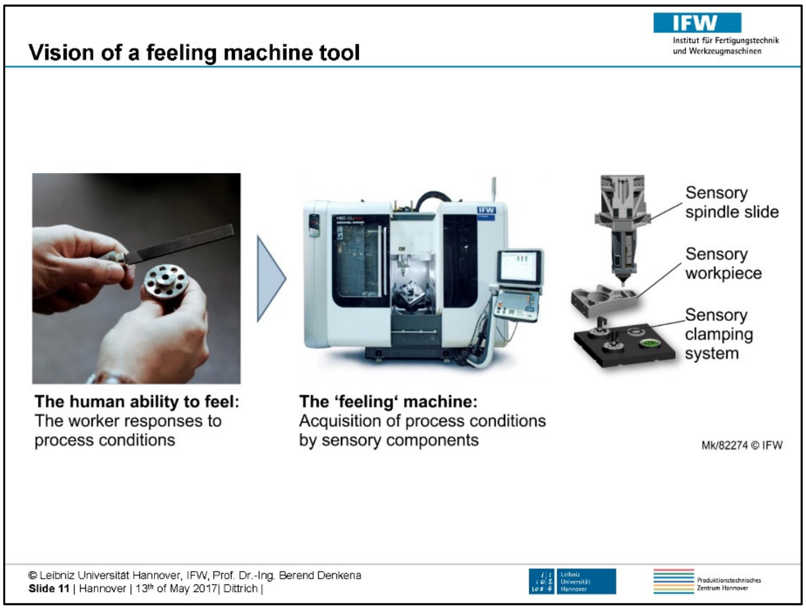
Vision of a feeling machine tool
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Sensory spindle slide
Sensory workpiece
Sensory clamping system
The human ability to feel:
The worker responses to process conditions
The 'feeling' machine:
Acquisition of process conditions by sensory components
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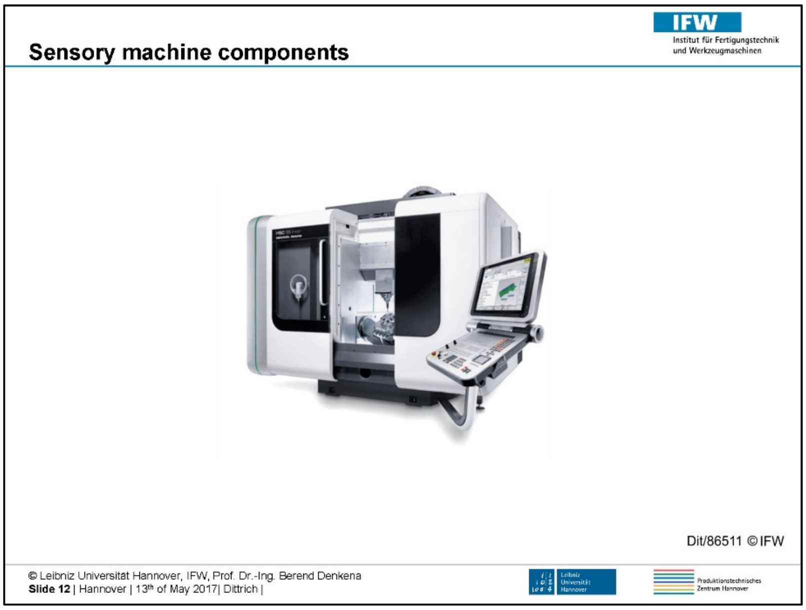
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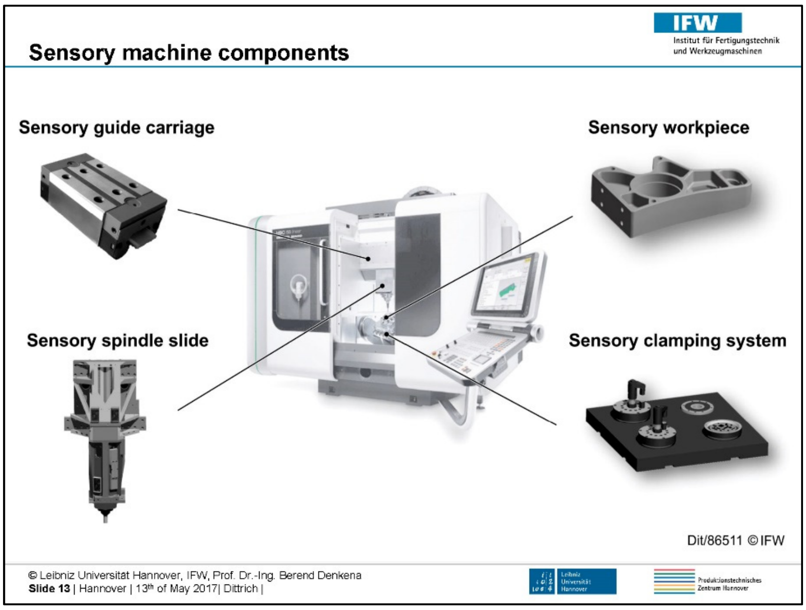
Sensory machine components
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Sensory guide carriage
Sensory workpiece
Sensory spindle slide
Sensory clamping system
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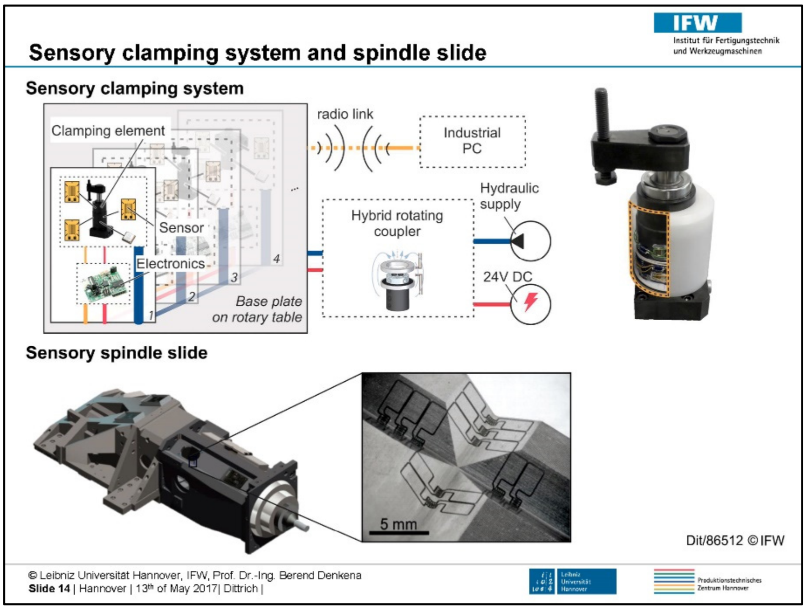
Sensory clamping system and spindle slide
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Sensory clamping system
Clamping element
radio link
Industrial PC
Hydraulic supply
Hybrid rotating coupler
Sensor
Electronics
24V DC
Base plate on rotary table
Sensory spindle slide
5 mm
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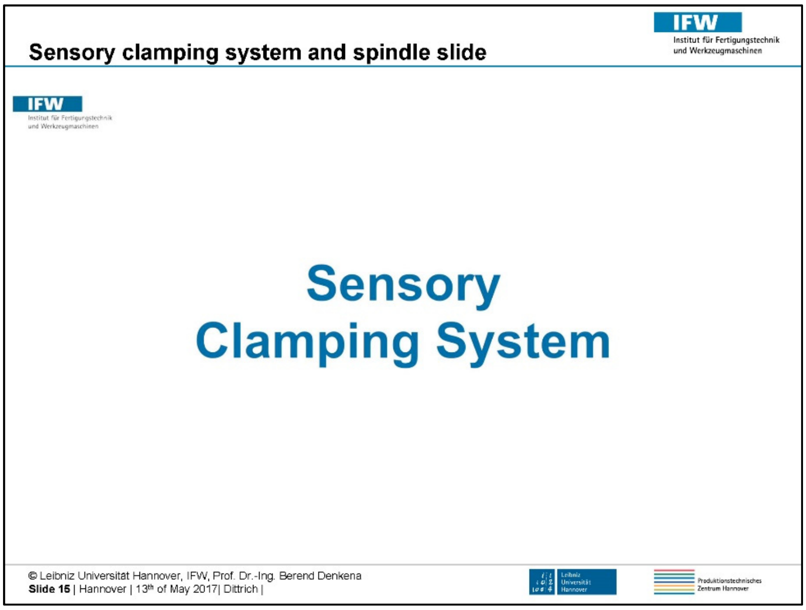
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Adaptive control of tool deflection

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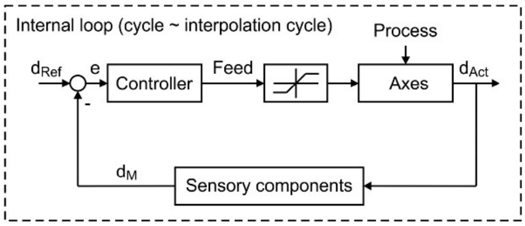

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Online Compensation of Tool Deflection

Adaptive control of tool deflection

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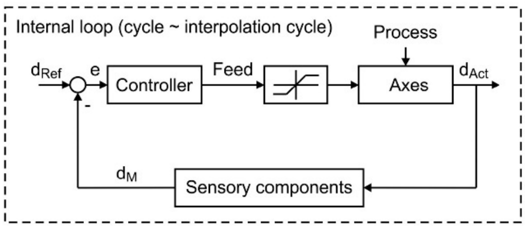

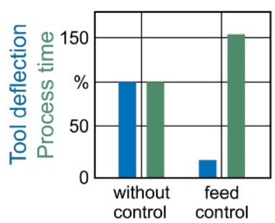

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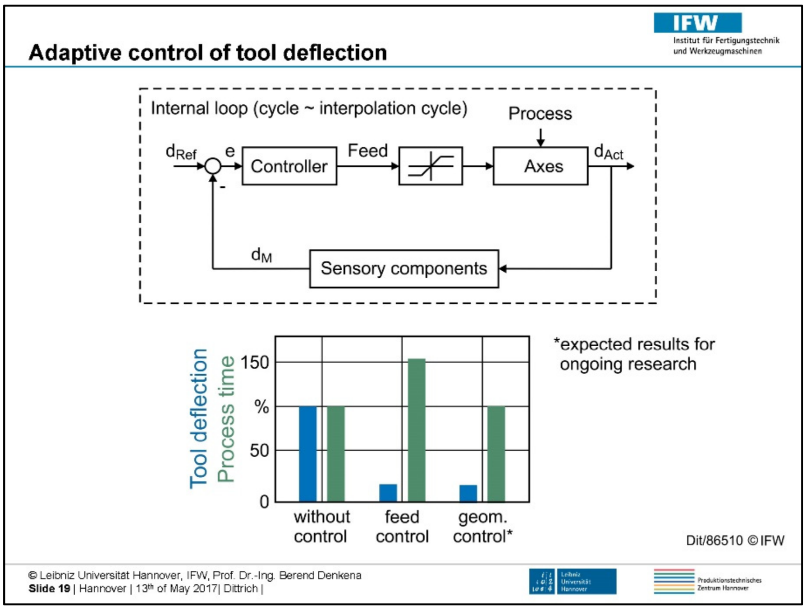
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Internal loop (cycle ~ interpolation cycle)
Process
dRef
e
Controller
Feed
Axes
dAct
-
dM
Sensory components
Tool deflection
Process time
150
%
50
0
without control
feed control
geom. control*
*expected results for ongoing research
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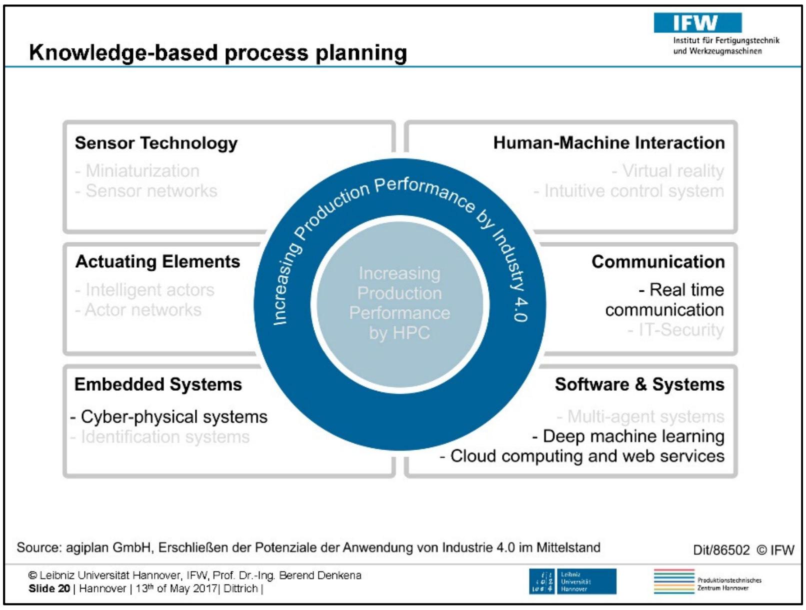
Knowledge-based process planning
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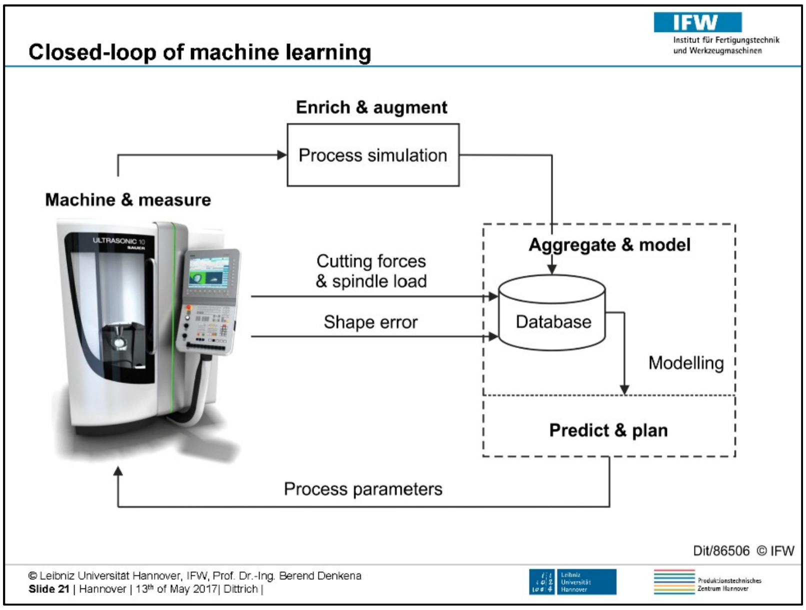
Closed-loop of machine learning
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Enrich & augment
Process simulation
Machine & measure
Aggregate & model
Cutting forces & spindle load
Shape error
Database
Modelling
Predict & plan
Process parameters
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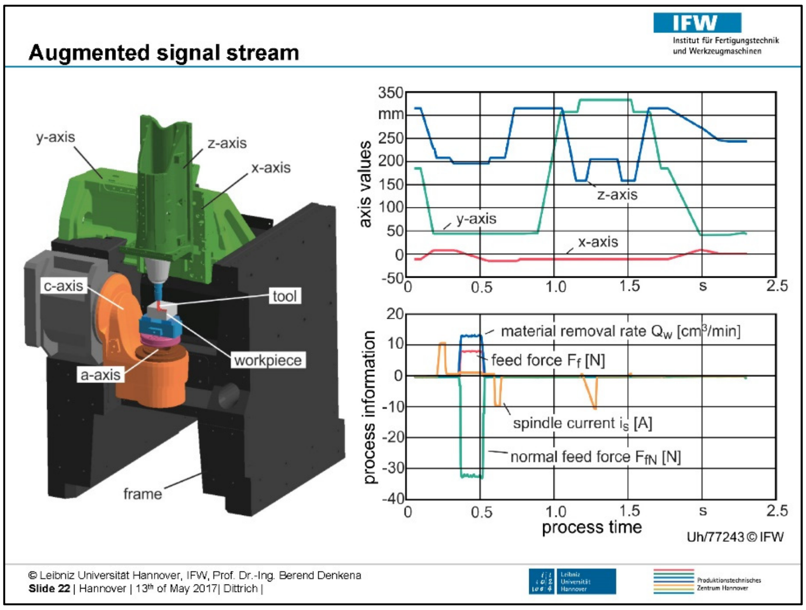
Augmented signal stream
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y-axis
z-axis
x-axis
c-axis
tool
workpiece
a-axis
frame
axis values
mm
process information
material removal rate Qw [cm³/min]
feed force Ff [N]
spindle current is [A]
normal feed force FfN [N]
process time
s
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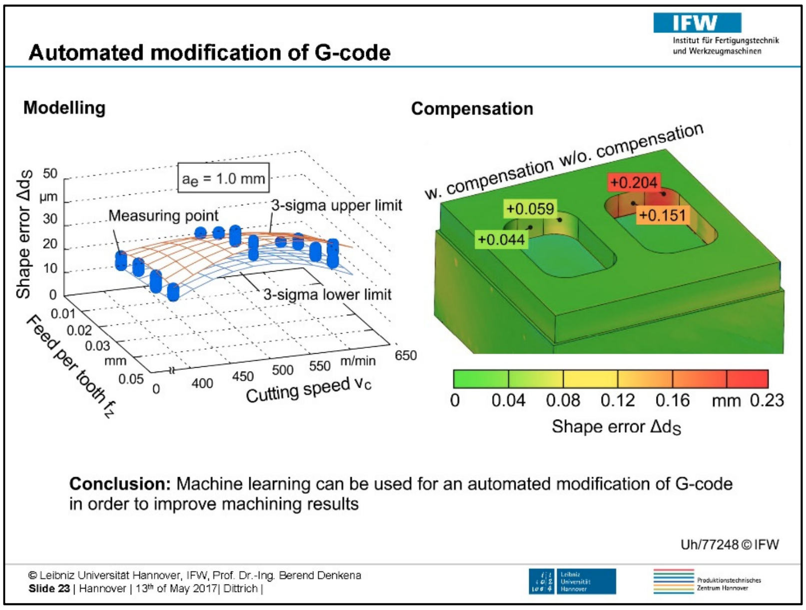
Automated modification of G-code
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Modelling
Compensation
ae = 1.0 mm
Measuring point
3-sigma upper limit
3-sigma lower limit
Shape error Δds
µm
Feed per tooth fz
mm
Cutting speed vc
m/min
w. compensation
w/o. compensation
+0.204
+0.059
+0.151
+0.044
0 0.04 0.08 0.12 0.16 mm 0.23
Shape error Δds
Conclusion: Machine learning can be used for an automated modification of G-code in order to improve machining results
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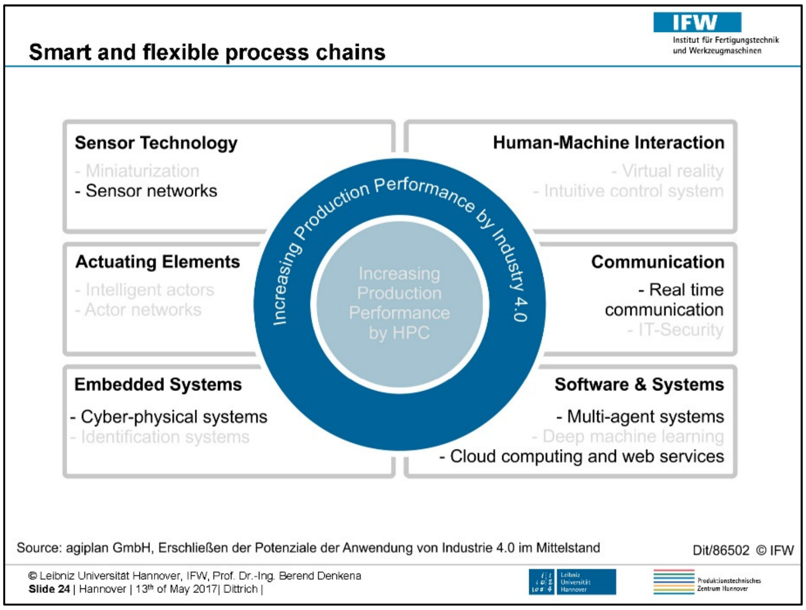
Smart and flexible process chains
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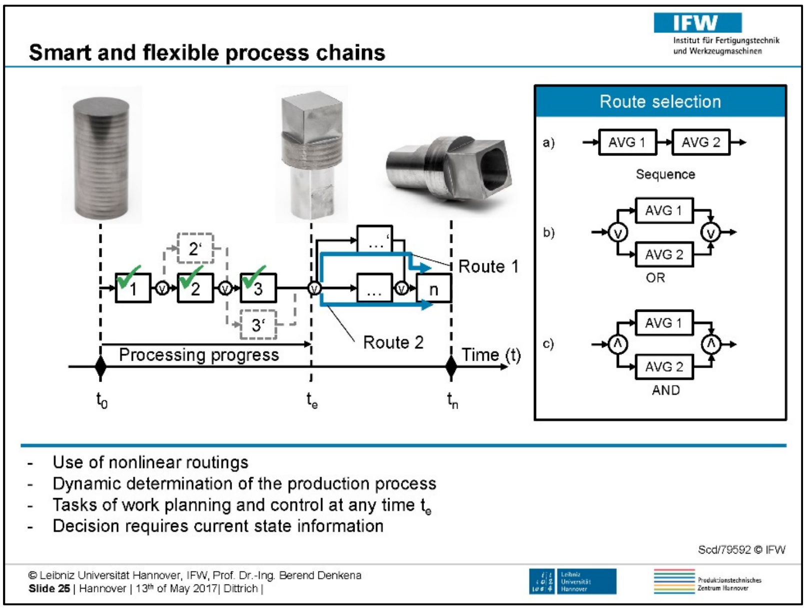
Smart and flexible process chains
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Route selection
a)
AVG 1
AVG 2
Sequence
b)
AVG 1
AVG 2
OR
c)
AVG 1
AVG 2
AND
Route 1
Route 2
Processing progress
Time (t)
- Use of nonlinear routings
- Dynamic determination of the production process
- Tasks of work planning and control at any time t_e
- Decision requires current state information
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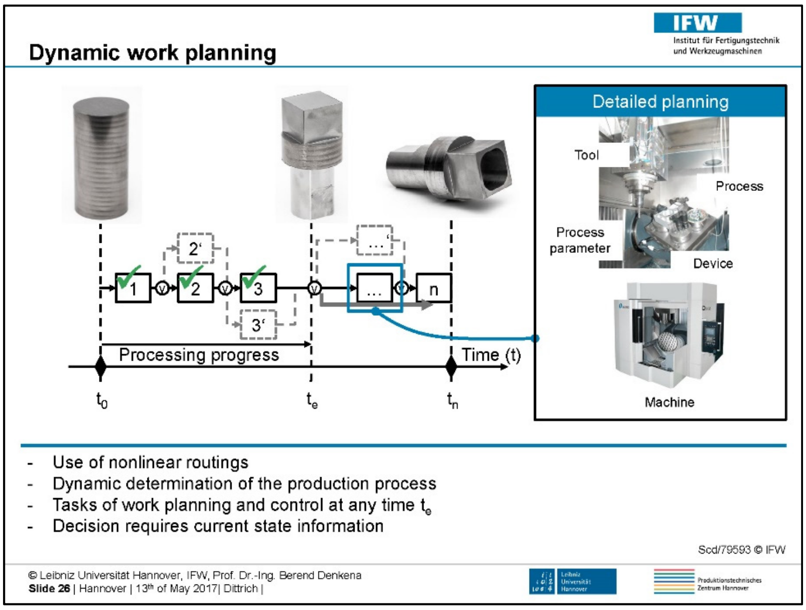
Dynamic work planning
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Detailed planning
Tool
Process
Process parameter
Device
Machine
Processing progress
Time (t)
- Use of nonlinear routings
- Dynamic determination of the production process
- Tasks of work planning and control at any time t_e
- Decision requires current state information
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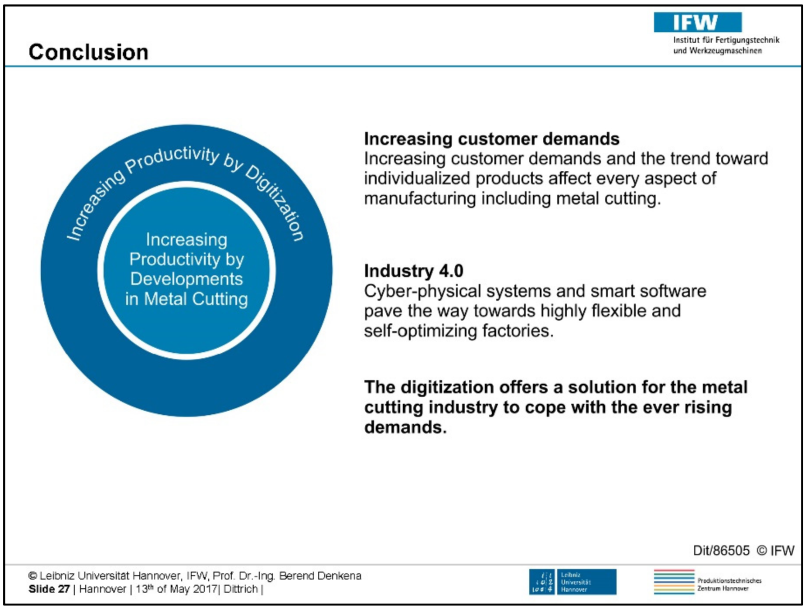
Conclusion
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Increasing Productivity by Digitization
Increasing Productivity by Developments in Metal Cutting
Increasing customer demands
Increasing customer demands and the trend toward individualized products affect every aspect of manufacturing including metal cutting.
Industry 4.0
Cyber-physical systems and smart software pave the way towards highly flexible and self-optimizing factories.
The digitization offers a solution for the metal cutting industry to cope with the ever rising demands.
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Outlook: Gentelligent production & life cycle

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Produktionstechnisches Zentrum Hannover

M.Sc. Jessica Klapper

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Changes in company organization and conceivable future production scenarios under the influence of Industry 4.0

Abstract

The reason for change in production work is change in the company environment. It is usually the increasing digitalization. However, the production work of the future is not only influenced by technological developments. The initial state of the company, in particular the experiences and attitudes of the employees as well as the strategy and the organization so far, exert a major impact. The central aim of this paper is to present the current organizational forms and the possible developments of the production work. What requirements do they face in the future? And how does production work under the influence of Industry 4.0? Based on the presented organizational forms, future development scenarios for the employees are described. These have been made using different approaches in the literature. Subsequently, these approaches to future scenarios were further developed. The plausibility of these future images was validated with experts from German companies. In the following chapter the possible transformation processes are briefly described. As a result, it is clear that a variety of work scenarios involving a different degree of automation and human work are possible from the actual state of the organization. Which of these scenarios will occur for a particular company can not be answered on a general basis. However this paper can be used as a decision-making aid, on the one hand to question the own organization, on the other hand to set the course for the development to the production system 4.0.

Keywords

Organization 4.0; Industry 4.0; Development Scenarios; Future Scenarios; Digitalization; Automation; Employees in Production.

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1 Introduction

Management theory postulates the end of functional division of labor and hierarchical leadership for decades. The flexibility of the company is limited and knowledge workers are demotivated. It is visible that many innovative concepts have emerged in the company, but that many companies still assert themselves in the market with traditional organization and leadership. The discussion about industry 4.0, globalization and new business models moves organization and leadership more into focus.

How can companies decide whether an adaptation of their organizational and management concepts is indispensable? And how can they justify the need for a new strategic course of action? This article outlines the requirements that companies will face in the future. Afterwards, two extreme manifestations of organization and leadership, called "traditional" and "innovative", and conceivable future scenarios in the production are sketched out. Finally, possible transformation processes are to be presented based on these future scenarios and the organizational forms.

2 Future challenges for enterprises

The organization and leadership have been characterized by rationalization, humanization and knowledge (Wüstner 2006). Rationalization originally aimed at high productivity in mass production. Over time, it became clear that employees' motivation and thus the company's performance could be increased by fulfilling human needs. The goal of productivity was complemented by humanization efforts. An increase in knowledge, i.e. problem-solving activities, which requires skills and experience, promoted decentralization, autonomy and self-organization. Current developments will have a strong impact on companies (BUNDESMINISTERIUM FÜR ARBEIT UND SOZIALES 2016). Digitalization is a trend, but it is only one of the most relevant changes. For companies, there is also the need to survive in global competition, to cope with demographic change and the social trends of individualization and health.

The following three success-relevant requirements result from these developments:

- Increase agility

Speed, flexibility and adaptability are gaining in importance. Future success factors in the market are fast innovations in products, services and processes as well as customer-specific services with the shortest delivery time. The number of variants increases, the quantity per variant decreases. Disruptive competition strategies and business models can lead to an unexpected need for short-term and far-reaching adjustments.

- Create “good work”

In order for an aging workforce to remain viable and motivated until retirement, humanization must be consistently pursued. Workable means to be able to keep up with performance, innovation and change. This requires physical and mental health as well as lifelong learning. Attractive working conditions are gaining in importance. If demographic change or digitization results in a deficit of skilled workers, the negotiation power is even shifted. There will be pressure on an individualization of working conditions for several reasons. The employees expect job satisfaction and meaningful work. Employee structures are becoming more diverse, such as age, gender and cultures. An increase in disease-related employment restrictions due to a higher average age of the employees has a strengthening effect.

- Deal with complexity

Because complexity is growing rapidly, companies need to learn to deal with uncertainty and ambiguity. Complex tasks are not managed by forecasting and planning, whether because of unclear contexts, or because the necessary effort is not provided. Unexpected situational management and making decisions in unclear situations becomes the norm and not the exception (in the past, this situation is referred as “VUCA” for Volatility, Uncertainty, Complexity and Ambiguity).

Traditional concepts

How can the organization and leadership manage the future requirements? First, the extreme "traditional" organization and leadership is considered. This aims at stability and high productivity in repeat processes.

- Functional work placement is aimed at specialization in execution;
- Centralization implements the hierarchical principle by separating management and execution;
- Mental effort and manual work are separated: Experts plan, workers perform under external control;
- Tasks and workstations are determined (objectively) independent of the individual. For this purpose they are anticipated by prognosis, documented by standardization and enforced as a binding specification;
- In the extreme, a taylorist image of man is used, according to which the worker is not capable and not willing to plan his work and perform rationally. According to the X-theory of McGregor, reluctant people can only be moved to efficient work execution by means of guidelines, control and pressure (KIRCHLER ET AL., 2004).

A traditional organization and leadership has proven itself over decades. Against the backdrop of changing markets and increasing demands on the workforce, the focus is on serious weaknesses. The potential to meet future requirements is limited.

Agility is difficult to increase. Because every product and process variant needs to be planned and documented, flexibility, adaptation and innovation generate bureaucratic effort. The achievable speed is limited by work sharing and interfaces, typical are full mail inlets or heaps of material in front of machines. Information loss is unavoidable, because, on the one hand, central planning does not overshadow the concrete situation on the ground, and on the other hand, it is impossible to document all the planning results.

The traditional concepts offer no solutions for the requirements for humanization and good work. It is assumed that people can be used as easily as any other tool. Anyone who wants to realize intrinsically motivating work must violate traditional premises.

Complexity creates gaps, because uncertainty and ambiguity cannot be managed systematically. Typical reaction is a multiplication of analysis and planning. Anyone who considers guidelines as a prerequisite for efficient execution cannot do without plans. However, complex tasks cannot be planned. The result would be false plans, which would be dominated by coincidence and which would seriously interfere with everyday business by inexplicable mistakes. If, however, neither planning, nor non-planning can work, then only “the principle of hope” remains. The traditional organization and leadership do not provide a foundation for knowledge work either. It is designed for the optimization of predictable repeat processes. But repetitive work in offices and production is increasingly being replaced by automation. It remains unclear how skilled workers, developers, experts or executives should be organized and managed and how intrinsic motivation should be strengthened.

"Innovative" concepts

The extreme of the "innovative" organization and leadership is tailored to future requirements. Once again, a manageable number of premises for characterization suffices.

- The objectives of an innovative organization and leadership are flexibility, adaptability and innovation. The key features such as customer-specific variants and speed are the basis for the market success;
- The division of labor into processes and products (mini-factories, production sites or order centers) creates transparency and places responsibility into the hands of an interdisciplinary team;
- Autonomy (extensive independence) and decentralization (relocation of decision-making and freedom of action to the place of execution) give employees the right and the duty to cope with uncertain and ambiguous conditions through creativity and intuition;

- The management of uncertainty and ambiguity is made an organizational principle. The key to this is motivated, qualified employees, who decide on the spot in a specific situation and act quickly. Self-organization, self-control and self-responsibility use the individual abilities, experiences and interests of the people (subjectivation). They can be methodically supported (e.g. by sociocracy);
- In order to quickly and competently perceive opportunities, employees and external crowd workers can network dynamically (virtual organization or swarm organization). Agile and learning methods (such as scrum or design thinking) are used for tasks with moving targets and incomplete information;
- The management becomes a coach and enabler for the employees. The human image is based on trust, in the sense of the theory Y of McGregor (KIRCHLER et al., 2004), that the employee is naturally motivated, capable and motivated from the inside. The task of organization and leadership is to create suitable performance conditions and benefits for all. Then people will take responsibility and develop their own initiatives. These suitable performance conditions take into account the individual and changing needs of the employees. Physical well-being through social contacts to self-realization are described by the human image of the Complex Man (KIRCHLER et al., 2004).

In the meantime, successful cases of innovative organization and leadership are known from many sectors (cf., for example, (LALOUX, 2015)). It seems to be proven that innovative organization and leadership helps companies to meet the future requirements, to become agile, to create good work and to cope with complexity. There are, of course, also weaknesses, which result in particular from of dissolution of work boundaries (BUNDESMINISTERIUM FÜR ARBEIT UND SOZIALES, 2016). Work from home, trust or permanent accessibility can break the boundaries between work and private life. Intrinsic motivation can lead to self-exploitation. It is necessary to create new protective mechanisms.

Mixed Concepts

Traditional organization and leadership were developed during the first industrial revolution. Science and companies are constantly looking for concepts to meet changing requirements. In most cases traditional approaches are supplemented by innovative methods (SPATH 2008). The above premises make it clear that traditional and innovative concepts can not be combined into a coherent overall concept. The imposed methods often do not produce the hoped-for effect, and it requires considerable support to be actively used. Only 40% of employees in Germany are clearly committed to their work and their company (HAUSER et al. 2008). In order to function well, organization and leadership need a coherent overall concept, which carefully co-ordinates staff, organization and technology.

3 Development scenarios

The demands on companies outlined above have already created the pressure to adapt work in the future. Companies are reacting to this pressure with a variety of strategies and measures. It can hardly be predicted whether more workers will be available than needed, or a labor force deficit will arise. If sufficient workforce is available, personnel policy can be carried forward in the company as before. If a labor shortage arises, this results in a struggle for workers, which shifts the bargaining power. Companies then have to create attractive work.

3.1 Alternative development directions

How will work in mechanical engineering develop? According to the literature, digitization can point in two opposing directions: the technology-centric automation concept and the assistance concept. In terms of work and qualification requirements, the experts also see two possible directions of development: polarization or upgrade. Before the presentation of possible future scenarios, the alternative development directions are briefly elucidated.

3.1.1 Digitization concepts

The division of tasks between man and machine plays a central role in distinguishing the digitization concepts. It decides whether the man or the machine takes control (WINDELBAND, 2014).

Substitution

A digitalization concept could be the major replacement of activity fields by automation with digital machines (BOTTHOF, HARTMANN, 2015). The highest level of automation in production would be achieved if decentralized production resources work completely independently. The management of production processes is then taken over entirely by machines that control, equip and repair themselves. Until this goal is reached of a manless factory, people fill the gaps of automation. The majority of employees in production remain in activities that are either cost-intensive or difficult to automate. People need only to make general checks as the machines recognize their mistakes themselves. Based on a comprehensive network and self-control of production, it can also be assumed that employees receive only the most necessary information and are guided by intelligent productions (HIRSCH-KREINSEN, 2015).

Assistance

In this digitization concept, digitization is a tool that supports the employee. In detail, a distinction is made between tool scenario (WINDELBAND, 2014), specialization scenario (HIRSCH-KREINSEN, 2015) and hybrid scenario (HIRSCH-KREINSEN, 2015). In the case of a development, as provided by the assistance, the new technologies provide a supportive decision-making aid. This means that employees in production have to make far more decisions than in substitution. The employees take over tasks such as process optimization and fault rectification. Automation will also take place in the assistance scenario, for example in order to eliminate monotonous or difficult tasks.

3.1.2 Work and qualification requirements

The two hypotheses about the future of work and qualification requirements differ in whether the work and qualification requirements for all employees are increasing (upgrading) or whether there are groups, whose requirements are decreasing (polarization).

Upgrading

In the case of the upgrading hypothesis, the work and qualification requirements for all groups of employees increase as a result of computerization of work (HIRSCH-KREINSEN, 2015). It is based on a growing availability of information, which has a high degree of diversity. The use of this complex information places new demands on activities. From the digitization also the requirement arises to understand processes and system connections. Upgrading does not exclude a progressive automation of simple activities, which are largely substituted by this (skill based technical change). Only those working groups that already have high and extensive qualifications are the winners of using digitized technologies (HIRSCH-KREINSEN, 2015). Even at the level of the low-skilled, there are complex, partly self-controlled requirements (BULLINGER, 2006). There the simple work proceeds to a work in which employees have a broader basis of knowledge and skill. Lowly qualified workers, whose work is not substituted, need a professional competence as well as a process competence in modern working environments.

Polarization

An opposing hypothesis is characterized by an increasing polarization of work and qualification requirements. The qualification level moves downwards and upwards. Production tasks at the average level of qualification are eliminated as a result of information technology automation (KINKEL et al., 2008). This development is expected to result in an increase in highly-qualified activities, which require cognitive abilities in particular. At the same time, there is erosion of the middle skilled workforce, combined with substitution and de-qualification processes, which means that only simple work remains in the production areas instead of specialist work.

4 Future scenarios

By combining the developmental trends prognosticated in the literature, four possible future images (Figure 1) are created. They describe possible work situations in an undefined future.

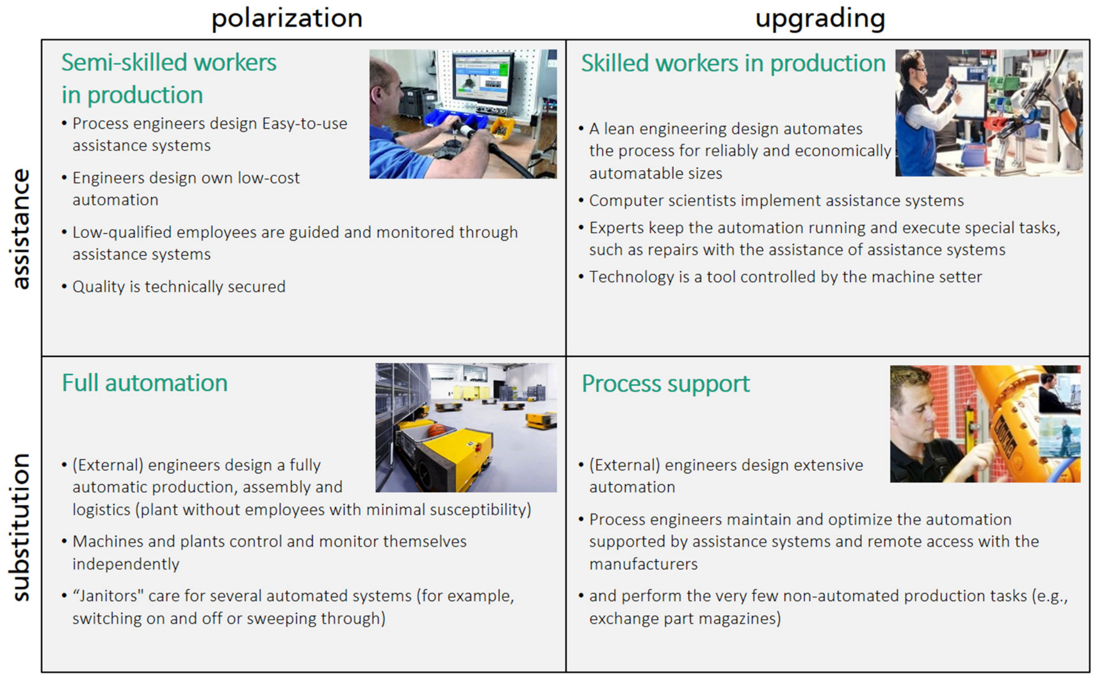

Figure 1: Future scenarios for production work

The future scenarios were secured, validated and evaluated by interdisciplinary expert interviews. The classification was perceived as plausible by the surveyed experts and fits into the current discussion. The future scenarios are close together, but they are clear counter-concepts. All scenarios will occur, depending on the industry, the company and the time periods.

The experts said that the future scenarios cannot only be understood as situation descriptions, but also as development processes that follow a company strategy. A migration path, for example, could be the development from professional work production through process support to full automation. A path dependency has to be considered, since decision-making processes also depend on the past as well as on the interests and needs of the stakeholders. For example, a connectivity to Lean management as well as an integration into the socio-technical system is necessary. There are also economic priorities.

4.1 Future scenario "semi-skilled workers in production"

In this future scenario the technology dominates the worker. Experts think that this scenario is plausible and probable. For certain production tasks, "semi-skilled worker in production" is realistic, in some cases it is already being implemented today. It is particularly suitable for non-easy-to-automate and labor-intensive work processes, such as the production of individual products. However, a surveyed expert pointed out, with the example of U.S.A., that a "semi-skilled worker in production" scenario might not be implemented one hundred percent. Experiences with the introduction of intensive assistance systems show that experts have to ensure the quality.

4.1.1 Requirements

Easy-to-use assistance systems and a technical assurance of quality are required. The necessary assistance is technically highly demanding. The question arises of how to get inexpensive assistance systems for many product variants. A process that is not carried out today by unskilled and semi-skilled workers. One difficulty here is to develop production knowledge, especially non-explicit knowledge, into digital platforms and to formalize them. It is unclear how commercial competence (e.g. dealing with materials) can be collected, transferred and used for digitization. The debate on the transfer of knowledge has already been the subject of the introduction of computer-assisted (CNC) tool and cutter grinder. However, not always highly modern assistance systems are necessary. Knowledge can also be formalized and illustrated using simple technological means. Examples are films (utility films), CAD visualizations or augmented reality.

4.1.2 Chances

From the point of view of the enterprise, the production allows a simple scaling of capacities with interchangeable semi-skilled workers. Employees can be employed according to the capacity requirements. With temporary workers, for example, production can be scaled up and down quickly. Low-cost labor permits a considerable efficiency. In terms of work, a production by semi-skilled employees might be desirable to keep low-skilled workers in the job or give them work. In terms of work, the semi-skilled workers production may be desirable in order to keep low-skilled workers in the job. In addition, new tasks are created for planners and designers. Polarization does not have to be negative, since not everyone can get involved creatively and technically. In the long term, it not impossible that higher quality work results from the semi-skilled worker production. For example, when employees control robots by showing something and the robot imitates, demanding tasks are created for employees, not just controlled work. Innovations from below can arise and the value of the employees increase. Well-designed assistance systems can shape the development of employees and resign with increasing experience.

4.1.3 Risks

Monotony and standardization limit the attractiveness, motivation and individualization of the work in a production. The activities are narrowly defined, strongly controlled and allow only a small amount of self-development. Lack of learning incentives due to supervised work restricts the company's future flexibility. The cost in the administration is rising, a large number of engineering experts in the company who are programming will arise. The experience migrates away from the shop floor to the designers. This makes it more difficult to innovate, develop processes, and react flexibly to changing conditions. In addition, hardly any effective improvement processes are possible with semi-skilled workers. Quality is technically difficult to secure. Economically, there is a risk that work without qualifications will migrate.

4.2 Future scenario “skilled workers in production”

In the future scenario “skilled workers in production”, man dominates technology. Skilled workers, as well as experienced semi-skilled workers with many years of experience, become managers. For this they need appropriate tools and assistance systems become more important. Qualification replaces planning. It is the fastest-to-achieve development direction. A specialized production is particularly suitable for complex, varied products, customer-specific sizes and small batches.

4.2.1 Requirements

Other competences are necessary in the future, especially more digitization competence. Keeping complex production systems running requires interdisciplinary teams and a new way of teamwork. The work organization has to be adjusted, otherwise it will result in frustration. Likewise, assistance systems for skilled workers are technically highly demanding. They are tied to persons rather than to the workplace and must be designed mobile and adaptive. They need opportunities to intervene for the employees' experience and the working capacity. However, in the case of assistance systems for skilled workers, not only high-tech functions are required but also communication or calendars. A critical point is safety in collaboration with physical assistance systems (e.g. robots), less in technical feasibility, but in legal approval.

4.2.2 Chances

A skilled workers production makes efficiency gain possible, especially in the case of production rich in varieties. In the skilled workers production, there are experienced contact persons for the designers, which enables high speed of innovation and flexibility. Employees are better involved and can influence their work, which is why they engage with commitment and ideas. This participation helps to formalize ideas, so that a knowledge transfer into the assistance systems takes place. Knowledge is stored and distributed. Innovation is possible. Improvement processes can be imaged digitally. New occupations could arise. From today's point of view this seems to be the most desirable perspective.

4.2.3 Risks

A skilled work production does not work if the parties do not understand the existing responsibilities. If the mix between automation and manual work is unclear, this results in a chaotic system with misleading responsibilities. If too much simple work remains, an irony of automation develops, because simple work and complex problem solving do not fit together. This raises the question of whether all employees can be upgraded qualitatively in this regard. Probably, not all unskilled employees will be able to cope with this transformation process. This creates a dependency on automation and assistance systems. No expert can be contacted for faults or breakdowns in the production.

4.3 Future scenario "full automation"

The full automation is close to the factory without employees. The workers needed in this future scenario are not qualified to understand complex automation. The scenario is not unrealistic. Such productions have existed for decades. Examples are SMD production or car body construction. In other areas, full automation would be possible today, but it is still expensive. Currently, automation islands are increasingly being networked. As a next step, massive progress in the field of machine learning is expected. With each step, the cost-effectiveness of the solutions changes because they become more complex, but also cheaper. In the long term, service robots or sensor systems will assume the tasks of the remaining employees. For artificial intelligence (AI) the abundance of different tasks is challenging. In the foreseeable future, this seems to work only for definable, highly formalized and reproducible tasks, for instance for the mass production of simple products.

4.3.1 Requirements

Full automation requires a comprehensive, autonomous and stable automation across the entire width with a real-time network of the affected individual systems. In the foreseeable future, this seems to be possible only for simple tasks, for example in the fields of semiconductor technologies, simple pre-assembly and in partial parts of logistics, e.g. Milk Run. For widespread application, this scenario is very unrealistic, even as a long term vision. It needs largely standardized products and processes with a large number of repetitions and a long service life. An important issue is that no disturbances are allowed to exist, since faulty probabilities multiply in chained systems. Robots that repair robots remain a vision and robots that construct robots, a research subject, in the nationwide operational practice of production. A reliable remote access to external specialists is also necessary. Further to external specialists, in-house consultants are required. Changes and decisions must be understood by the company to manage external experts. In addition, the clarification of legal and organizational questions, for example, who owns the service data, and who owns the value out of it?

4.3.2 Chances

From the point of view of the companies, full automation is able to achieve immense productivity potential by saving workforce when successfully implemented. Efficiency and cost reduction can improve international competitiveness. Automated systems could become an export hit. This would be positive for Germany as a location because the existing automation knowledge and front end design can be used.

4.3.3 Risks

Full automation is very complex. Their susceptibility is problematic. In the case of deficiencies, there is a risk of a poor overall efficiency and a large increase in indirect costs. Full automation involves great difficulties with flexibility and scalability. The systems are rigid and lethargic, innovations are only possible with high effort. There will continue to be non-automated activities. Possibly, they will even increase as a result of economic production as the number of variants increases. In terms of work, full automation would be desirable only in the case of full employment. Otherwise the question is: what do low-skilled and skilled workers do in the future, which carry out these activities today? The employee becomes the gap filler of incomplete automation. Small and medium-sized enterprises may be decoupled as they often do not have the necessary investment opportunities. Moreover, their typical production tasks require great flexibility and dynamism. An extreme automation of production may lead to a dead end. On the one hand, the knowledge about production technology is lost, so that external experts are often needed, for example in the case of disturbances and changes. This can become a bottleneck and the company's internal knowledge is lost. There is a danger to the system security with the independence of technic, data gaps and hacker attacks. On the other hand, it is questionable whether full automation is the right way for Germany. Today, our most important raw materials are the knowledge and education of people. At present, manufacturers of automation solutions are primarily constructing such systems for export reasons. Compared to international locations, full automation in Germany does not achieve the same low level of costs, e.g. due to existing regulations in the fields of machine safety, environmental and energy management.

4.4 Future scenario “process support”

This scenario is very probable, possibly as an intermediate stage on the way to full automation. The design of information technology, in particular software, is challenging. The future scenario of the process support needs employees who understand automation technology and keep it running. The associated task profile extends well beyond that of classical maintenance. Today, the typical maintenance worker is a mechanic or an electrician without a computer training. Consequently, a corresponding training or assistance is needed. Assistance today can be mainly mechanical and electrical support, but often do not locate programming errors. The development of self-healing software is still ongoing. It should be borne in mind that learning systems must first run for a long time in order to gain sufficient experience.

4.4.1 Requirements

The prerequisite for the future scenario "process support" is a comprehensive, autonomous and stable automation. Highly standardized products and processes are suitable. Process engineers need a broad qualification with automation competence. It requires a new teamwork to keep such complex production systems running.

4.4.2 Chances

From a company perspective, high productivity gains are possible through a high saving of manpower. Compared to the two future scenarios from the field of assistance, "the heavy work is largely abolished". New occupations could arise.

4.4.3 Risks

Extensive full automation is very complex. Scalability and flexibility are low, innovation needs much effort. Many professions fall away. What will semi-skilled and skilled workers do in the future? For the responsible process technicians there is a risk of high workload. They would always be in charge as "bottleneck manager" and would have to be constantly attentive. Due to the high degree of automation, the risk of loss of competence for decision making and a loss of self-assurance in the case of trouble increases.

5 Transformation Processes

Starting from the four future scenarios described in detail, transformation processes in companies and organizations are possible. As elucidated in the first part, the requirements of the industry will have an influence on the organization, sooner or later, and on which future scenario these companies are developing.

These developments mainly concern fields of:

- Qualification and employment structure;
- Organization and leadership;
- Thinking patterns and principles.

In the following, three possible transformation processes are briefly explained.

5.1 Transformation to Agile Organization and Leadership 4.0

In the global market, many companies will face a strong pressure to increase flexibility. The complexity in companies is expected to continue to grow. This complexity cannot be managed by central planning and control, even if digital technologies are used. One of the experts stated in evaluating the future scenarios: "The perfidy is that we are trying to combat complexity through complex technical systems. We are building systems that are becoming more and more complex to remove complexity in production. This creates a world that is so complex that it can hardly be mastered." Variance, dynamism and indeterminacy require the creativity and qualification of the employees in the company. Only they are able to make innovations and to deal with unplanned conditions quickly on the spot. Self-organization and self-responsibility need freerooms. A centralized organization with hierarchical management structures is not suitable to make use of personal experiences. Correspondingly, in companies that follow the

Taylorist doctrine, an adjustment of organization and leadership is required if they want to increase the flexibility effectively. It is necessary to design decentralized and process-oriented areas, self-responsible teams and a less strict management.

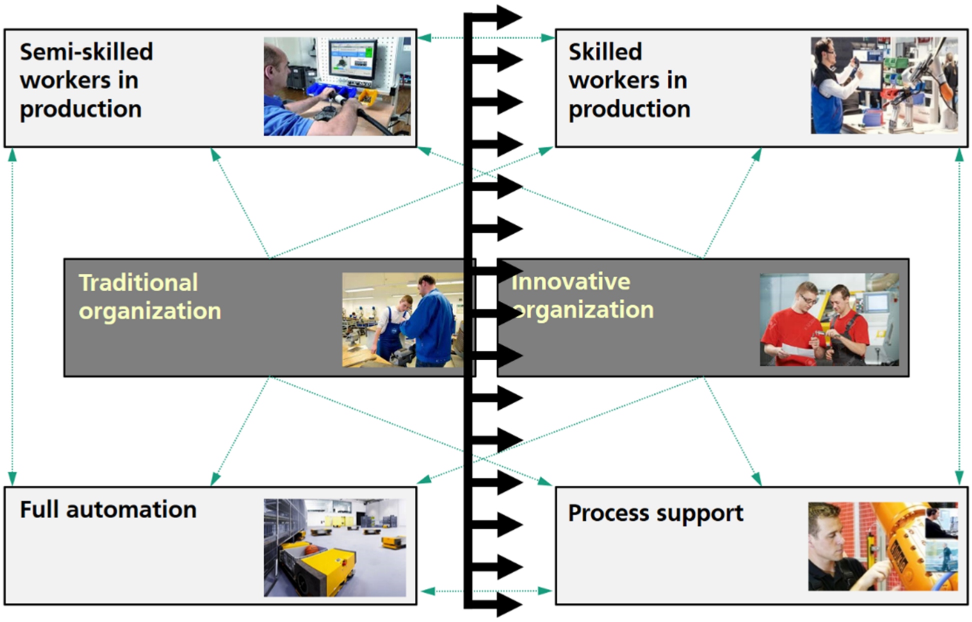

Figure 2: Transformation to Agile Organization and Leadership 4.0

5.2 Transformation to simple work contents

In the transformation to simple work contents, there is an erosion of the middle skilled worker level, combined with substitution and de-qualification processes of specialized work, so that only simple work remains in the production areas instead of specialist work.

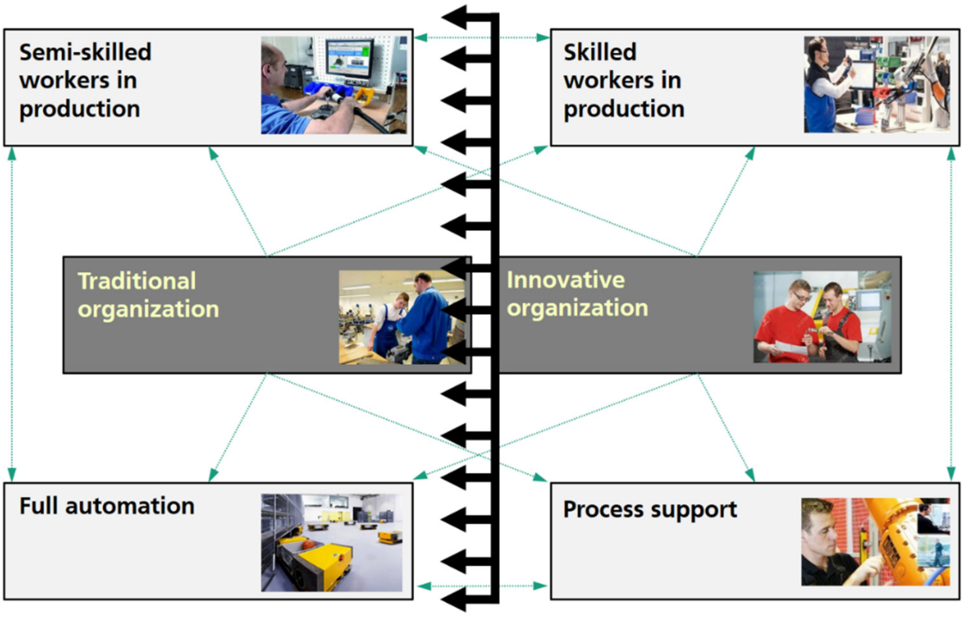

Figure 3: Transformation to simple work contents

5.3 Transformation to substitution (automation)

The substitution has already been described under 3.1.1. The development towards this scenario means that much more IT competencies have to be created. In the future, employees in particular will be needed for system provision, system application and system maintenance. This entails a restructuring of the employee structure. In addition, the content of the necessary training, as well as the skills required on the labor market, is changing.

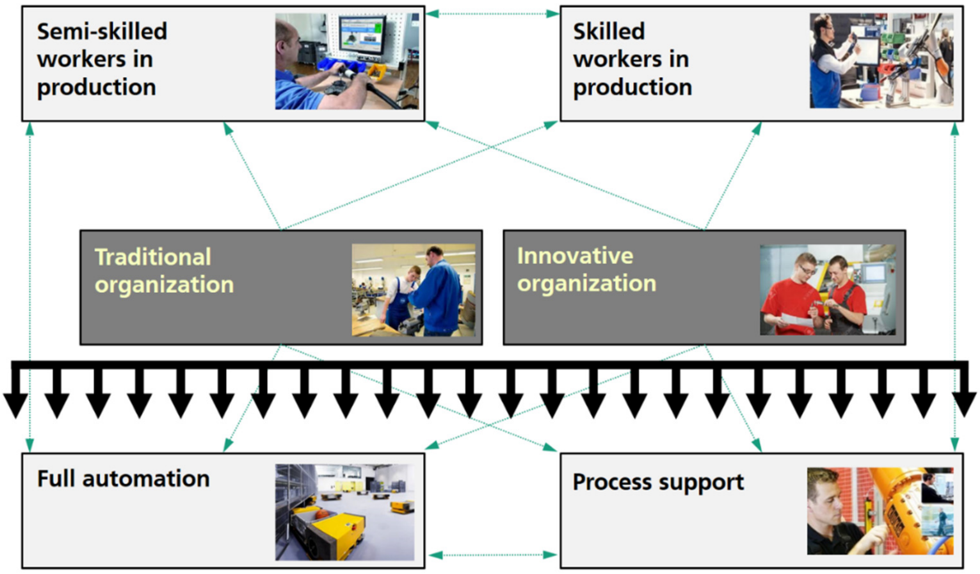

Figure 4: Transformation to substitution (automation)

6 Conclusion

Based on the described future requirements for the companies and the currently available organizational forms, this article has illustrated four future scenarios. These were created on the basis of the developments discussed in the literature and checked for plausibility by the German experts.

On the basis of this elaboration, it can be said that traditional concepts allow high productivity, but limit flexibility and motivation. Future demands on companies generate pressure towards an innovative organization and leadership. Integrating innovative methods into a traditional basic concept often results in only minor improvement. Significant improvements are achieved through a transformation to comprehensive and coherent innovative concepts. In order to decide whether a transformation process with fundamental change is necessary, companies should first analyze future requirements and, secondly, create a development roadmap for the organization and management. This paper can only show possibilities, which must then be adapted individually to the company. The results presented are also intended as a basis for discussion for research and associations. A systematic roadmap on how to get to the individual future scenarios based on the transformation processes is now to be developed.

7 Publication bibliography

Botthof, Alfons; Hartmann, Ernst Andreas (Eds.) (2015): Zukunft der Arbeit in Industrie 4.0. Berlin: Springer Vieweg

Bullinger, Hans-Jörg (Ed.) (2006): Qualifikationen im Wandel. Nutzen und Perspektiven der Früherkennung ; [Tagung "Qualifikationen im Wandel - Nutzen und Perspektiven der Früherkennung" im April 2005]. Qualifikationen im Wandel - Nutzen und Perspektiven der Früherkennung. Bielefeld: Bertelsmann (Qualifikationen erkennen - Berufe gestalten, 12)

Bundesministerium für Arbeit und Soziales (Ed.) (2016): Diskussionsentwurf Weißbuch Arbeiten 4.0. Arbeit weiter denken. Bundesministerium für Arbeit und Soziales

Hauser, Frank; Schubert, Andreas; Aicher, Mona (2008): Unternehmenskultur, Arbeitsqualität und Mitarbeiterengagement in den Unternehmen in Deutschland. Abschlussbericht zum Forschungsprojekt Nr. 18/05. Berlin

Hirsch-Kreinsen, Hartmut (Ed.) (2015): Digitalisierung industrieller Arbeit. Die Vision Industrie 4.0 und ihre sozialen Herausforderungen. With assistance of Lars Windelband, Bernd Dworschak. [Elektronische Ressource]. Berlin: Nomos

Kinkel, Steffen; Friedewald, Michael; Hüsing, Bärbel; Lay, Gunter; Lindner, Ralf (Eds.) (2008): Arbeiten in der Zukunft. Strukturen und Trends der Industriearbeit. 1. Aufl. Berlin: Ed. Sigma (Studien des Büros für Technikfolgen-Abschätzung beim Deutschen Bundestag, 27)

Kirchler, Erich; Meier-Pesti, Katja; Hofmann, Eva (Eds.) (2004): Menschenbilder in Organisationen. Wien: WUV-Univ.-Verl. (Arbeits- und Organisationspsychologie, 5)

Laloux, Frederic (Ed.) (2015): Reinventing organizations. Ein Leitfaden zur Gestaltung sinnstiftender Formen der Zusammenarbeit. With assistance of Mike Kauschke. München: Verlag Franz Vahlen

Spath, Dieter (Ed.) (2008): Organisatorische Wandlungsfähigkeit produzierender Unternehmen. Unternehmenserfahrungen, Forschungs- und Transferbedarfe. Fraunhofer-Institut für Arbeitswirtschaft und Organisation. Stuttgart: Fraunhofer IRB Verl

Windelband, Lars (2014): Zukunft der Facharbeit im Zeitalter „Industrie 4.0". In Journal of Technical Education (JOTED) Bd. 2 (2)

Wüstner, Kerstin (2006): Arbeitswelt und Organisation. Ein interdisziplinärer Ansatz. 1. Aufl. Wiesbaden: Betriebswirtschaftlicher Verlag Dr. Th. Gabler | GWV Fachverlage GmbH Wiesbaden (Gabler Lehrbuch)

Future images and development paths

FUTURE DEVELOPMENT OF PRODUCTION

- **Requirements**
- **Future images and development paths**
- **Transformation**

22nd International Seminar on High Technology

Jessica Klapper, M.Sc.

Fraunhofer-Institut für Arbeitswirtschaft und Organisation IAO, Stuttgart

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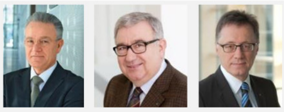
Profil of Fraunhofer IAO and IAT, University Stuttgart

Fraunhofer Institute for Industrial Engineering IAO ⟷ Cooperation ⟷ **Institute of Human Factors and Technology Management IAT, Universität Stuttgart**

Fraunhofer IAO

Universität Stuttgart
Institut für Arbeitswissenschaft und Technologiemanagement IAT

Founded:
IAO 1981
IAT 1991



Director:
Prof. Dr.-Ing. habil. Prof. e.h. mult. Dr.-Ing. h.c. mult.
Hans-Jörg Bullinger (1981 – 2002)
Prof. Dr.-Ing. Dr.-Ing. E.h. Dr. h.c.
Dieter Spath (2002 – 09/2013)
Prof. Dr.-Ing.
Wilhelm Bauer (seit 2013)

Budget and Staff:
IAO: 25 Mio. €, 377 employees (incl. students)
IAT: 8 Mio. €, 133 employees (incl. students)

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Fraunhofer IAO Stuttgart – With ideas to success

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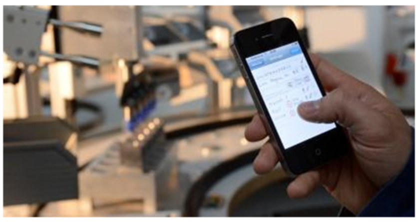
Production management at Fraunhofer IAO

Activities and areas of competence

- Reduce production and order processing processes (fast, flexible, low-inventory)
- Optimization of assembly and material supply and coordination
- Use of personnel flexibility in production
- Support companies in the direction of "Industry 4.0"



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Project Work Environment 4.0 Baden-Württemberg

- Develop future work designs
- Initiate dialogue of stakeholders

https://wm.baden-wuerttemberg.de/de/arbeit/arbeitsmarktpolitik/zukunftsprojekt-arbeitswelt-40/

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Universität Hohenheim Soziologie

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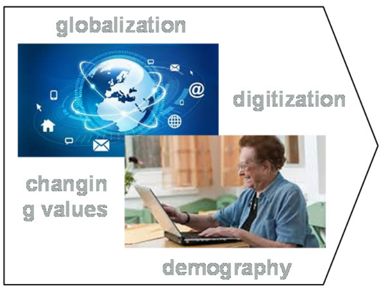
Production requirements 2030



Increase agility
- Speed and flexibility
- Innovation and adaptability
- Personalization (up to quantity 1)

Deal with complexity
- Variance and networking
- Uncertainty and ambiguity
- Characteristics of social systems

Create „good work“
- Keep empoyees workable
- Individualize working conditions
- Occupation and leisure

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Future scenarios for production work

polarization | upgrading

assistance

Semi-skilled workers in production

- Low-Cost-Automation
- Low-qualified employees are guided and monitored through assistance systems

Skilled workers in production

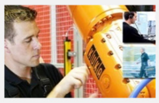
- Automation in economic terms only
- Highly qualified workers are supported by assistance systems for special tasks

substitution

Full automation

- Comprehensive and complete automation
- Machines control and monitor themselves independently

Process support



- Automation as far as possible
- Process engineers maintain and optimize the automation supported by assistance systems

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Folie 7

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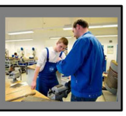
The basic design philosophy

instructions

Traditional organization



Versatile features

- *Series production*
  - *large quantity*
  - *stable markets*
  - *repetitive work*
- *Semi-skilled workers*
  and (dequalified) skilled workers
- *Rather large companies*

self-organisation

Innovative organization

Versatile features

- *Customized*
  - *Great variance*
  - *flexibility needed*
  - *Share of knowledge work*
- *skilled workers*
  and experienced workers
- *rather small and medium sized companies*

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Folie 9

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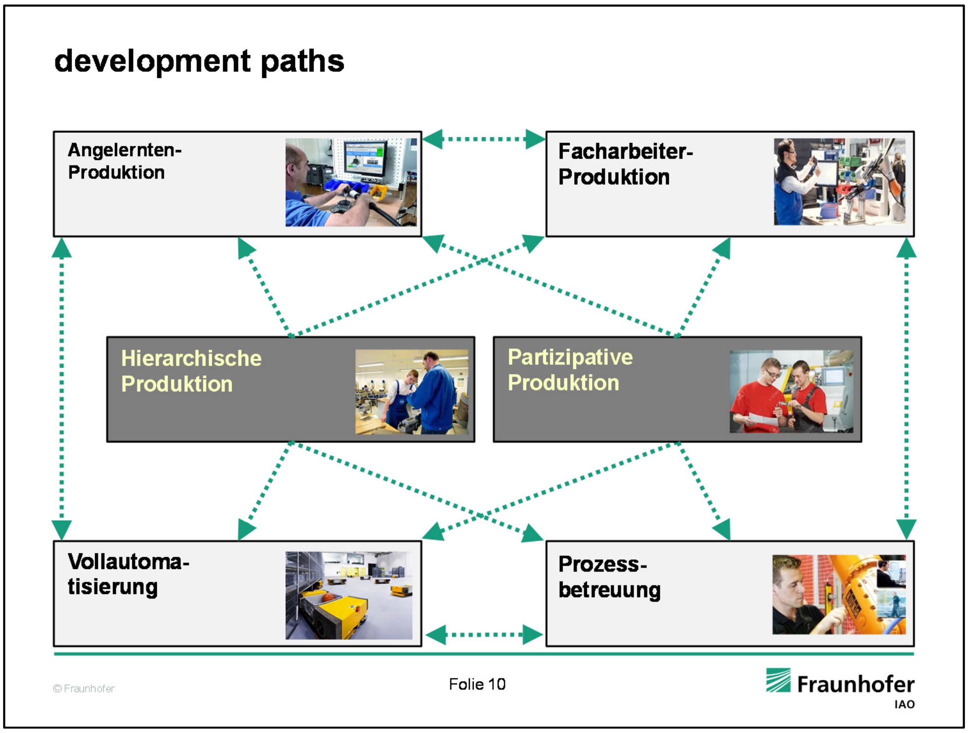
development paths
Angelernten-Produktion
Facharbeiter-Produktion
Hierarchische Produktion
Partizipative Produktion
Vollautoma-tisierung
Prozess-betreuung
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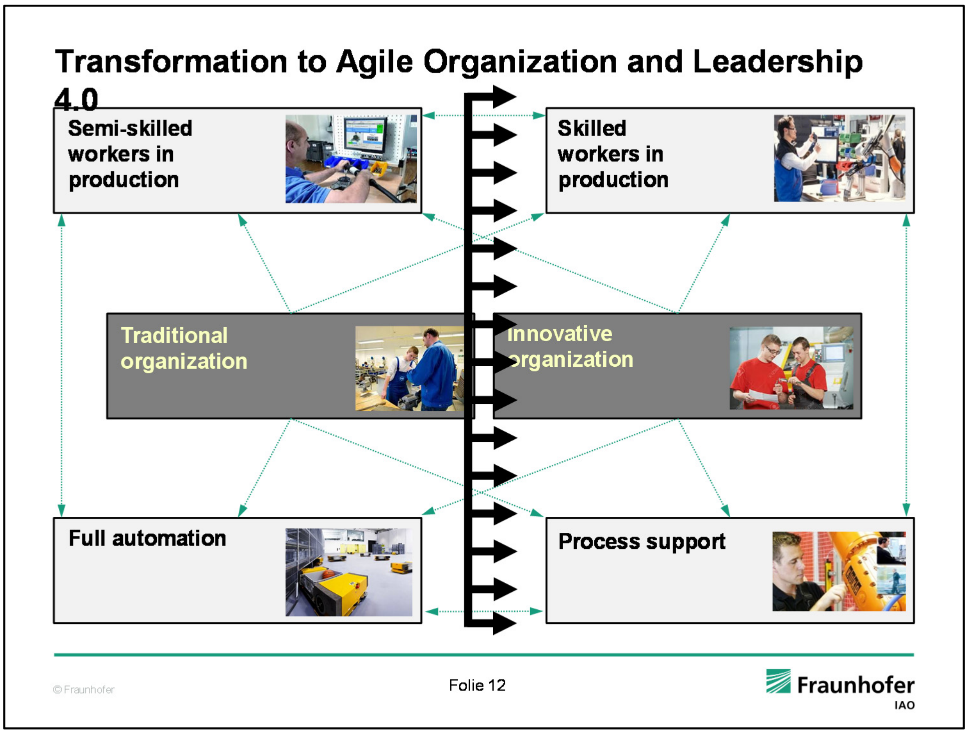
Transformation to Agile Organization and Leadership 4.0
Semi-skilled workers in production
Skilled workers in production
Traditional organization
Innovative organization
Full automation
Process support
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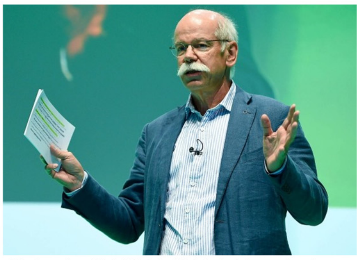
Agile organization and leadership 4.0

F.A.Z. exklusiv

Daimler baut Konzern für die Digitalisierung um



http://www.faz.net/aktuell/wirtschaft/daimler-baut-konzern-fuer-die-digitalisierung-um-14424858.html

"We imagine that in the short term, within a half year or a year, we will switch to about 20 percent of our employees on a swarm organization."

"This is a cultural revolution!"

"We will be a very large organization that is flexible and adaptable, always up-to-date and ready to pioneer, to be a pacesetter."

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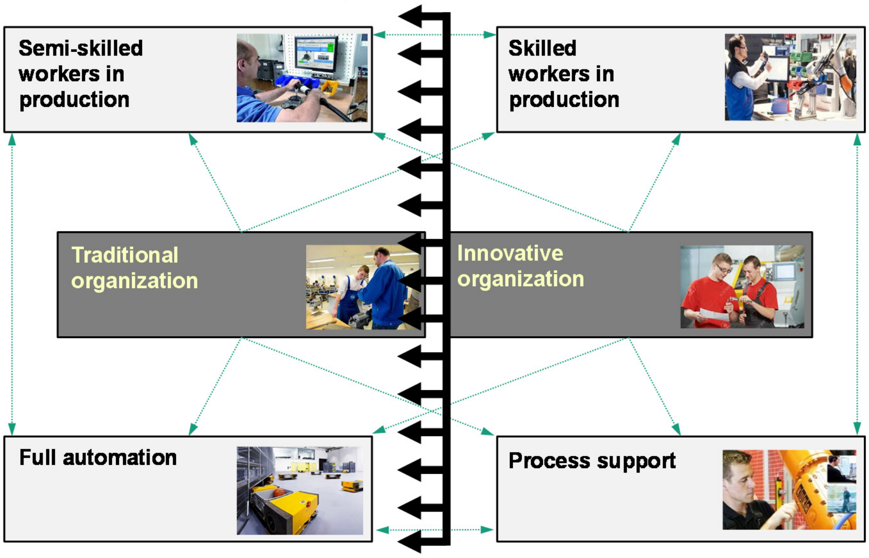
Transformation to simple work contents



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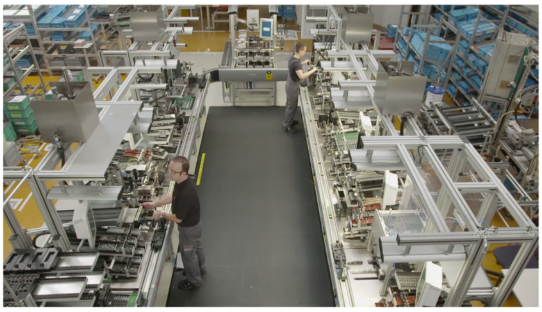
Avoid de-qualification through simplification
(irony of automation)



Lean-Management
- Standardization and visualization
- Separation of value added chain and logistics
- Line balancing

Digitization
- Pick-by-Light
- plant introduction (monitors)
- quality monitoring
- Order planning by MES

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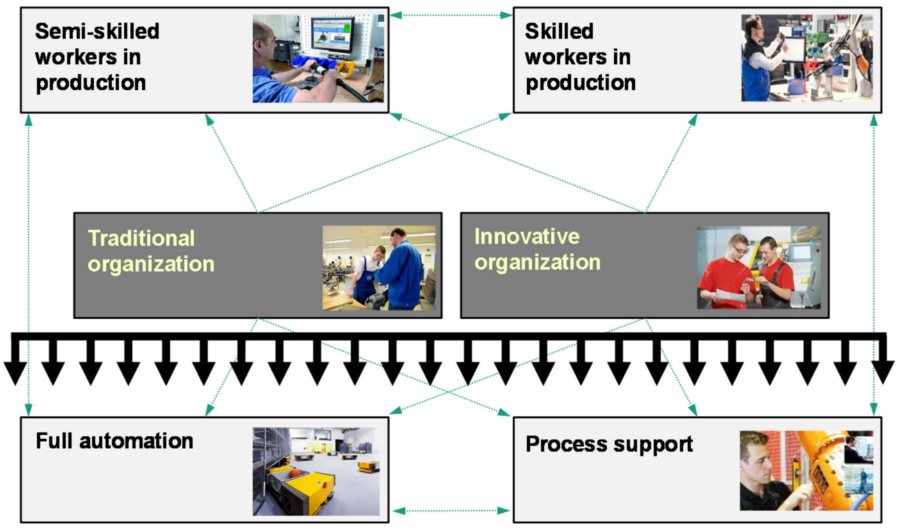
Transformation to substitution (automation)



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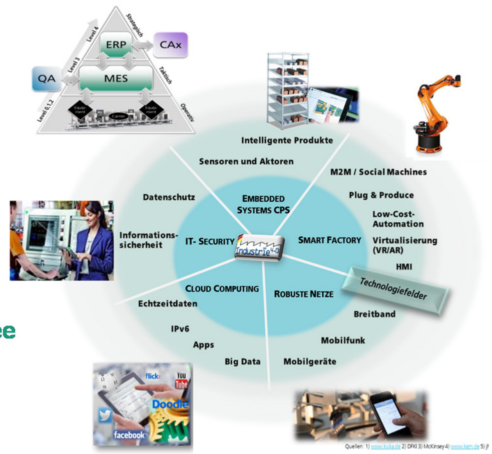
Substitution requires IT competence

More IT experts, fewer workers

- Maintain IT basic systems
- Design of a digitalized work system
- Maintain data
- Maintenance of systems
- Use of IT



→ **Reorganization of the employee structure**

→ **company training**

→ **Attractiveness in the "war for talents"**

→ **Organize Knowledge workers**

- Use of many available techniques
- Networking the participating objects

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Questions and discussion

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✉ antonio.carmesini@embraer.com.br

Empresa Brasileira de Aeronáutica – Embraer

Empresa global com sede no Brasil, a Embraer atua nos segmentos de Aviação Comercial, Aviação Executiva, Defesa & Segurança e Aviação Agrícola. A empresa projeta, desenvolve, fabrica e comercializa aeronaves e sistemas, além de fornecer suporte e serviços de pós-venda. Desde que foi fundada, em 1969, a Embraer já entregou mais de 8 mil aeronaves. Em média, a cada 10 segundos uma aeronave fabricada pela Embraer decola de algum lugar do mundo, transportando anualmente mais de 145 milhões de passageiros. A Embraer é líder na fabricação de jatos comerciais de até 130 assentos e a principal exportadora de bens de alto valor agregado do Brasil. A empresa mantém unidades industriais, escritórios, centros de serviço e de distribuição de peças, entre outras atividades, nas Américas, África, Ásia e Europa.

EMBRAER

Developing Advanced Manufacturing in the Aerospace Industry: Embraer's Success Cases

Abstract

The 4th Industrial Revolution promises higher quality products, shorter time-to-market, and overall reduced manufacturing costs. Best-in-class corporations are investing in Industry 4.0 related initiatives aiming to build the factory of the future. The portfolio of digitalization tools available to the manufacturing industry is rising exponentially and technologies once deemed complex and costly such as product virtualization, plant simulation, augmented reality, among others, are now becoming feasible. Even though, the simple application of these technologies by themselves will not assure expected Return On Investment (ROI) [1]. A structured strategy is required to drive and coordinate efforts in order to enforce alignment to business drivers. In this scenario, Embraer is working to consistently develop advanced manufacturing capabilities in three main lines of action: Digital Engineering, Shop floor Automation, and Manufacturing Intelligence. A series of projects are being orchestrated, each adding up to the next, focusing on reuse, budget optimization, and mitigation of technology risks. In this material, success cases will be presented to support Embraer's vision of digitalization. Initially, some cases related to the Digital Factory concept are presented (Digital Engineering) followed by examples of Advanced Robotics, Augmented Reality (Shop floor Automation) and Connected Machines (Manufacturing Intelligence). A final case of a Smart Tubing Fabrication Cell is then presented. These implementations are contributing to strategically increase the technological level of Embraer's manufacturing with the final goal of promoting competitive advantage.

Keywords

Industry 4.0; Manufacturing Strategy; Digitalization; Digital Engineering; Shop Floor Automation; Manufacturing Intelligence.

1 Introdução

O produto aeronáutico é complexo e, como consequência, sua manufatura depende de processos de fabricação que envolvem materiais não-convencionais, controle estrito de parâmetros, máquinas avançadas, inspeções rígidas, uma gama de sistemas digitais de apoio (ERP, MES, PLM, APS, etc.), além de outros fatores que acabam por determinar investimentos de capital intensivo na infraestrutura e na engenharia para viabilizar a operação industrial [1].

A Estratégia de Manufatura é um plano de longo prazo para o desenvolvimento de diretrizes e estruturas operacionais consistentes que provêm instalações focalizadas no atingimento de objetivos estratégicos. Nela, são endereçadas decisões estruturais que poderão limitar a operação por anos – são as coisas difíceis de mudar, como o número, tamanho e localização de plantas, os maiores sistemas de controle, organização e gerenciamento dos recursos humanos, seleção de equipamentos e processo tecnológico [3,4].

A Embraer, dentro de sua Estratégia de Manufatura, vem investindo há alguns anos em equipamentos e no seu processo tecnológico. Implantou mais de uma centena de robôs de furação, cravação e pintura na produção; desenvolveu novas máquinas de laminação de compósitos e centros de usinagem metálica de alta-precisão; adquiriu impressoras 3D; automatizou processos especiais de tratamento de superfície e usinagem química; adaptou ao seu contexto ferramentas de manufatura digital e simulação; dentre outras iniciativas tecnológicas.

Estas implantações visaram em última instância, contribuir com as Prioridades Competitivas do negócio: redução dos custos de fabricação e montagem, redução do ciclo de manufatura da aeronave, aumento da qualidade e flexibilidade da produção. Esta estratégia centrada no desenvolvimento de tecnologias de manufatura tem trazido retornos significativos para o negócio e garantido a eficiência produtiva da Embraer [5].

Contudo, o panorama do cenário internacional de manufatura tem mudado rapidamente, e a indústria está se transformando digitalmente e investindo no conceito de Indústria 4.0 como forma de construir Fábricas Inteligentes para elevar a sua competitividade a novos patamares [6].

Neste novo contexto, a Embraer revisitou sua Estratégia de Manufatura e estabeleceu o Desafio Manufatura 4.0 adaptado à realidade da indústria aeronáutica para transformar suas operações em fábricas conectadas e inteligentes.

2 Frentes de Manufatura Avançada

O Desafio Manufatura 4.0 foi estruturado na forma de um plano estratégico denominado PDTM - Plano Diretor de Tecnologias de Manufatura – que tem três frentes de ação em Manufatura Avançada: Engenharia Digital, Automação de Chão de Fábrica e Inteligência de Manufatura.

2.1 Engenharia Digital

A frente de Engenharia Digital tem por objetivo desenhar, construir e alavancar a operação de um ambiente de engenharia de manufatura digitalizado no qual seja possível conceber o produto e processos inteligentes, simulá-los com alta-resolução (Gêmeo Digital), monitorá-los em tempo real (Manufatura em Loop Fechado), automatizá-los aumentando a produtividade e reforçando os conceitos de melhoria contínua e de antecipação da maturidade (Fazer Certo da Primeira Vez).

2.2 Automação de Chão-de-Fábrica

A frente de Automação do Chão de Fábrica tem por objetivo aplicar tecnologias de Manufatura Avançada no chão de fábrica para aumentar a eficiência, flexibilidade, *throughput* e qualidade do processo produtivo viabilizando a manufatura dos aviões do futuro.

2.3 Inteligência de Manufatura

A frente de Inteligência de Manufatura tem por objetivo promover a conectividade dos dispositivos, processos e sistemas das plantas produtivas da Embraer permitindo a coleta, processamento e transformação dos dados em informação estratégica que suporte a tomada de decisão inteligente baseada em evidências.

2.4 Manufatura em Loop Fechado

As três frentes de ação do PDTM se integram para formar o conceito da Manufatura em *Loop* Fechado [7,8], no qual:

- Num primeiro momento, em um processo iterativo, produto e fábrica são criados e melhorados virtualmente no ambiente de Engenharia Digital;
- A fábrica é então construída, já num estágio de maturidade avançada, com as melhores tecnologias de manufatura e de suporte às operações com foco na Automação do Chão de Fábrica. Neste ponto, a despeito dos aspectos específicos de cada tecnologia, todos os ativos industriais (máquinas, equipamentos, ferramentas) e processos, são dotados de conectividade e desenhados para que publiquem seus dados operacionais;

- A partir da coleta dos dados produtivos, de sua harmonização, processamento e análise são construídas visibilidades que permitem planejar ações de melhoria no produto e produção com base em evidências (dados extraídos em tempo-real);
- Os pontos de melhoria identificados são analisados novamente no ambiente virtual para análise de impactos e resultados para que, somente então, o produto ou ambiente operacional físico seja alterado, fechando o *loop* de manufatura.

3 Casos de Sucesso

No contexto do Desafio Manufatura 4.0 e em ressonância com seu planejamento estratégico (PDTM) para digitalizar as operações, a Embraer vem atuando consistentemente para desenvolver suas capacidades de Manufatura Avançada. Na sequência, serão apresentados alguns casos de sucesso ligados às frentes de atuação em Manufatura Avançada.

3.1 Engenharia Digital – Caso da Fábrica Digital

A Fábrica Digital é um conceito baseado na integração de ferramentas e metodologias diversas e pode ser definida como uma rede compreensiva de modelos digitais, métodos e ferramentas que incluem:

- A modelagem e simulação 3D dos processos e recursos produtivos de modo integrado ao desenvolvimento digital do produto;
- O planejamento e autoria eletrônica dos planos de processo e instruções de trabalho em 3D;
- Gestão digital das operações no chão-de-fábrica (MES).

A arquitetura deste *hub* digital que integra desenvolvimento de produto, processos e gestão da produção é mostrada na figura 1:

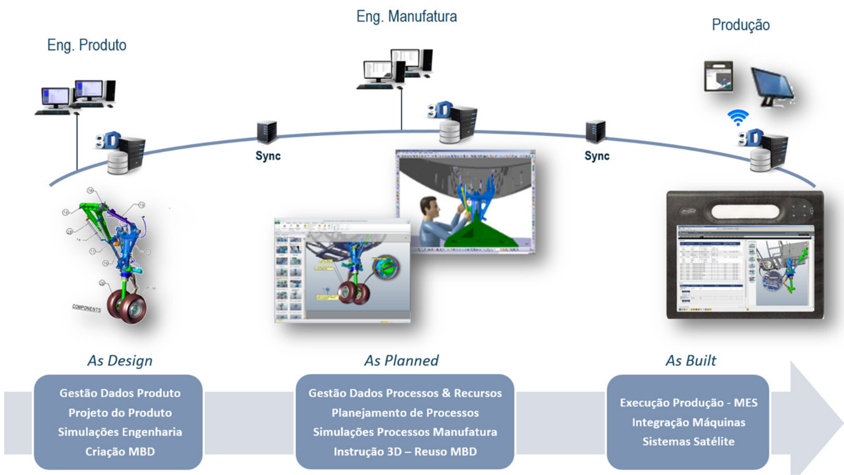


Figura 1: Estrutura da Fábrica Digital

A Embraer iniciou a estruturação do seu projeto de Fábrica Digital ilustrada na figura 2, há muitos anos e mais recentemente vem adaptando sua abordagem para os conceitos de Manufatura Avançada. Dentre as diversas aplicações implementadas pode-se destacar: a simulação de eventos discretos no *layout* de fábrica (Figura 3); simulação de montagem e ergonomia (Figura 4); gestão digital do ambiente operacional (Figura 5).

Figura 2: O Conceito de Mockup Digital e Manufatura Digital

Figura 3: Simulação de Eventos Discretos

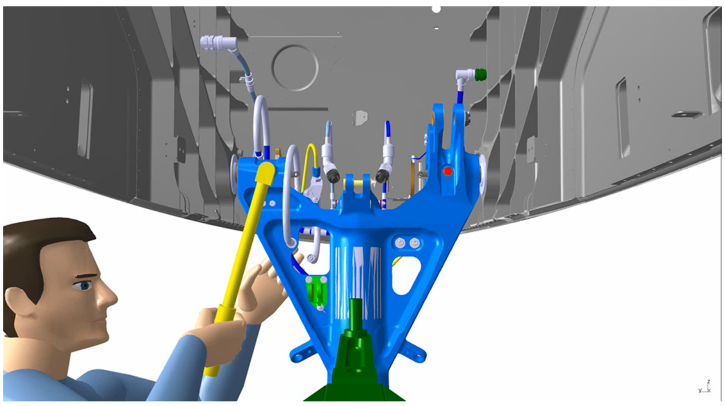


Figura 4: Simulação de Montagem e Ergonomia

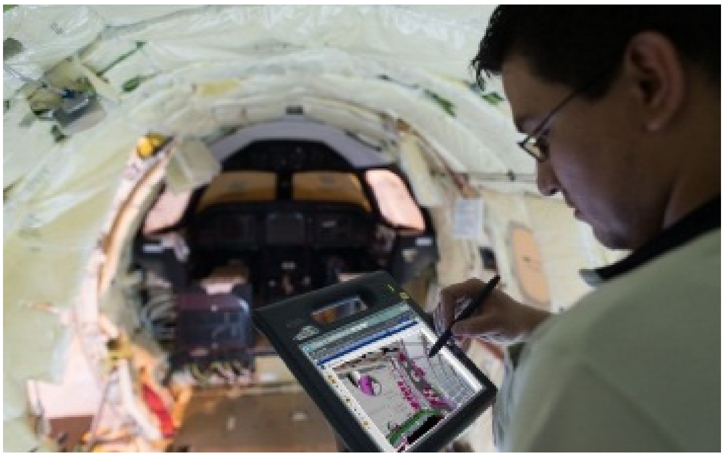


Figura 5: Gestão Digital Paperless da Produção com MES

3.2 Automação de Chão de Fábrica – Casos de Realidade Aumentada e Robótica

As tecnologias aplicadas ao chão de fábrica usualmente têm por objetivo automatizar o trabalho para elevar eficiência, reduzir custos e aumentar qualidade. Esta automação pode ser realizada em quatro níveis:

- Automação Completa de Processo – neste caso, uma célula, máquina ou dispositivo é automatizado por completo, eliminando ou minimizando a necessidade de ação humana;
- Automação Parcial de Processo – neste caso, parte do processo é automatizado e parte permanece manual. Convencionalmente, este tipo de automação precisa ser feito isolando-se as partes automatizadas daquelas na qual ocorre atuação humana em função de normas de segurança;
- Automação Colaborativa de Processo – neste caso, o processo é automatizado parcialmente, mas em função dos recentes avanços tecnológicos em robótica colaborativa, é possível que a máquina ou robô trabalhe em colaboração direta (sem necessidade de isolamento físico) com o ser humano;
- Automação Periférica – nos casos onde não é possível automatizar o processo em si, atua-se perifericamente a partir da digitalização, automação de dispositivos de apoio ao ser humano, como por exemplo, o emprego da tecnologia de Realidade Aumentada em processos de montagem.

Nos casos de automação completa e parcial a Embraer vem atuando ao longo de muitos anos para implantar robótica de produção avançada nos seus processos. Como muitos dos processos de manufatura aeronáuticos são complexos, boa parte destes robôs foram desenvolvidos em parceria usando tecnologias de Manufatura Avançada tais como: visão computacional, cálculo inteligente de trajetórias, comunicação M2M (Máquina-Máquina), dentre outras, como ilustrado nas figuras 6 e 7.

Figura 6: Robô de Pintura Pioneiro no Setor Aeroespacial

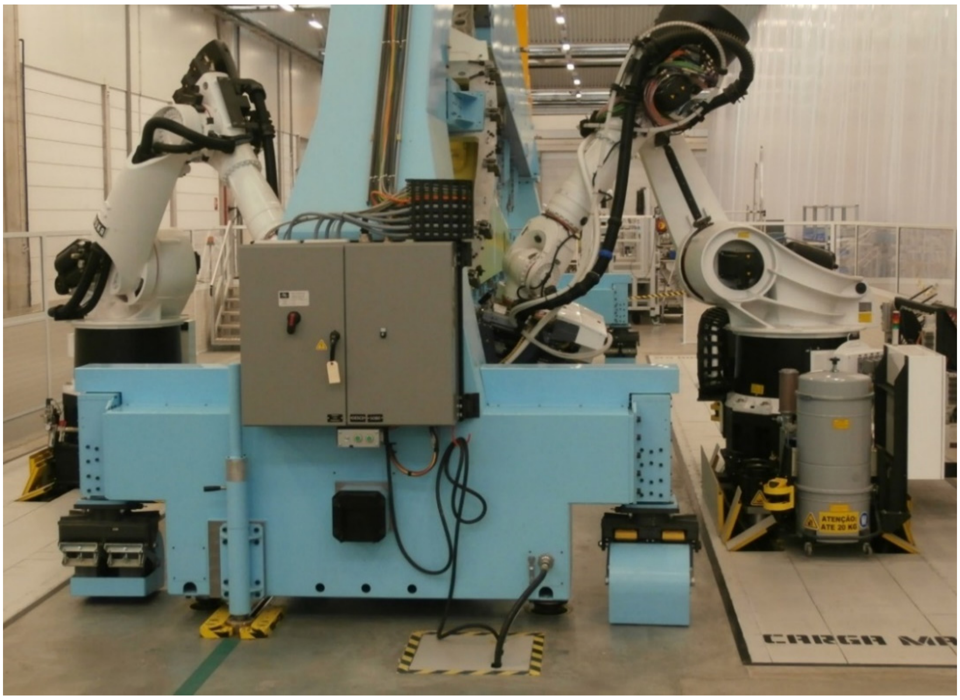


Figura 7: Robôs Cooperativos: Comunicação Máquina-Máquina e Visão Computacional

Para os casos de aplicação de automação periférica, novos conceitos estão sendo testados com tecnologias de realidade aumentada, realidade virtual, robôs colaborativos, dispositivos vestíveis (*wearables*) tais como exoesqueletos, à exemplo da figura 8. Especificamente no caso da tecnologia de realidade aumentada, a Embraer desenvolveu uma aplicação para posicionamento de peças em mesa flexível (pogos) na célula de recorte de material composto.

Figura 8: Realidade Aumentada com uso de Tablet aplicado à Fabricação de Composto

3.3 Inteligência de Manufatura – Caso do Sistema de Gestão de Informações da Planta

A frente de Inteligência de Manufatura tem como substrato de trabalho os dados operacionais. Com o intuito de construir, de modo faseado, a infraestrutura requerida para coletar, transportar, armazenar e processar os dados dos seus processos no chão de fábrica, a Embraer está desenvolvendo seu próprio Sistema de Gestão de Informações da Planta, ilustrado na figura 9.

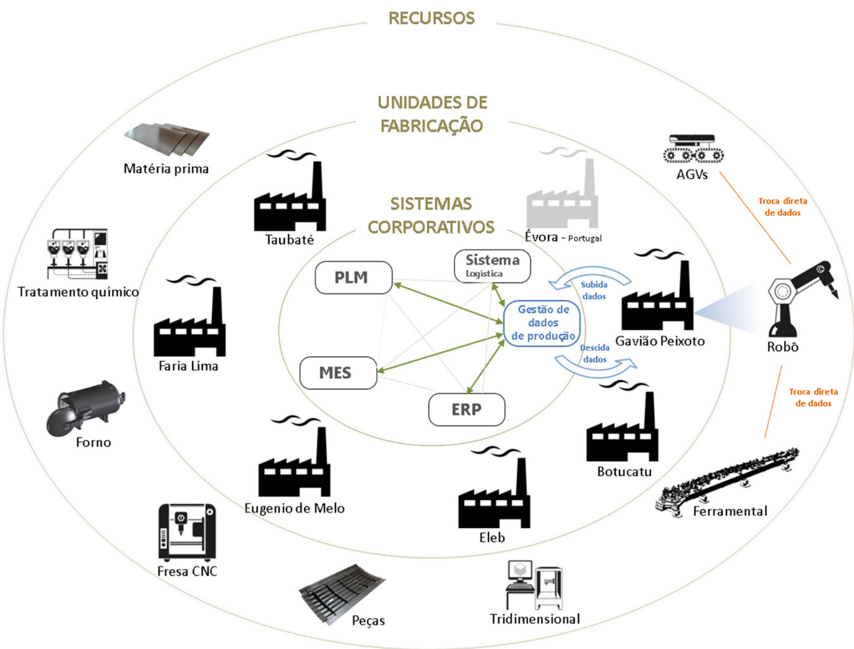


Figura 9: Estratégia de Implantação Incremental: Gestão de Informações da Planta

Este novo sistema está sendo construído para viabilizar a implantação da fábrica conectada de modo aderente aos conceitos de Manufatura Avançada. Dado que a Embraer possui plantas em diversos países, o sistema precisa ter alcance e escala mundial e, portanto, sua concepção e implantação precisa ser incremental. Assim, tecnologias tais como *Big Data, Analytics, Machine Learning, CyberSecurity, Advanced Dashboarding,* estão sendo aplicadas.

Figura 10: Arquitetura básica do Sistema de Gestão de Informações da Planta

3.4 Manufatura em Loop Fechado – Caso da Célula de Fabricação de Tubos

Conforme descrito anteriormente, as três frentes de ação do PDTM se integram para formar o conceito da Manufatura em *Loop* Fechado. O caso da Célula Inteligente de Fabricação de Tubos demonstra esta interdependência.

A partir de uma avaliação criteriosa, o processo de fabricação de tubos foi redesenhado para aplicar os conceitos de Manufatura Avançada, como apresentado na figura 11.

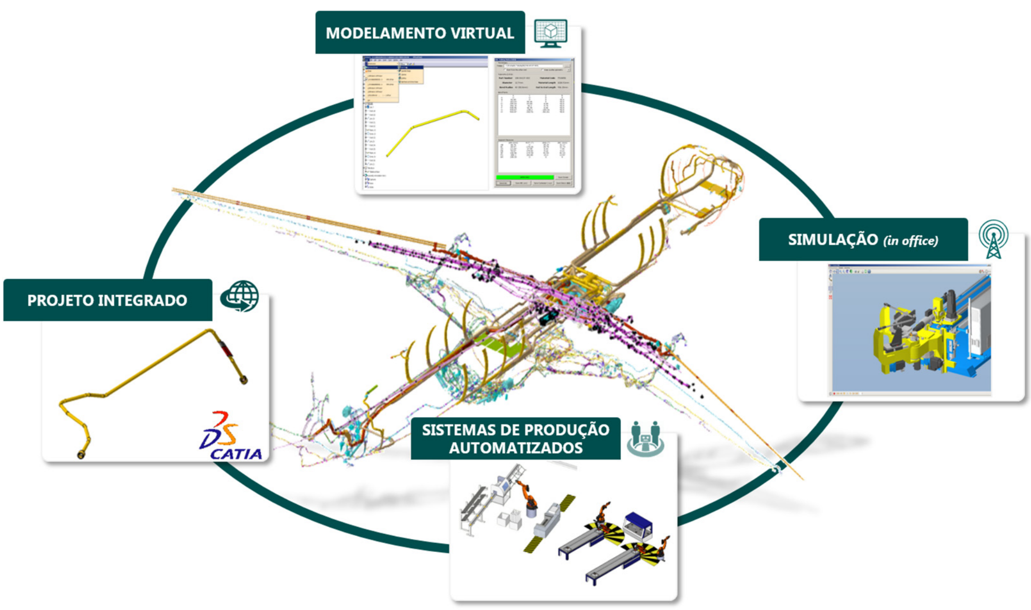


Figura 11: Digitalização do Processo de Fabricação de Tubos

Ainda na fase de projeto, *softwares* de automação de conhecimento, denominados *KBE*, foram desenvolvidos pela Embraer para garantir que os requisitos técnicos de engenharia de produto e de engenharia de manufatura sejam atendidos simultaneamente de modo a garantir um desenvolvimento integrado na fase do projeto dos tubos (frente de Engenharia Digital - *Design for Manufacturability – Figura 12*).

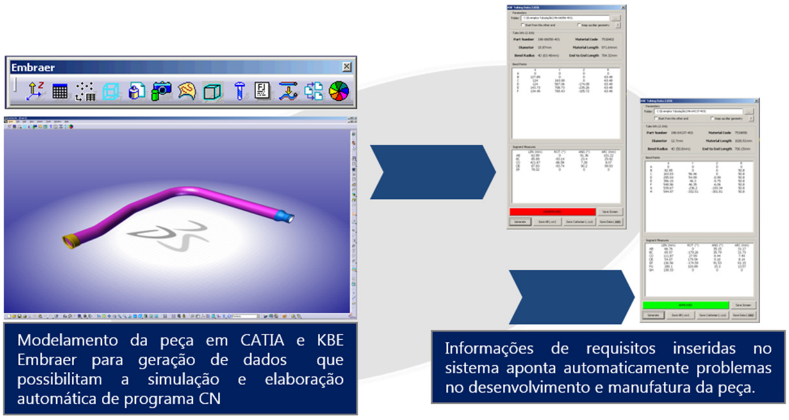


Figura 12: Automação de Conhecimento a partir de Software KBE

Uma vez projetados os tubos, é possível executar simulações para entender a dinâmica de fabricação e fazer ajustes ainda no ambiente virtual. Para tal, foram desenvolvidos modelos das peças em CAD 3D e da máquina e sua dinâmica de fabricação, como ilustrado na figura 13.

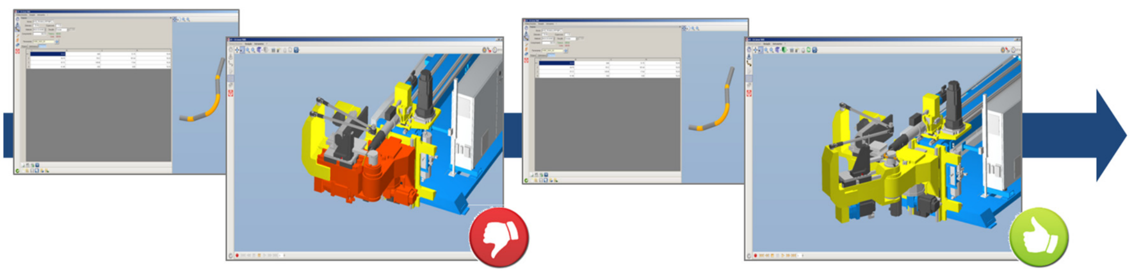


Figura 13: Simulações de Fabricação no Modelo Dinâmico da Máquina de Dobra

Do ponto de vista da operação (frente Automação de Chão de Fábrica), a célula de fabricação de tubos conta com corte automático de matéria prima com *software* inteligente de *nesting* para otimizar o consumo durante a fabricação em lote; movimentação automatizada das peças através do uso de *AGVs*; uso de máquinas dobradeiras automatizadas e de robôs colaborativos.

Finalmente, do ponto de vista da Inteligência de Manufatura, o processo de fabricação é instrumentado para realizar medições *in-process* de modo a identificar possíveis desvios dimensionais ou geométricos a cada peça fabricada e automaticamente ajustar parâmetros de da máquina de dobra corrigindo o programa de geração de tubos para a próxima peça.

Esta abordagem de medição *in-process* (em adição às simulações), neste caso se provou muito efetiva, dado que a modelagem matemática de todos os efeitos e variáveis que influenciam o processo de fabricação seria muito complexa e custosa.

4 Conclusão

A dinâmica imposta pela quarta revolução industrial ao setor de manufatura como consequência da rápida convergência entre os mundos de Tecnologia de Operações (TO) e Tecnologia de Informação (TI) tem alavancado o processo de Transformação Digital.

Embora em seu cerne, esta seja uma revolução tecnológica, a viabilidade desta transição da terceira para a quarta onda dependerá fundamentalmente da capacidade das empresas de planejar e executar de modo viável uma nova Estratégia de Manufatura adaptada ao seu cenário peculiar.

Ciente dos desafios à frente, a Embraer vem já há alguns anos desenvolvendo capacidades tecnológicas avançadas e mais recentemente estruturou o Desafio Manufatura 4.0 na forma de um plano estratégico, adaptado ao seu cenário e posicionamento, denominado PDTM. A partir do avanço em três frentes tecnológicas integradas de Engenharia Digital, Automação de Chão de Fábrica e Inteligência de Manufatura vem orquestrando criteriosamente a implantação de projetos de modo a mitigar riscos tecnológicos e otimizar investimentos pelo reuso das soluções geradas.

Neste artigo, foi apresentada a nova Estratégia de Manufatura Embraer bem como casos significativos em cada uma das suas frentes de ação. O portfólio de iniciativas em Manufatura Avançada é amplo e cresce rapidamente alicerçando a construção das Fábricas Inteligentes que irão em última instância garantir o diferencial competitivo do negócio, promovendo impacto no cenário mundial de fabricação de aeronaves.

5 Referências

[1] Mark Humphlett, Industry Week, Can the CFO Predict ROI of Digitalization in Manufacturing? Disponível em: <http://www.industryweek.com/technology/can-cfo-predict-roi-digitalization-manufacturing>. Publicado em 12 de outubro de 2016

[2] Lou Washington, Cincom Website, Aerospace Manufacturing is Advanced Manufacturing. Disponível em: <http://www.cincom.com.au/blog/advanced-erp/aerospace-manufacturing-advanced-manufacturing/>. Publicado em 6 de junho de 2016

[3] Wickham Skinner, HBR, Manufacturing – Missing Link in Corporate Strategy. Disponível em: <https://hbr.org/1969/05/manufacturing-missing-link-in-corporate-strategy>. Publicado em maio de 1969

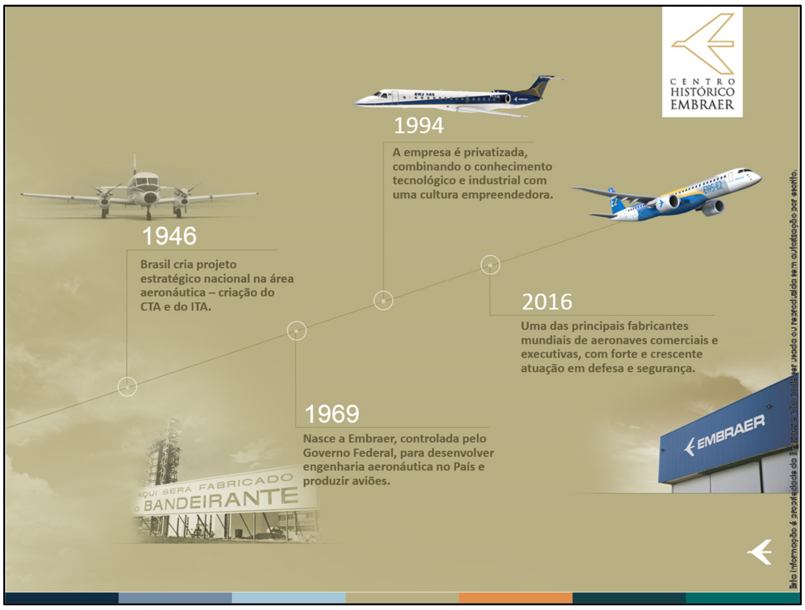
[4] Wickham Skinner, HBR, The focused factory. Disponível em: <https://hbr.org/1974/05/the-focused-factory>. Publicado em maio de 1974

[5] Terry Hill, Alex Hill. Manufacturing Operations Strategy Texts and Cases 3rd Ed. McMillan Education UK, 2009

[6] Roland Berger, Digital Factories – The renaissance of the U.S. automotive industry. Disponível em: <https://www.rolandberger.com/en/Publications/pub_digital_factories.html>. Publicado em fevereiro de 2016

[7] Conrad Leiva, Industry Week, Demystifying the Digital Thread and Digital Twin Concepts. Disponível em: <http://www.industryweek.com/systems-integration/demystifying-digital-thread-and-digital-twin-concepts>. Publicado em 1 de agosto de 2016

[8] Christine Furstoss, CIOReview, Digital Thread: Creating a Self-Improving, Brilliant Factory. Disponível em: <https://digital-wallet-solutions.cioreview.com/cxoinsight/digital-thread-creating-a-selfimproving-brilliant-factory-nid-194-cid-170.html>. Acessado em 16 de julho de 2017


CENTRO HISTÓRICO EMBRAER
1946
Brasil cria projeto estratégico nacional na área aeronáutica – criação do CTA e do ITA.
1969
Nasce a Embraer, controlada pelo Governo Federal, para desenvolver engenharia aeronáutica no País e produzir aviões.
1994
A empresa é privatizada, combinando o conhecimento tecnológico e industrial com uma cultura empreendedora.
2016
Uma das principais fabricantes mundiais de aeronaves comerciais e executivas, com forte e crescente atuação em defesa e segurança.
BANDEIRANTE
EMBRAER


19 MIL
MAIS DE 19.000 EMPREGADOS DE MAIS DE 20 NACIONALIDADES
90
MAIS DE 90 COMPANHIAS AÉREAS EM 61 PAÍSES
850
850 JATOS EXECUTIVOS ENTREGUES EM MAIS DE 50 PAÍSES
50
MAIS DE 50 FORÇAS ARMADAS
5 MIL
MAIS DE 5.000 AERONAVES ENTREGUES
3ª
MAIOR FABRICANTE DE JATOS COMERCIAIS NO MUNDO
MIL
MAIS DE 1.000 E-JETS ENTREGUES
16 BILHÕES
CONTRIBUIÇÃO DA EMBRAER PARA BALANÇA COMERCIAL BRASILEIRA NOS ÚLTIMOS DEZ ANOS
*Número não inclui empregados de suas subsidiárias não-integrais, OGMA e HEAI.
**Dados consolidados em legislação societária.

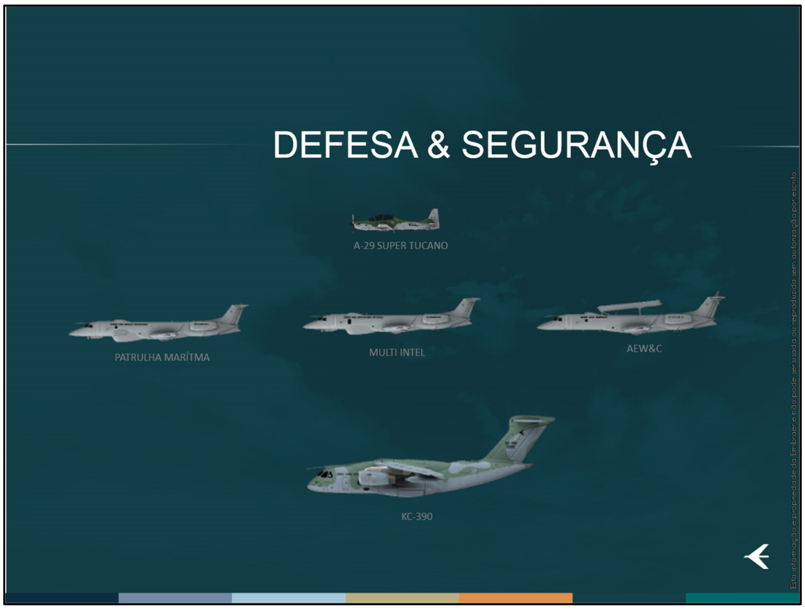

ONDE ESTAMOS
HOLANDA
Amsterdã
REINO UNIDO
Farnborough
IRLANDA
Dublin
FRANÇA
Le Bourget
PORTUGAL
Évora
Alverca - OGMA
EUA
Nashville
Fort Lauderdale
Melbourne
Mesa
Windsor Locks
Jacksonville
Irwindale
Titusville
EMIRADOS ÁRABES UNIDOS
Dubai
CHINA
Pequim
Harbin – HEAI
SINGAPURA
Singapura
BRASIL
São José dos Campos
Gavião Peixoto
Botucatu
Taubaté
Brasília
Belo Horizonte
São Paulo
Rio de Janeiro
Sorocaba
Campinas


AVIAÇÃO COMERCIAL
ERJ 135
ERJ 140
ERJ 145
ERJ 145 XR
EMBRAER 170
EMBRAER 175
EMBRAER 190
EMBRAER 195
E175-E2
E190-E2
E 195-E2


E195-E2
BEHOLD THE POWER OF 2
118 - 132
Motores GTF
PW1900G
2.000 mn


AVIAÇÃO EXECUTIVA
PHENOM 100E
PHENOM 300
LEGACY 450
LEGACY 600
LEGACY 650
LINEAGE 1000E
LEGACY 500


LEGACY® 500
MIDSIZE
8 - 12
2
3.125 mn


DEFESA & SEGURANÇA
A-29 SUPER TUCANO
PATRULHA MARÍTMA
MULTI INTEL
AEW&C
KC-390


KC-390
Novos padrões de capacidade e desempenho na sua categoria
Menor custo de ciclo de vida do mercado
Genuíno multimissão


LEGACY 500
ÚNICO DA CATEGORIA DE JATOS EXECUTIVOS DE PORTE MÉDIO COM CONTROLE DE VOO 100% DIGITAL.
KC-390
O MAIOR AVIÃO JÁ PRODUZIDO NO BRASIL.
E190-E2
O PRIMEIRO MODELO DA FAMÍLIA E-JETS E2. OS JATOS MAIS EFICIENTES DO MUNDO NO SEGMENTO ATÉ 130 ASSENTOS.
EMBRAER, ELEITA A EMPRESA MAIS INOVADORA DO BRASIL.
PRÊMIO VALOR
INOVAÇÃO BRASIL
OBRIGAÇÃO DE OLHAR 15 ANOS À FRENTE
Num mercado de trilhões, a Embraer investe mais de R$ 1 bilhão por ano em P&D para cruzar a fronteira da tecnologia e avançar no mercado global
1º
EMBRAER
Por João José Oliveira
Estratégia
Investimento 5,6%*
Centros de pesquisa 8**
Patentes no Brasil e no exterior 533***
Funcionários em P&D 200****
Parcerias 50*****
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INOVAÇÃO
Mais de 5.900 pessoas dedicadas à Pesquisa e Desenvolvimento
Cerca de US$ 625 milhões investidos em P&D e CAPEX em 2015 (10,5 % da receita)
46% da receita líquida provêm de inovações implantadas entre 2010 e 2014
286 patentes internacionais depositadas entre 2011 e 2015
Prêmio FINEP de Inovação
Programa Innova – Estímulo e viabilização da inovação
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PROGRAMA INNOVA
INNOVA embraer
Green Light
Tempo e recursos para as pessoas com propostas inovadoras.
Desafio Innova
Processo para busca de soluções para questões específicas por meio de um desafio proposto para todos as pessoas da empresa.
Espaços
Ambientes e laboratórios que favorecem a experimentação e a criatividade.
Reconhecimento À Inovação
O Gestor reconhede a inovação implantada, que esteja gerando resultados positivos.
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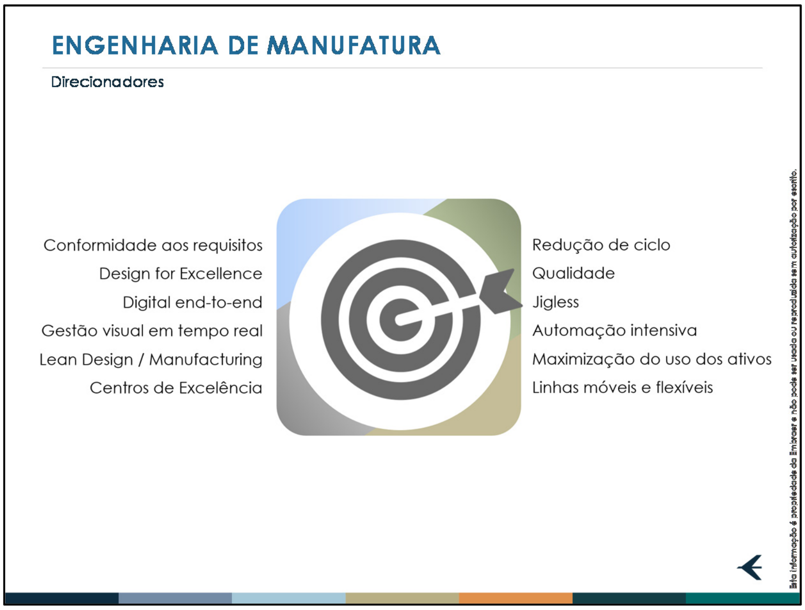
PROGRAMA BOA IDEIA
boa idéia
Ideias apresentadas
Ideias implantadas
7.200
2.200
10.500
3.400
11.500
4.600
12.400
5.800
13.300
6.600
11.800
7.200
13.100
7.600
17.000
10.400
15.700
10.070
2007
2008
2009
2010
2011
2012
2013
2014
2015
Custo
Benefício
1,6
14,1
2,5
22,7
3,8
28,3
2,2
22,7
2,5
26,3
2,8
26,3
3,6
32,4
3,2
32,2
2,7
32,4
2007
2008
2009
2010
2011
2012
2013
2014
2015


ENGENHARIA DE MANUFATURA
A amplitude de atuação
Prover soluções competitivas de produto e processo nas várias etapas de desenvolvimento dos diferentes produtos, desde o desenvolvimento tecnológico e concepção até o atendimento a serialização, com foco principal em qualidade, flexibilidade e custos.


ENGENHARIA DE MANUFATURA
Direcionadores
Conformidade aos requisitos
Design for Excellence
Digital end-to-end
Gestão visual em tempo real
Lean Design / Manufacturing
Centros de Excelência
Redução de ciclo
Qualidade
Jigless
Automação intensiva
Maximização do uso dos ativos
Linhas móveis e flexíveis
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FUTURO DA MANUFATURA
Os primeiros passos
13
TECNOLOGIAS
LEGACY 500
Alinhamento fuselagem
One-up assembly
Selagem prendedores
Medição de furos
Fábrica de móveis
Sistemas de movimentação
Laminhação automática (ATL)
Compósitos termoplásticos
Resin Film Infusion (RFI)
Design for Testing
Vaccum Assisted RTM (VARTM)
Roteiro 3D na produção
MES paperless


FUTURO DA MANUFATURA
Os primeiros passos
13
TECNOLOGIAS
E-jets E2
Lavagem
Aplicação de Dinitrol
Selagem de filete e contra-cabeça
Limpeza por laser
Ativação a Plasma
Hot Forming (HF)
Co-cura
Out of Autoclave (OOA)
Manufatura Aditiva Termoplásticos
Creep Age Forming (CAF)
Integração de Sistemas
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GESTÃO DIGITAL DA PRODUÇÃO
Manufatura Digital
Ambiente *Paperless*
Desenvolvimento end-to-end
Informações em tempo real
4200
Roteiros digitais
nos E-jets E2
Eng. Produto
CAE/CAD
VPM
CATIA
Eng. Manufatura
CAPP
DPE
DPM & WKC
Produção
MES
DELMIA
OP
Sync
Sync
As Design
As Planned
As Built
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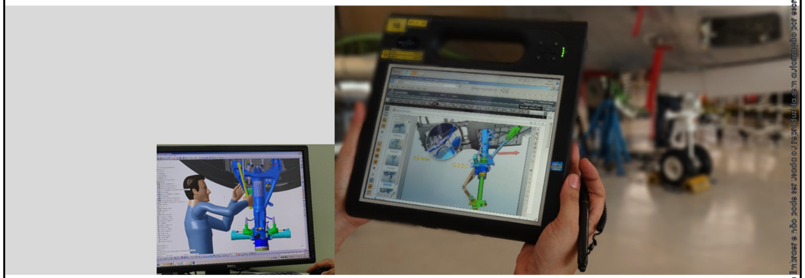
GESTÃO DIGITAL DA PRODUÇÃO

Manufacturing Execution System



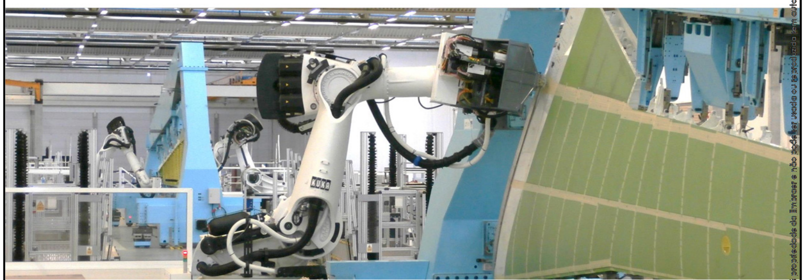
AUTOMAÇÃO DE MONTAGEM

Furação Automatizada

One up assembly

Eliminação da dependência de operadores especializados

Automação intensiva



AUTOMAÇÃO DE PROCESSOS

Pintura Automatizada

Embraer pioneira em pintura automatizada

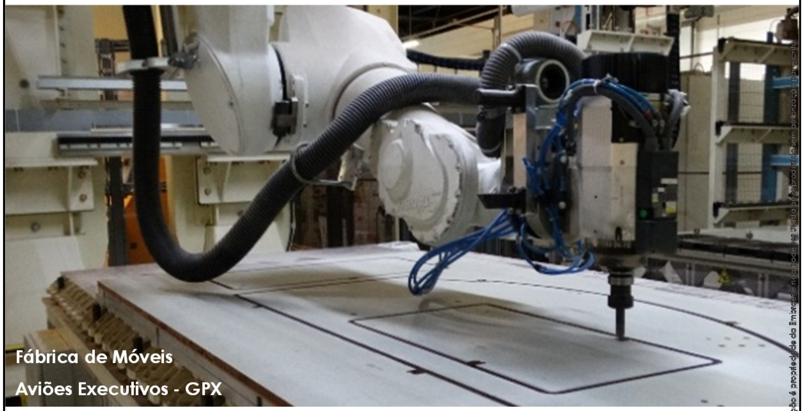
Aplicação uniforme no produto

Redução no consumo de tinta

45
Soluções Implantadas

AUTOMAÇÃO DE PROCESSOS

Fábricação de Móveis



MOVIMENTAÇÃO AUTOMÁTICA

Automated Guided Vehicles

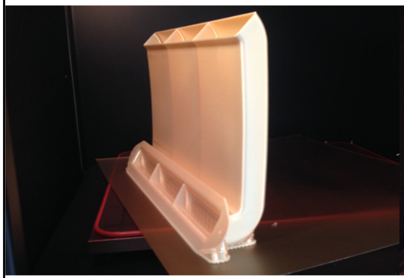
Precisão e segurança no transporte de peças e ferramentas
Rentabilização do tempo de expedição
Aumento de produtividade

120 km
Percorridos por mês, em média

MANUFATURA ADITIVA

Eliminação de ferramental
Flexibilidade para revisão de desenho
Redução do tempo de desenvolvimento, fabricação e entrega

59
Peças voando no Legacy 500 e E-jets E2




A 4ª REVOLUÇÃO INDUSTRIAL
Vapor e mecanização
Séc. 18
Séc. 19
Produção em massa
Séc. 20
Computador e automação
Sistemas interconectados
Séc. 21
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INDÚSTRIA 4.0
Tendência Global
Em cinco anos, 85% das empresas terão implementado soluções da Indústria 4.0 em todos os importantes segmentos de negócio.
Fonte: PWC
BOEING
Boeing to open new manufacturing facility in Sheffield City Region, alongside the Advanced Manufacturing Research Centre
GE Power Opens Firs Advanced Manufacturing acility,
a $400 Million Digital Industrial Investment for South Carolina
AIRBUS
Airbus' Filton site was chosen as the location for this facility because it already is home to some 2,000 engineers who specialize in wing design, as well as fuel and landing gear systems integration. The site also is home to Airbus Group Innovations' 3D printing plateau and digital manufacturing laboratory and the Airbus low-speed wind tunnel, and is close to other research facilities including the National Composites Centre.
BOMBARDIER
Government of Canada and Bombardier announce significant investment to strengthen leadership in aerospace
February 7, 2017 — Montréal
Bombardier Inc., Press Release
The Government of Canada has a long-standing relationship with Bombardier, Canada's biggest private sector investor in research and development activities. These activities strengthen the skills and knowledge of Canadians working in the aerospace sector, and new manufacturing platforms that position Canadians working in the sector for the jobs of tomorrow. The resulting benefits enable Canada to maintain a competitive position in the global supply chain that forms
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INDÚSTRIA 4.0
Tecnologias relacionadas
CROWNDSOURCING
GENÉTICA
TRANSPORTES AUTÔNOMOS
REALIDADE AUMENTADA
PROCESSOS DE FABRICAÇÃO
MANUFATURA ADITIVA
NOVOS MATERIAIS
BIOTECNOLOGIA
SIMULAÇÃO
DIGITALIZAÇÃO
NANOTECNOLOGIA
DIGITAL TWIN
BIG DATA
SIMULAÇÃO
NOVAS FONTES DE ENERGIA
CLOUD COMPUTING
INTERNET DAS COISAS
ROBÓTICA COLABORATIVA
ANALYTICS
INTELIGÊNCIA ARTIFICIAL
MÁQUINAS AVANÇADAS
DRONES
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MANUFATURA EMBRAER 4.0
Plano Diretor de Tecnologias de Manufatura
Estratégia tecnológica para elevar a competitividade e produtividade da manufatura da Embraer
MANUFATURA
4.0
3D
IoT


ENGENHARIA DIGITAL
A transformação digital para acelerar a maturidade dos processos
Digital Twin
Imersão no CAD por realidade virtual
Simulações Avançadas


AUTOMAÇÃO INTENSIVA
Produtividade e flexibilidade para nossos processos produtivos
Célula Robótica
Soluções Integradas com AGVs
Drones


SOLUÇÕES COLABORATIVAS
A tecnologia contribuindo com o trabalho dos nossos operadores
Robótica Colaborativa
Realidade Aumentada
Wearable Devices


SISTEMAS CONECTADOS
Interligando nossas máquinas e sistemas para obter dados
Industrial Internet of Things (IIoT)
Machine to Machine (M2M)
Rastreabilidade


INFRAESTRUTURA DIGITAL
Soluções para armazenamento e proteção das nossas informações
Armazenamento de Dados
Segurança da Informação
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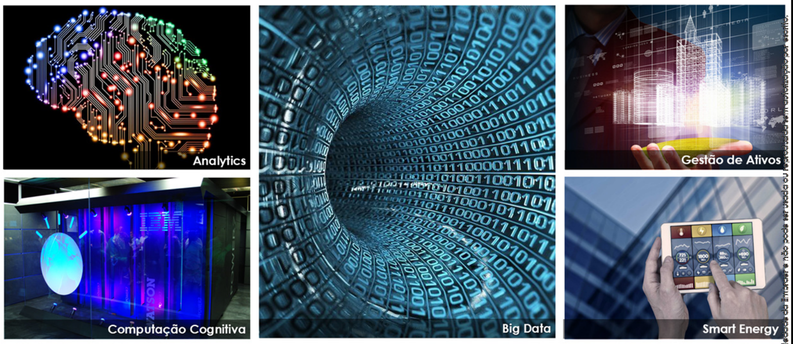
ANÁLISE DE DADOS

Aplicando inteligência artificial para extrair valor dos dados



INTELIGÊNCIA DE MANUFATURA

A geração do conhecimento para nossas decisões estratégicas

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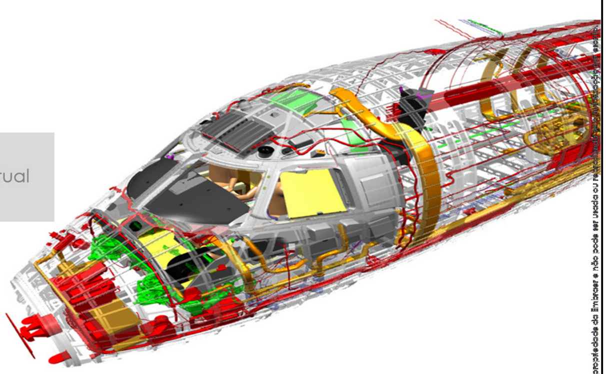
A EMBRAER 4.0

Digitalização do Produto

Engenharia Digital:
a representação virtual
do produto



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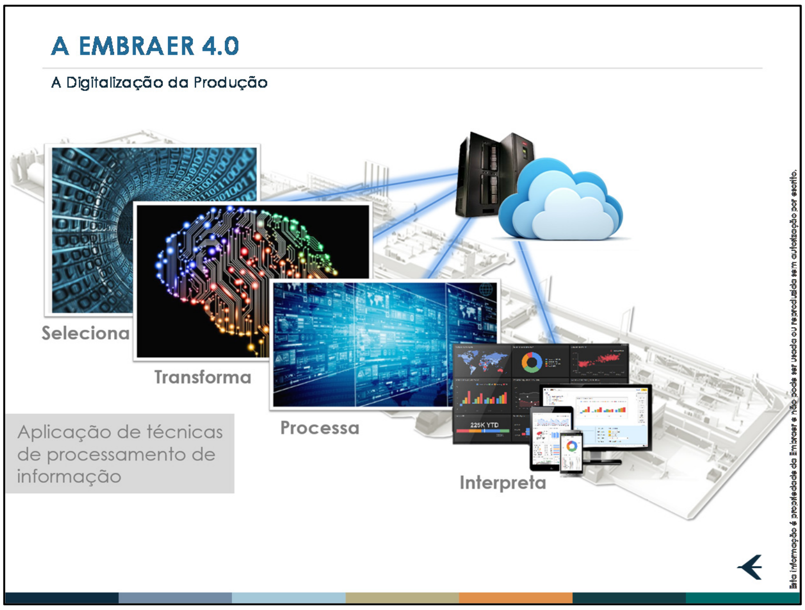
A EMBRAER 4.0
A Digitalização da Produção
Seleciona
Transforma
Processa
Interpreta
Aplicação de técnicas de processamento de informação
225K YTD
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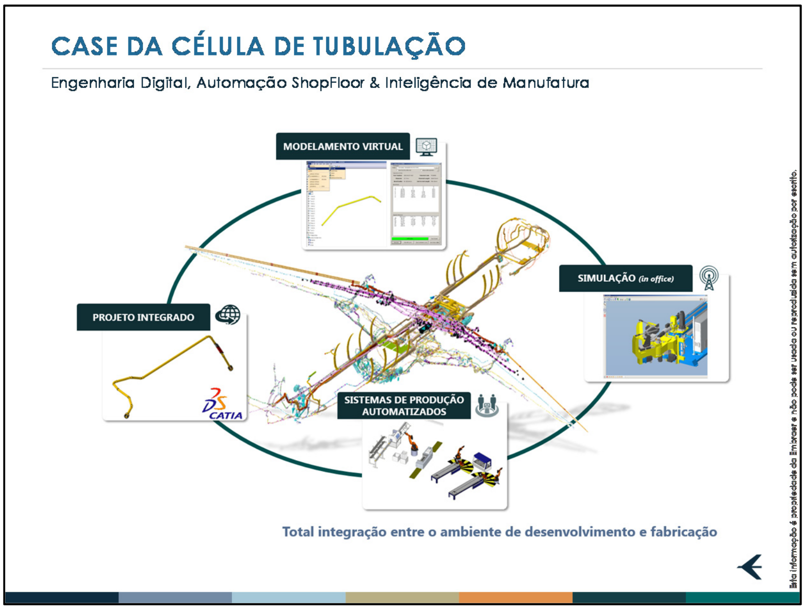
CASE DA CÉLULA DE TUBULAÇÃO
Engenharia Digital, Automação ShopFloor & Inteligência de Manufatura
MODELAMENTO VIRTUAL
SIMULAÇÃO (in office)
PROJETO INTEGRADO
CATIA
SISTEMAS DE PRODUÇÃO AUTOMATIZADOS
Total integração entre o ambiente de desenvolvimento e fabricação
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EMBRAER
ESTAS INFORMAÇÕES SÃO PROPRIEDADE DA EMBRAER E NÃO PODEM SER USADAS OU REPRODUZIDAS SEM AUTORIZAÇÃO POR ESCRITO.

Dr. Reinhard Pittschellis

Born 1968, studied mechanical engineering from 1988 to 1993 at the Technical University Braunschweig, where he finished his PhD. studies in 1998. He started his professional career at Siemens AG in Munich in 1998. In 2000, he moved to Maxon Motor AG in Switzerland as Head of Development of small DC motors. After that, he started in 2002 his activities at Festo Didactic GmbH & Co KG as Head of Product Management and since 2015 as Head of Global R&D.

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Festo Didactic SE

Festo Didactic is the world-leading provider of equipment and solutions for industrial education. We design and implement learning centers and laboratories, educational equipment and programs that train people to perform in highly dynamic and complex industrial environments. Our goal is to maximize learning success in educational institutions and industrial companies around the globe. Our product and service portfolio offers solutions for rapid learning and retention in a broad spectrum of technologies, including a complete coverage of automation: pneumatics, hydraulics, electronics, electrical engineering, manufacturing technology, process control engineering, mechatronics, CNC technology, HVAC as well as telecommunication. In addition, it meshes the technical learning content with knowledge and training courses from other specialist areas, such as process optimization, management and communication.

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Education and Training as a Success Factor for Industrie 4.0

Abstract

The introduction of Industrie 4.0 will lead to new challenges and opportunities for the employees. Well-qualified people will be one of the major preconditions for the successful introduction of Industrie 4.0. The necessary competencies has to be trained in an efficient way – in universities, in vocational schools and in the industry itself as well. Learning Factories, combined with a fitting didactical approach, has been proven an efficient way to teach the necessary competencies. The presentation will describe examples from universities, vocational schools and industry. Furthermore, methods of Industrie 4.0 can be used to optimize the production process, but the learning process itself as well. Examples of how Virtual Reality and Augmented Reality can support the learning process - already implemented or in the research stage - will be given.

Keywords

Industrie 4.0; Competencies; Learning Factories; Didactic Approach.

1 Introduction

Industrie 4.0 will change the way we produce and the way we work. Based on new emerging technologies like (Figure. 1):

- Cyber-Physical Systems, intelligent sensors and embedded controllers;
- Universal networks, cloud computing, Internet of Things, 5G;
- Autonomous and collaborative robots;
- New and intuitive ways of man-machine interaction, e.g. by mobile devices or data goggles;
- Virtual and Augmented Reality;
- Additive Manufacturing;
- Data Analytics.

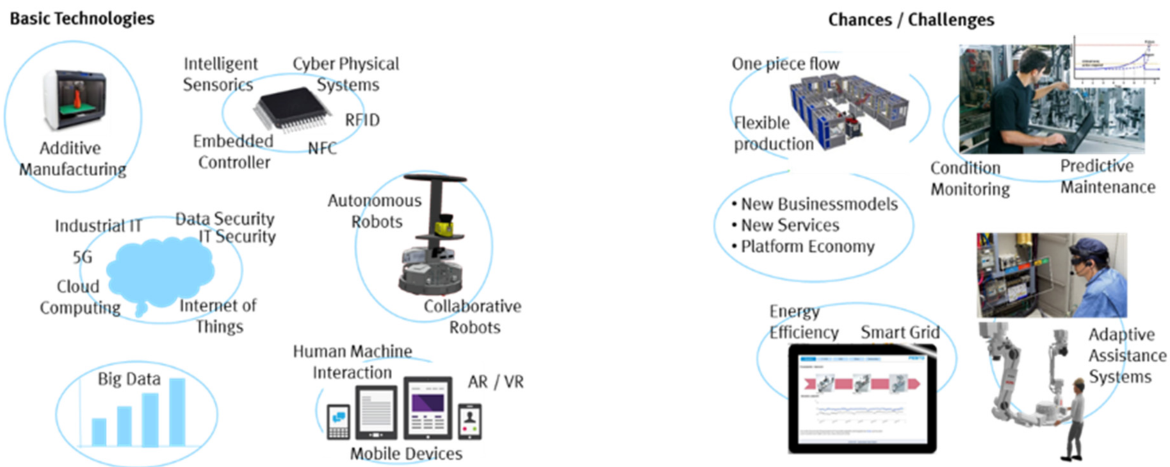

Figure 1: Impact of new technologies in Industrie 4.0

Industry will face new opportunities like:

- Smart Sensors will improve condition monitoring and therefore enable predictive maintenance and hence reduce waste in production;
- Cyber-Physical Systems and intelligent workpieces and decentral control structures will help to implement one piece flow structures;
- Augmented Reality will support maintenance on site with appropriate information;
- Collaborative robots will support workers in assembly with heavy loads and enable elder employees to stay longer in the job;

- Smart Sensors and smart grids will help to reduce significantly the energy consumption in a factory;
- And last but not least, there will be new business models, which might revolutionize the industry.

These changes will take place in a faster rate than the changes in industry we saw in the past (see Figure. 2). While the first industrial revolution (based on the introduction of water and steam power and the mechanization of the production) and the second industrial revolution (based on the invention of the assembly line) took 100 years, the third industrial revolution (based on Electronics) needed only 40 years to come. The fourth industrial revolution, this time based on the innovations depicted in figure 1, will take place much faster. The Smart Phone was introduced in 2008 and is virtually everywhere today, only eight years later. Digital photos replaced analogue photos within a few years. So it is a fair estimation that the digitalization of the industry will also take place much faster than the changes we saw in the past.

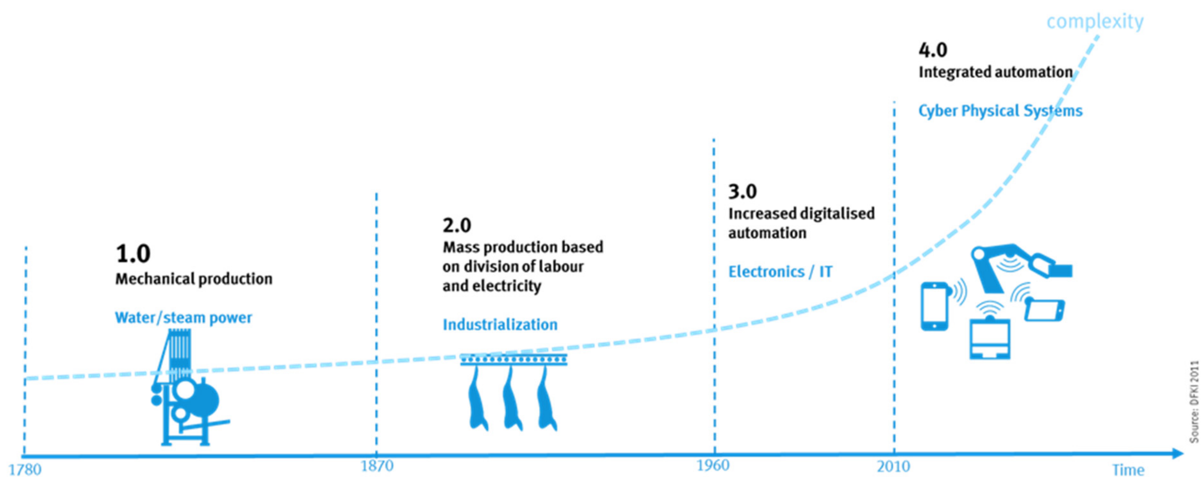

Figure 2: Innovation Cycles becomes shorter

This fast change raises the question how education can compete with these changes. How can we qualify people for the changes coming? In addition, will there still be people in the factories, or will they be replaced by robots and artificial intelligence?

2 *Industrie 4.0* and Training Needs

Since the implementation of *Industrie 4.0* is an ongoing process and will be for the years to come, it is hard to predict what exactly employees will have to learn.

In principal, we can distinguish between training needs concerning new technologies and generic competencies. A good source for technologies required for developing *Industrie 4.0* is the Toolbox Industry 4.0 created in 2016 by the VDMA (German Association of Machine Tools and Plant Engineering), see Figure. 3. Separated between production and product the toolbox provides a guideline on how to implement *Industrie 4.0* related technologies and therefore also an overview about technologies, which have to be mastered by the employees.

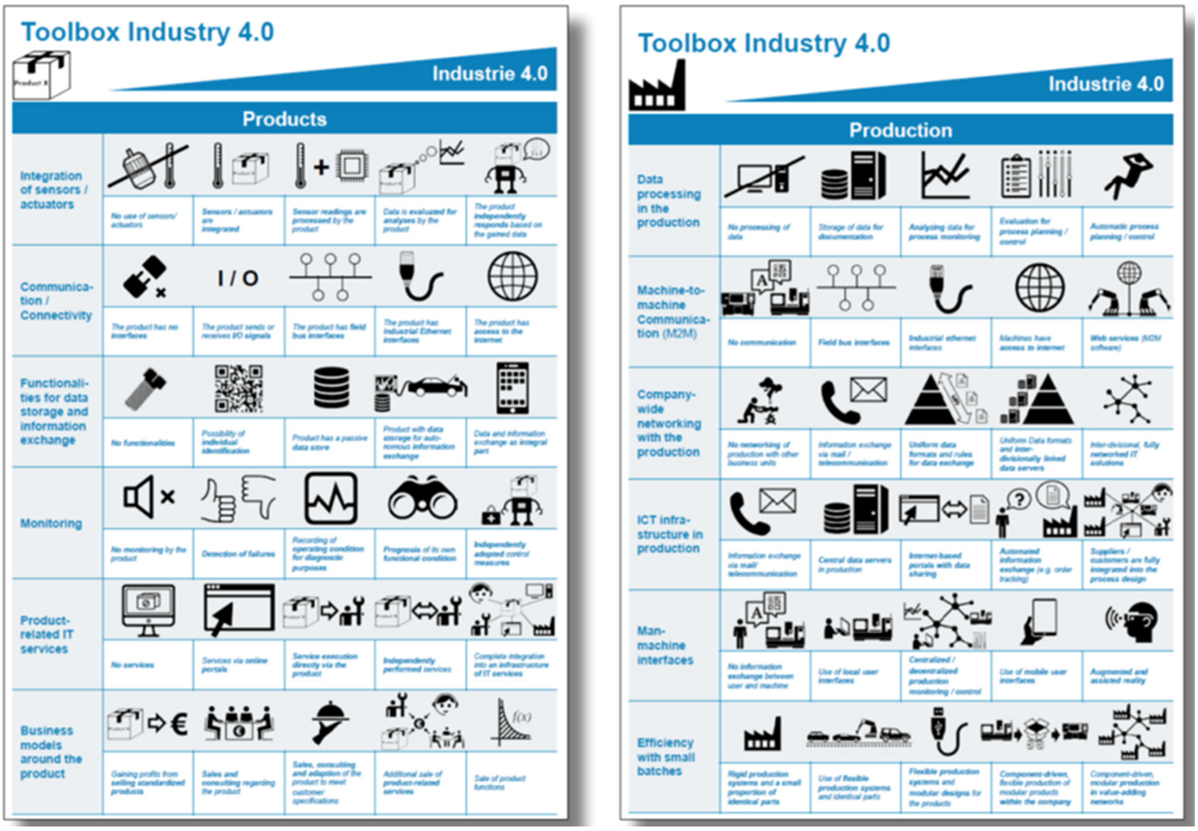

Figure 3: Toolbox Industrie 4.0 (Source: VDMA 2016)

Let us consider some of the topics in more detail. The first example may be man-machine interface. The path leads from local user interfaces (e.g. user panels for a single machine) over mobile devices like tablets, connected to the cloud, to augmented reality solutions with head-mounted displays.

What does the introduction of such a technology mean for the workers or the engineers?

Maintenance can be supported by mobile devices providing online data about the status of the machine, maintenance needs, components which might fail in the near future and have to be replaced, as well as to replace the old paper based records, which are in use today to track the service history (Figure. 4). Today this data is stored in folders next to the machines, HMI are mounted to the machines. In the future, the data is collected in the cloud and accessible from everywhere with a mobile device. This data can serve as a basis for predictive maintenance and data analytics (Figure. 4).

Maintenance technicians could get instructions from remote specialists how to fix a problem, which they cannot fix on their own.

Figure 4: Maintenance Support by Mobile Devices (Source: Festo)

Even more advanced scenarios are shown in Figure. 5. Assembly workers get direct instruction how to assemble a part on a car with the help of augmented reality. This means that the desired location of the part on the car body and the steps to fix it are displayed on the real environment. Logistic workers can get information about the location of the parts in a warehouse and the destination displayed in their glasses.

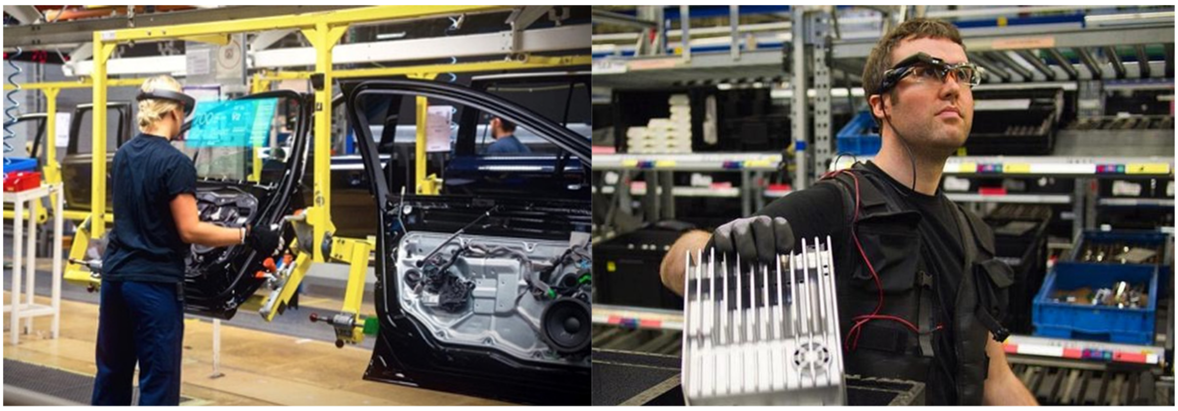

Figure 5: Sample for the use of data googles: assembly instruction and information system for logistics

The employees have to be able to use these new devices. While this might be an easy task for the younger generation, elderly might need training with the new software apps. Long-term usage of head-mounted devices might lead to pain, so there is also training needed on how to avoid this.

Workers will get access to much more data than today. To make use out of it, they have to understand how to access the data, interpret this data and check them for correctness, and finally derive appropriate action. They have to understand which indicators point to a system failure in the near future, where to get the information, how to react and how to document their actions for future use. In short, the workers need a good understanding of the whole system – meaning the machinery they have to maintain, the production processes, but also the software system supporting their work.

Engineers will design systems and machines, which will be connected to the cloud in the future. It will be crucial to know the IT systems, but also to understand what kind of sensor is necessary to collect appropriate data. To do so, they need a very good understanding of the production process, but at the same time, they need to understand the possibilities of data analytics. A similar knowledge will be required for engineers working in the production.

Another kind of assistance will come up with collaborative and mobile robots. These robots will interact directly with humans, certainly with latest safety technology. Nevertheless, the workers need special training on how to interact with these robots to avoid damage and make the best possible use of it.

The main goal of using collaborative robots is a flexible support of manual labor, even for production of small quantities. Flexibility is of high importance and hence most of the collaborative robots will come with intuitive programming environments, allowing the worker to create the necessary programs directly at his workplace (Figure. 6). While the programming might be intuitive and simple, nevertheless the workers need to learn this.

Figure 6: Sample of a collaborative robot in production

One of the most important developments for *Industrie 4.0* will be the usage of data collected from machines and smart devices. This can help to detect relations and connections that we are unable to see today, but this will be the basis for new business models and may help to take better decisions in the future. A profound knowledge about the production processes and data collection systems is the basis for realizing these possibilities.

Data Analytics combined with Artificial Intelligence may also lead to a situation in which the decisions are taken by machines, not by humans any more. Humans might only implement what the machine is telling them. Scenarios like the worker assistance might result in a de-qualification of the employees rather than a higher qualification. Similar to the earlier industrial revolutions many jobs might completely vanish. Call centers might be replaced by systems based on artificial intelligence, both technologies and artificial voice.

So we can distinguish between two possible qualification scenarios [GANZ 2017] (Figure. 7):

- Automation scenario: artificial intelligence will make the decisions, humans take over wherever machines cannot do the job. In this scenario we will see less demands for qualification, experience has less importance. Only a few very high qualified employees will be left, designing and implementing the systems;
- Specialization scenario: digital technology delivers information and helps humans to make better decisions. In this scenario human skills and experience are crucial to make use of the data offered by the systems.

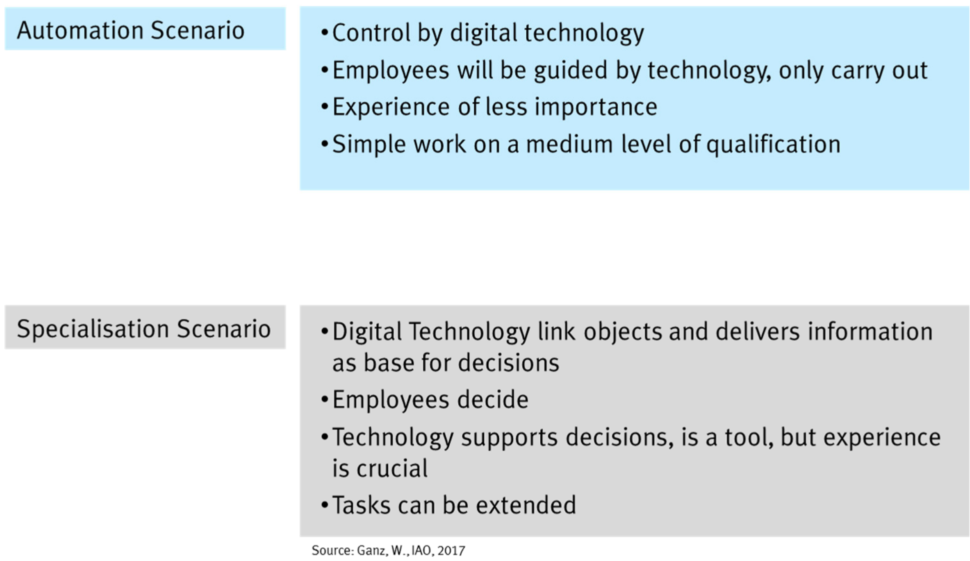

Figure 7: Two Scenarios for future work

Today it is not sure which scenario will take place, but it is a fair assumption that low skilled jobs will be replaced by improved automation and the remaining jobs will need higher understanding for systems and processes and an ability to handle the complexity.

This is also the result of a survey made by Acatech in 2016 [ACATECH 2016]. Companies were asked about the competencies, which companies and their employees will need in the future. A summary of the result is depicted in Figure. 8. It is interesting that the “technical” competencies – such as IT security, data analytics or cloud technology – are related to the companies, while the necessary competencies for the employees are more generic like “handle complex work” or “solve problems”.

	Competencies of Company	Competencies of Employees
TechnologyProcess / Data Orientation	• Analyze Data • IT Security • Cloud Architectures • Artificial Intelligence • User Support / Service	• Thinking and Acting interdisciplinary • Ability to handle complex work • Ability to interact with machines • Ability to solve problems and optimize
Process / Data Orientation	• Process Management • Customer Relation Management • Analzze IT Business • eCommerce • Online Marketing • Consulting	• Understanding Processes • Support Innovation Processes • Ability to coordinate work flows • Service orientation
Infrastructure/ Organisation	• Handling of IT systems • Administration of Networks and data bases • IT architecture • Data Security	• Ability to lead • Decide on own responsibility • Social competencies • Communication competencies

Figure 8: Future Competencies of Companies and Employees [ACATECH 2016]

So we can state that employees will need in the future:

- Good understanding of systems and processes;
- Generic competencies.

Furthermore, they will have to further learn during their whole work-life due to the rapid change of technology, and they will have to learn efficiently and quickly. This leads to the questions how we can improve the learning process and how we have to organize learning to match these requirements.

3 Some basics about Technical Education

In difference to general education in technical education the main goal is to make the learner able to act professionally on his later job. The ability to act professionally requires, beside personal preconditions, such as willingness and decisiveness, mainly two kinds of knowledge:

- The knowledge of procedures and practices, the expertise how to do something, when to do it and where to do it. This knowledge enables the learner to act (Procedural Knowledge);
- The knowledge about the theoretical background, the why we do something in the way we do it. This knowledge enables the learner to adapt his actions to changed environments accordingly (Declarative Knowledge).

It is obvious that a skilled worker needs both competencies. Knowing only the theory will not enable him to do the job efficiently. However, without a knowledge of a certain part of the theory, he will not be able to adjust his actions to changed circumstances. What is he supposed to do, if another type of screw is available? Can he use it?

Example: A worker shall assembly a product and fasten screws.

Procedures and Practices:	The worker knows how to use the tools, he knows which screws to use and where to find them. He knows how to adjust the required torque and where to find the required values in the technical documentation.
Theoretical Background:	The worker knows about the relation of torque and holding force of the screw. He knows the different screw types and their usage and the different material types.

It is important to mention that this relation is valid not only on the vocational level, but on the engineering level as well. The engineer for example needs to know how to dimension a screw, but needs also the theoretical background to decide if the calculation scheme can be applied.

Pure theory is useless without the ability to apply ("dead knowledge"), but pure application knowledge is of very limited usefulness, too ("unreflected actionism").

The two kinds of knowledge must be learned in different ways. You will never learn welding by talking about it. And you will never understand the theory of welding by only doing it.

Learning the theory means learning the relation between the different topics, how they interact and where to look for solutions. This should be done in a systematic way, therefore we call it systematic learning.

While listening to a lecture, reading a book or working on a web-based training are efficient ways of learning theory, they fail to teach practical competencies.

Practical abilities can be learned only by doing and training them. The learner has to deal with real exercises and projects. He has to apply the procedures and sometimes repeat them until he has achieved the necessary practical skills. He has to learn in real cases or casuistic (Figure. 9).

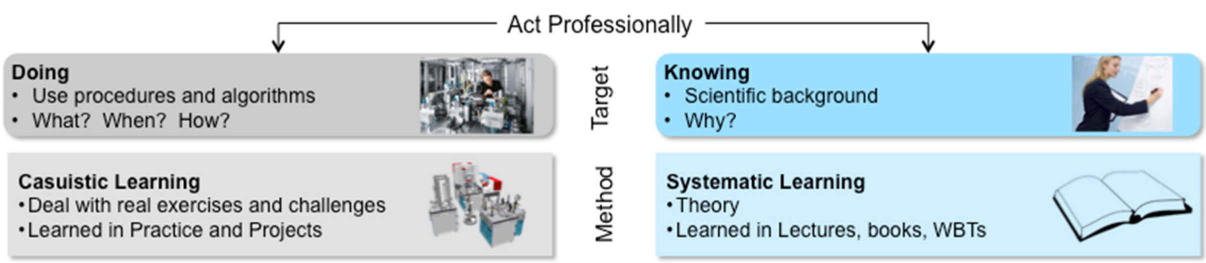

Figure 9: Relation between learning goals and learning method

Since an employee needs both types of knowledge, we need also both types of learning to achieve this knowledge. Every procedure should be connected with the necessary theory background. And every theory part should be backed by a practical application. In an ideal scenario, there is an exchange of casuistic and systematic phases, supporting each other.

Figure 10 shows a simple example. Let us assume we want to teach students how to optimize a production line with the help of KPI's, such as cycle time, OEE, MTBF etc. A sequence could look like this:

1. Show the students a model production line and let them explore the process. Explain them the goal, which might be to produce a certain amount of products in a limited time. This is the casuistic introduction, a realistic scenario, which makes the students interested and motivated;
2. Then you explain the most important KPI's and their meaning for the productivity and how they help to optimize the line. Furthermore, you show them how to measure these KPI's;
3. In the third step the students measure the KPI's and derive first actions (e.g. line balancing based on the different cycle times). They measure their results;
4. In the next step, the students compare the results with the desired output and (if the learning unit was designed well) will find their results insufficient. This encourages them to look for additional ways of improvement and therefore study the theory again.

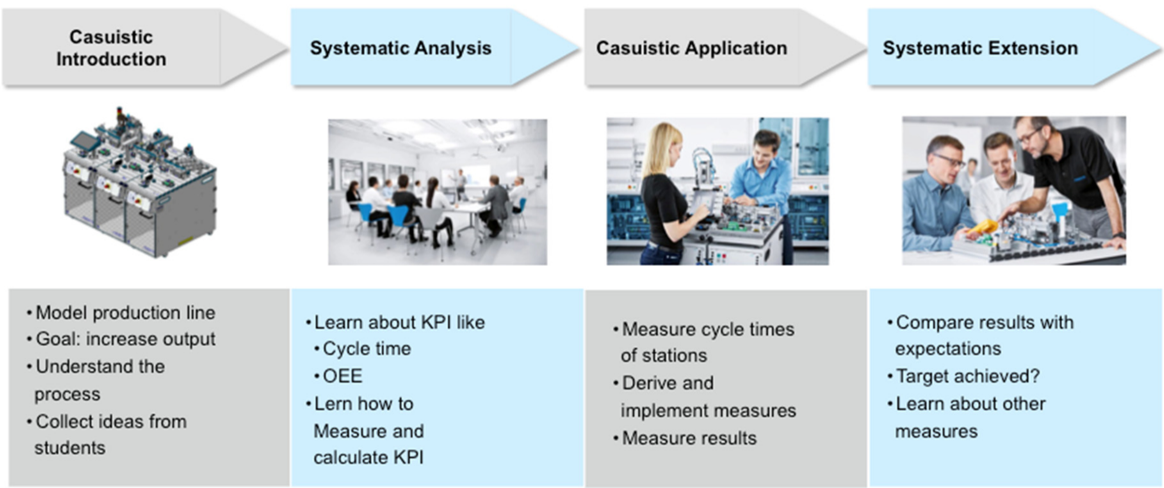

Figure 10: Exchange between casuistic and systematic phases in a training

Please note that the course design makes sure that there is a constant change between practical and theory phases. Furthermore, there is a reflection phase, which helps the students to think about what they learned and incorporate the new knowledge.

The design of a training course is carried out in three steps:

1. Define the competencies the learner shall achieve. These competencies should correspond with the later job role and typical actions in this job;

2. Define the necessary declarative (theory) and procedural (practice) knowledge;
3. Design the courseware and the learning system. The learning system must allow to perform the actions, which are related to the practical skills, the courseware must be written in a way that is understandable for the learner. The procedural knowledge determines the kind of practical exercises you will give to the students.

4 The role of Learning Factories for training

As shown in the last chapter a constant change between theory and application, between systematic and casuistic learning is necessary to understand the theory and become able to apply it. The Learning Factory is the place where the practical application takes place.

Therefore, Abele defines a learning factory as follows [ABELE 2010]:

"A Learning Factory […] is a place with realistic factory environment and direct access to production processes, which enables a problem-based and action-oriented learning".

What requirements a learning factory has to fulfil to serve this purpose? Basically it needs to be a realistic factory environment, allowing students to experience similar actions like in the real factory. But it is more than just this. To serve as a learning factory there needs to be a didactical design.

1. Based on the competencies to be achieved, the learning factory has to support exactly those processes the learner shall perform later on his job and it has to use the same technologies he will be confronted with in his job. Therefore, the job role, the technology and the education level influence the design of the learning factory;
2. There should be a didactical reduction. This means the learning factory reduces complexity wherever possible depending on the learning goals. The learner shall acknowledge the principles and not be disturbed by minor, unimportant details. This is the main difference of a learning factory to a real factory, where a lot of details and interacting processes adds a lot of complexity;
3. The learning factory needs a didactical framework. This might be instructors leading the learners or workbooks or electronic courses guiding them through their learning experience;
4. Compared to real factories learning factories should be cost-optimized. This is possible because the main purpose of a learning factory is not to produce a certain output of products, but knowledge. So very often the production process can be simplified, the product is reusable, there is only a limited number of machines, etc.

Especially point 1 leads to very different approaches for learning factories. In the following we will discuss samples of learning factories for different levels (vocational and university) and different topics (automation technology, *Industrie 4.0*, energy efficiency and lean production).

5 Samples of Learning Factories

5.1 CIP (TU Darmstadt)

The CIP (Center for Industrial Productivity) in Darmstadt (Figure. 11) was one of the first learning factory for lean production in a German university. The main objective was to create an environment where students can experience the principles of lean production.

Therefore, the setup of the CIP is very similar to a small sized industrial production. The learning factory "produces" pneumatic cylinders. Therefore, there are machine tools to make the cylinder and the piston and there are manual assembly workplaces to assemble the product.

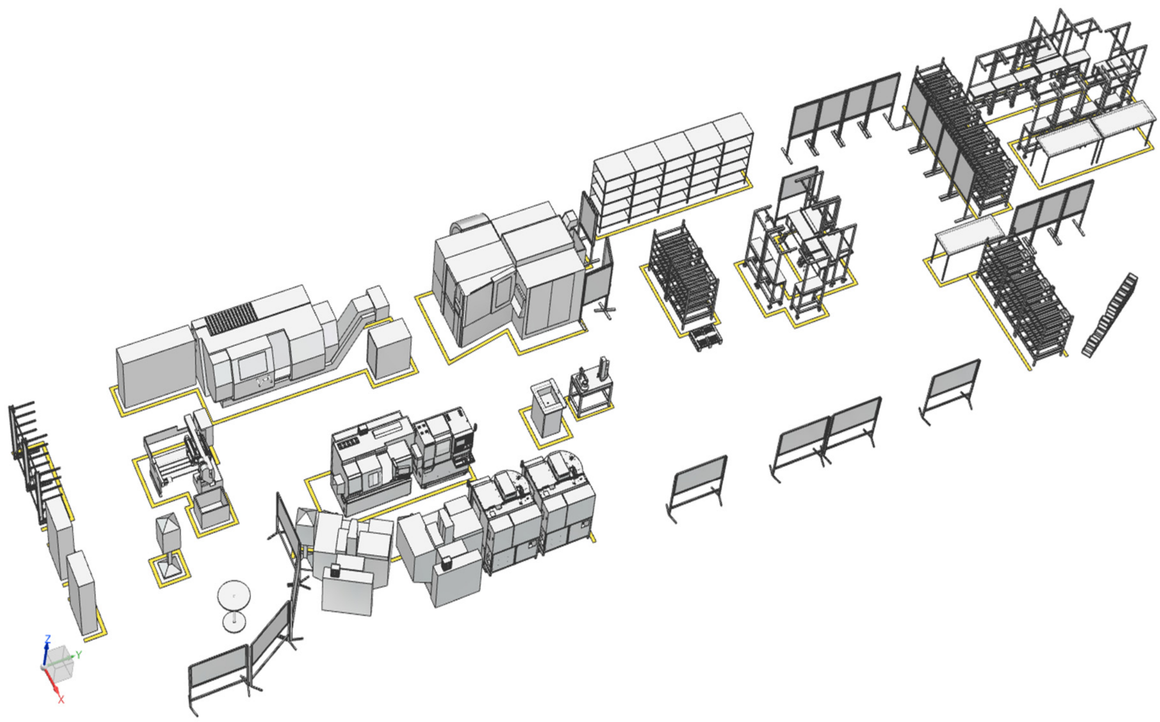

Figure 11: Layout of the CIP with machine tools, manual assembly workplaces and warehouse (Source: PTW, TU Darmstadt)

The factory is "staffed" with a group of students who "work" in the factory and produce in an initial setup. The learners observe what is going on and are guided through a process of optimizing the factory by means of improving the layout, the logistics and the setup of the workplaces. Obviously this a costly concept, since one needs a crew to run the learning factory.

Meanwhile the CIP has been developed further to integrate also *Industrie 4.0* related topics and to explore how *Industrie 4.0* can support the principles of Lean Production.

5.2 Festo Learning Factory in Scharnhausen

The Learning Factory in Scharnhausen (Figure 12) is an example for a learning factory inside a company. The Festo plant Scharnhausen produces pneumatic valves and is only four years old, incorporating latest technologies. The purpose of the learning factory inside the plant is to support all learning objectives of the plant.

Figure 12: Layout of the Learning Factory in Scharnhausen

The Learning Factory has three main parts:

- A seminar area, where short presentations take place, but also discussions and reflection phases;
- A simplified model of the highly automated valve production line. The model factory produces the same valves as the real factory;
- The “Azubibüro” (Apprentice office) is the administration of the learning factory. Apprentices are doing the administration like course booking (but not the courses itself). Furthermore, the learners can find a PC to have access to e-learning.

Why did Festo put a learning factory inside the plant? When the plant was build, a lot of new technologies were introduced. For these technologies the employees of the plant needed training. Furthermore, the plant continuously introduces within the framework of the Continuous Improvement Process new or adjusted processes and technologies. In the past, the employees had to be sent to external seminars, which was a costly and time-consuming procedure. Now ad hoc trainings, especially short ones, can be scheduled at any time. If the team manager discovers training needs, he communicates this with the learning factory management, which schedules a training at once. Very often very short training units are sufficient, e.g. 2 hours only. This is possible only because the learning factory is located in the center of the plant. And because the model factory inside the learning factory is a simplified, but realistic copy of the real production line, it is easy to create learning units which can be transferred into practice quickly.

5.3 Learning Factory 4.0 in Baden Württemberg

In 2016 the ministry of economy in Baden Wüerttemberg decided to equip 15 vocational schools in the federal state with learning factories especially for *Industrie 4.0*. Baden Württemberg is a federal state with a large number of companies producing factory equipment. The ministry considered *Industrie 4.0* as of major importance, and this measure was intended to avoid any shortage of skilled workers, which could prevent the introduction of *Industrie 4.0*.

The schools had to apply for the grant by providing a didactical concept and a concept how to train the local SMEs (**S**mall and **M**edium **S**ized **E**nterprises) in the area of the school. Since the lab hardware is not sufficient, a concept for teacher training is also needed. Driven by specialized teachers, who are responsible for training their colleagues, a concept based on six scenarios was developed:

- Scenario 1: Product Development / Planning for Industry 4.0;
- Scenario 2: Flexible Manufacturing;
- Scenario 3: MES;
- Scenario 4: Maintenance;
- Scenario 5: Energy Management;
- Scenario 6: Networking, Data Security.

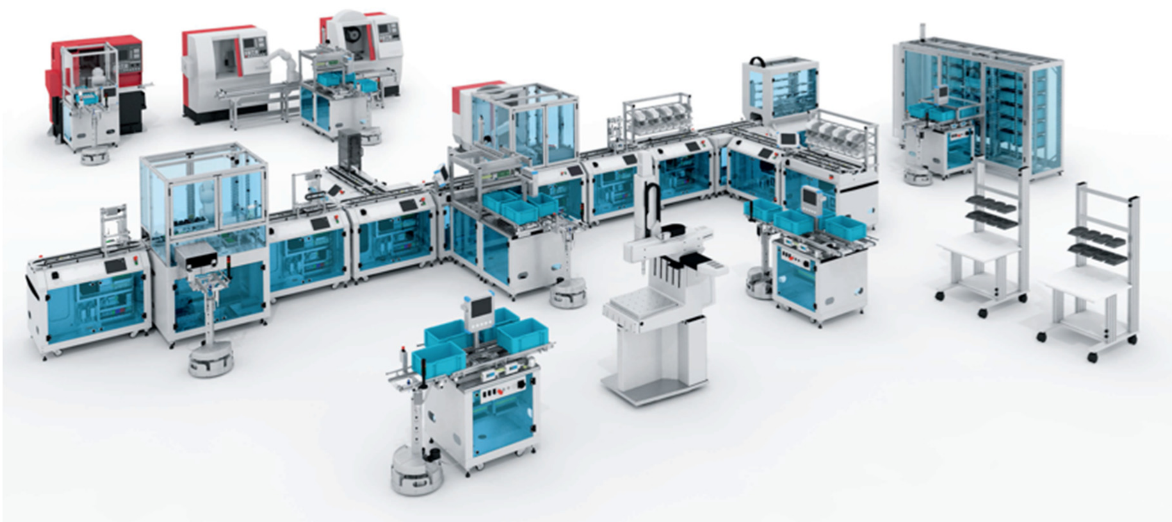

Figure 13: CP Factory, a learning factory for Industrie 4.0

For every scenario a course concept has been or will be developed, which can be used directly by the teachers. Since 13 of the 15 schools use the same system (see Figure. 13), the developed trainings can be based on one set of hardware and therefore efficiently be implemented.

What qualifies the CP Factory (Cyber-Physical Factory) for training for *Industrie 4.0*? *Industrie 4.0* requires knowledge about latest technologies, like embedded controller, RFI based logistics, mobile robots, Industrial IT as well as IT security and many more. So, the learning factory has to incorporate all these technologies and need to be open for later developments, as it is the case for the CP Factory. Actually, the CP Factory is more advanced than most installations in the industry today.

Figure. 14 shows one example of the technologies used in the CP Factory: the Cyber-Physical Stop Gate. Every base station is equipped with two conveyors for the material transport. The product is processed by modules fixed on top of the conveyor. Every position of a module is equipped with a CP Stop Gate. This stop gate serves many functions:

- It reads the information on the RFID of the palette, therefore learning the kind of workpiece and the required processing step;
- Via NFC it reads the kind of module sitting on top of the CP Stop Gate. If the module can perform the process step required by the workpiece, the process is started;
- After the processing, the CP Stop Gate changes the information on the RFID to document the progress.

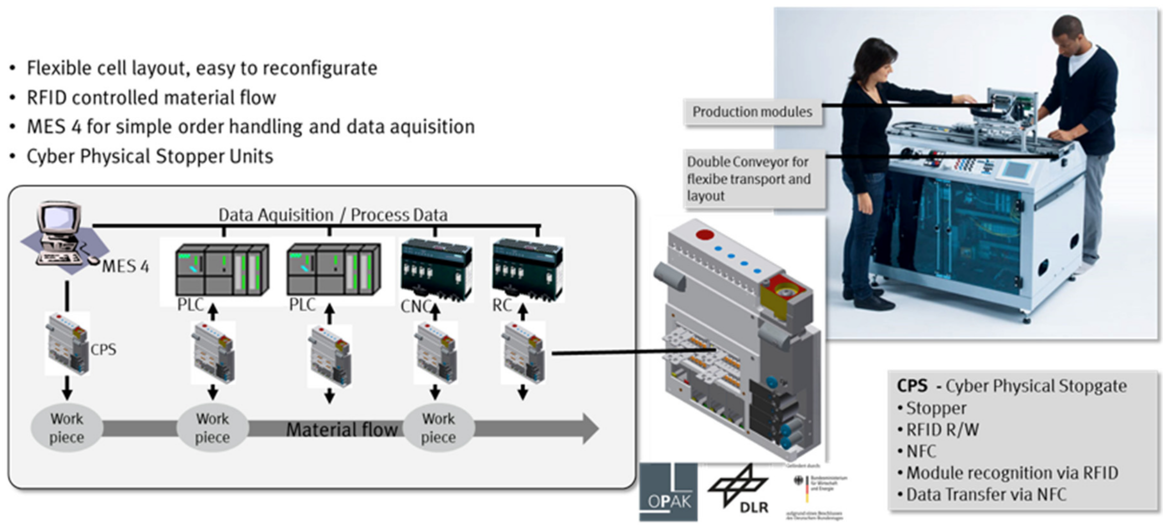

Figure 14: Cyber-Physical Stop Gate in the CP Factory

Therefore, a decentralized control architecture is implemented and can be demonstrated to the learner, as well as the RFID and NFC components. Furthermore, the learner can program the controllers and learn the new way how to program decentralized structures.

The CP Stop Gate is a cyber-physical system, which is not implemented in industry today.

6 Support learning by means of *Industrie 4.0*

Industrie 4.0 is a challenge for the education and training system, but it offers opportunities to improve learning as well. This chapter will show some examples.

6.1 QR App

MPS is a Modular Learning Factory for vocational schools and universities. Main training aims are automation, energy efficiency and Lean production. All main modules and components of a MPS station carry a sticker with a QR code. This QR code encodes the part number of the component. An app for different operating systems reads the QR code and links to the information in the Festo Didactic Info Portal see Figure 15. Here the learner finds information about the component or the complete station like:

- Description of the function;
- Description of components;
- Animation and videos explaining the function of the component;
- Circuit diagrams;
- Data sheets;
- Exercises.

Figure 15: Information via QR Code App

The learner can use his personal mobile device since the information is available freely. This function serves three main goals:

- Have always the most actual information available;

- Allow individual learning paths, depending on the knowledge of the learner;
- Support alternation between systematic and casuistic learning within the lab.

In addition to that, learners like the way the information is presented, resulting in increased motivation.

6.2 Augmented Reality

Augmented Reality means to overlap real things with additional, virtual information. Obviously, this can be used in education. Figure. 16 shows the principle. An MPS station is equipped with a tag (in this case a cube with printed markers on it). Once the AR app detects the marker additional information is displayed. The user can choose "standard" information like I/O lists, videos showing the desired function, but also can be guided through the commissioning step by step. So, the AR App can help learners to train processes. Using smart goggles like Microsoft ® HoloLens could make the use even more comfortable, because you can use both hands. On the other hand it is also advantageous, if every mobile device can be used, e.g. the learner's smart phone.

Figure 16: Commissioning guided by Augmented Reality

In this example, the border between qualification and de-qualification is a thin line. On the one hand the AR system might help to train important and typical processes more efficiently, but on the other such apps might replace skilled workers in the future, especially if combined with artificial intelligence in the background, guiding the personnel on site.

6.3 Virtual Reality

Figure 17 shows a real waste water plant and a training system (EDS Water Management). The training system is intended to demonstrate the water cycle and to understand the most important components of a waste water plant and the public water supply. Different to the learning factories we saw in the examples earlier this system looks much different than a real water plant. Furthermore, the learner needs to train certain procedures which can be trained only in the real waste water plant (e.g. safety procedures). Here a virtual waste water plant can help.

The Virtual Reality system resembles a real plant. The learner wears a VR headset and can navigate through the plant freely. Furthermore, he can manipulate important components of the plant (e.g. valves, pumps) and perform exactly those procedures that have to be trained (see Figure 18). This way VR can provide exactly the kind of training that cannot be done with a training system like in Figure 17.

Figure 17: Real Waste Water Plant and Training System EDS Water (Environmental Discovery System)

The development of complex and realistic VR scenarios is time consuming and costly. But whenever the real equipment is not available (e.g. for safety reasons) or very expensive, Virtual Reality is a way to provide practical experience in a lab environment.

Figure 18: Virtual Waste Water Plant for Training

7 Summary and Outlook

The introduction of *Industrie 4.0* will take place much faster than other changes in the past, and it will be successful only if we are able to qualify people for it. Future qualification profiles will ask not only for knowledge about the technologies involved, but also generic competencies and system understanding.

An efficient training towards these competencies needs a constant exchange between theory input and practical application.

Learning Factories are a measure to provide an environment for these practical applications. Learning Factories provide challenges and motivation. A well designed learning factory, based on the definition of target competencies, equipped with motivating and didactical designed hardware and comprehensive courseware, is an efficient way of achieving the goal.

In the future new technologies like VR, AR, etc, will offer new applications to the idea of learning factories.

8 References

[Acatech 2016] acatech – DEUTSCHE AKADEMIE DER TECHNIKWISSENSCHAFTEN in Kooperation mit Fraunhofer IML und equeo: Kompetenzentwicklungsstudie Industrie 4.0 Erste Ergebnisse und Schlussfolgerungen April 2016

[Abele 2010] Abele, E., Tenberg, R., Wenemer, J., Cachay, J., 2010.: Kompetenzentwicklung in Lernfabriken für die Produktion. Zeitschrift für wirtschaftlichen Fabrikbetrieb

[Blume et al. 2015] S. Blume, S. Böhme, N. Madanchi, G. Posselt and C. Herrmann, 2015: Die Lernfabrik – Research-based Learning for Sustainable Production Engineering

[Abele 2015] Abele et al.: Learning Factories for research, education, and training, Proc. Of The 5th Conference on Learning Factories 2015

[VDMA 2016] VDMA: Guideline Industrie 4.0, 2016

[Ganz 2015] Ganz, W.: Digitale Transformation – Herausforderungen für die Arbeitswelt, Presentation for the Plattform Industrie 4.0, AG5, 18.5.2017

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05.10.2017
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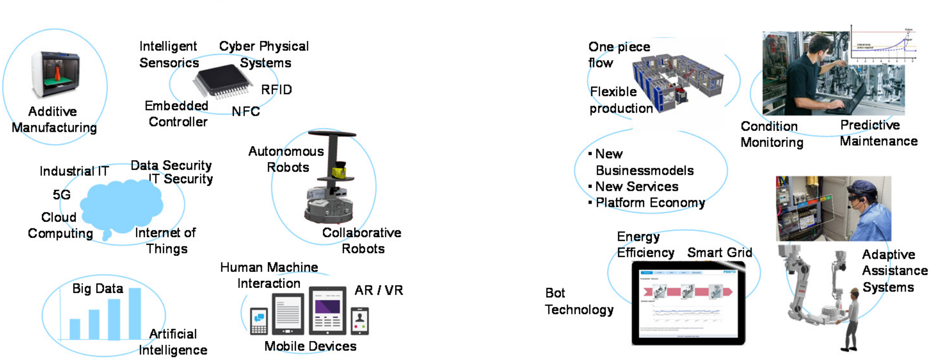
Industrie 4.0 – from Technology to Education



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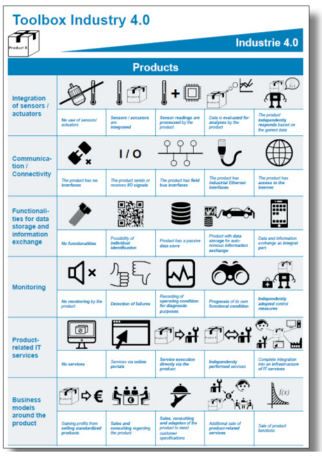
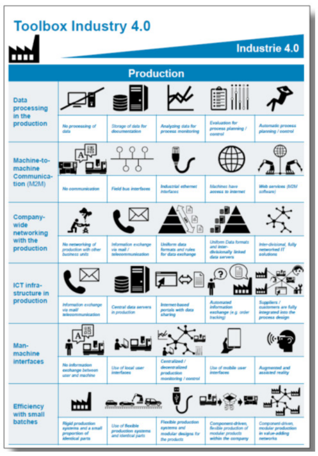
Training Needs
The Technology View

Industrie 4.0 will change
- Products
- Production

Toolbox Industry 4.0 shows what technologies will be used





Source: VDMA: Guideline Industrie 4.0, 2016

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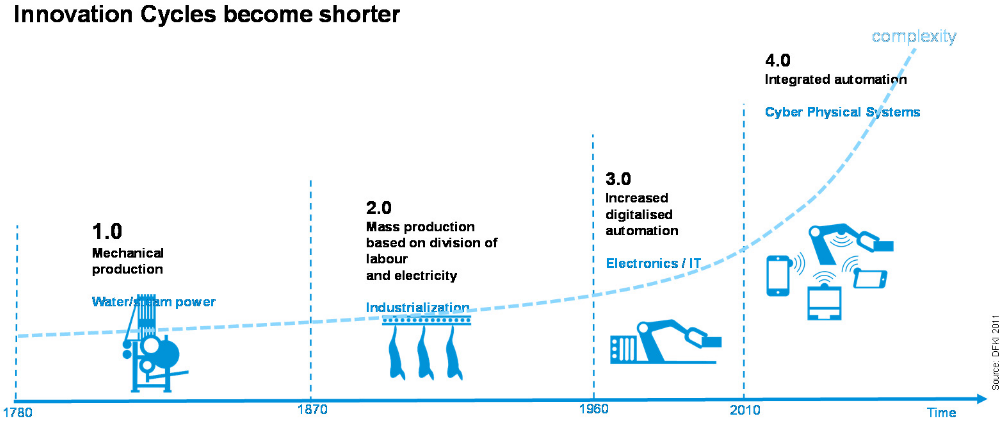
Innovation Cycles become shorter



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Detailed View – Collaborative Robots

- Collaborative Robots interact directly with humans
- Support handicapped or elderly
- Higher flexibility by intuitive programming
- Suited for small batch sizes

Training Needs:

- Shop floor programming
- Human machine interaction

Risks:

- Humans has to follow machines

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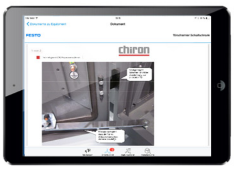
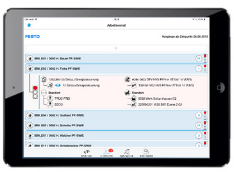
Detailed View – Workers Assistance





Information/guidance for
- commissioning
- Maintenance
- logistics

Source: www.ingenieur.de/mediaviewer/show/43 5840/435837

Training Needs:
- Using mobile devices
- Find and use data
- Understanding systems

Risks:
- Humans has to fulfil orders from machines
- dequalification

Srce: www.ingenieur. oude/Branchen/Verkehr-Logistik-Transport/Autoteile-schneller-fehlerfreier-Datenbrille-kommissionieren

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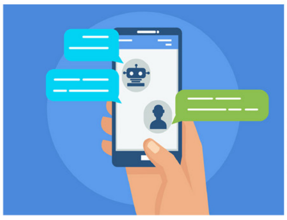
Detailed View – Data Analytics, Artificial Intelligence

- Artifical Intelligence helps analysing data
- Bot Technology to interact with humans
- Data as the new oil

Training Needs:

- Data Analytics
- Understanding systems
- Data based decisions



Source: https://chatbotnewsdaily.com/5-examples-of-chatbots-in-apps-taking-us-into-the-future-98b0743bfc8

Chatbots in Callcenter

Source: http://www.ecommercetimes.com/story/81053.html IBM's Watson May Change the Face of Business Analytics

Artifical Intelligence to analyse data

Risks:

- Decisions made by machines
- Dequalification
- Loss of jobs in administration

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Future of Work – Two Possibilities

Automation Scenario	•Control by digital technology •Employees will be guided by technology, only carry out •Experience of less importance •Simple work on a medium level of qualification
Specialisation Scenario	•Digital Technology link objects and delivers information as base for decisions •Employees decide •Technology supports decisions, is a tool, but experience is crucial •Tasks can be extended

Source: Ganz, W., IAO, 2017

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Industry 4.0 – Competencies of Companies and Employees

	Competencies of Company	Competencies of Employees
TechnologyProcess / Data Orientation	• Analyze Data • IT Security • Cloud Architectures • Artificial Intelligence • User Support / Service	• Thinking and Acting interdisciplinary • Ability to handle complex work • Ability to interact with machines • Ability to solve problems and optimize
Process / Data Orientation	• Process Management • Customer Relation Management • Analzze IT Business • eCommerce • Online Marketing • Consulting	• Understanding Processes • Support Innovation Processes • Ability to coordinate work flows • Service orientation
Infrastructure/ Organisation	• Handling of IT systems • Administration of Networks and data bases • IT architecture • Data Security	• Ability to lead • Decide on own responsibility • Social competencies • Communication competencies

Source: acatech2016

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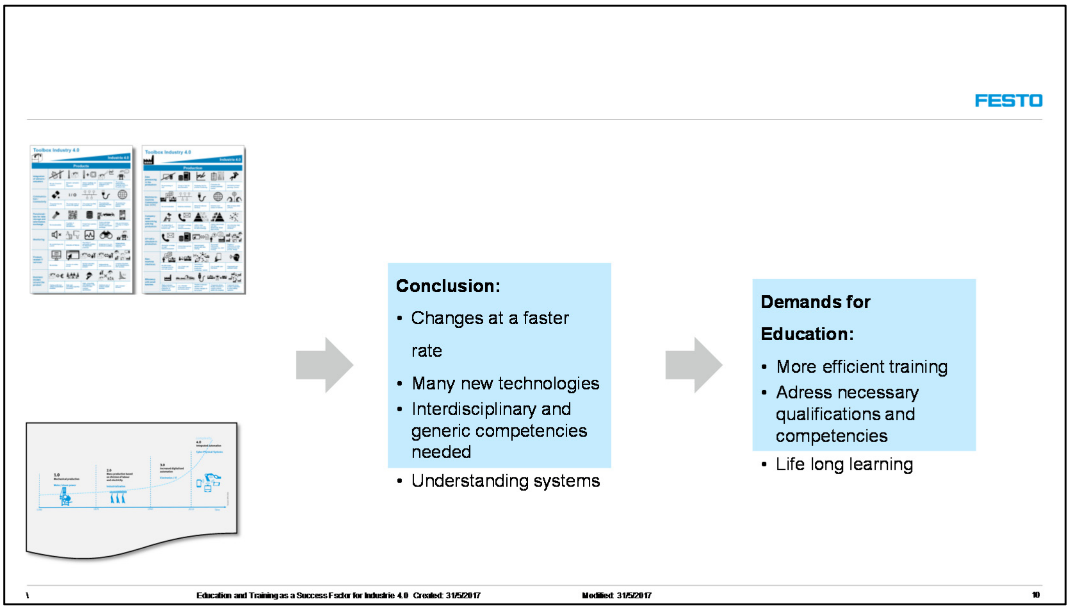
FESTO
Conclusion:
• Changes at a faster rate
• Many new technologies
• Interdisciplinary and generic competencies needed
• Understanding systems
Demands for Education:
• More efficient training
• Adress necessary qualifications and competencies
• Life long learning
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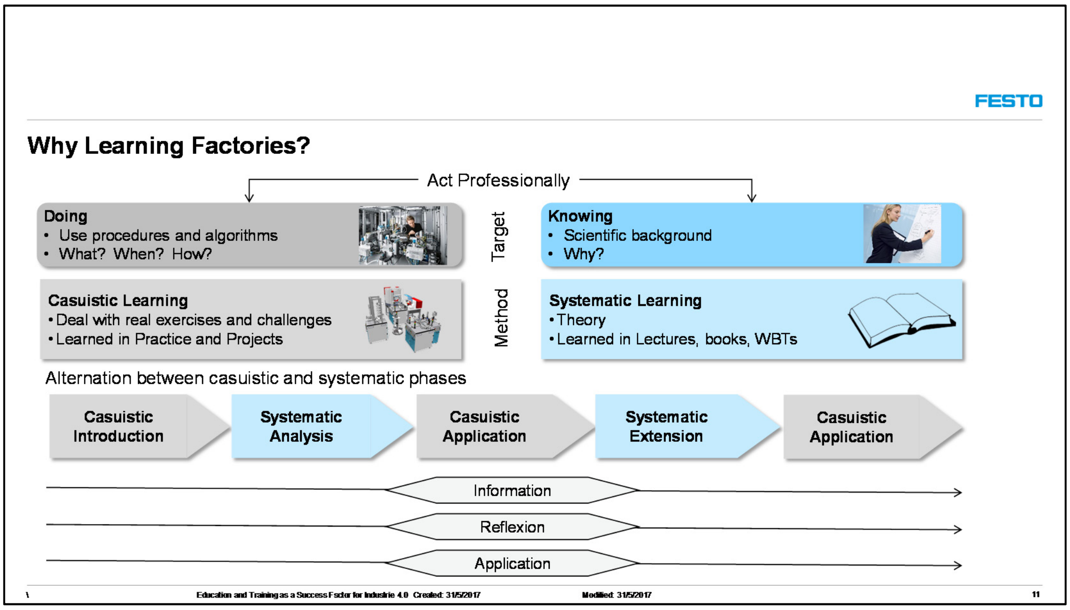
FESTO
Why Learning Factories?
Act Professionally
Doing
• Use procedures and algorithms
• What? When? How?
Target
Knowing
• Scientific background
• Why?
Casuistic Learning
• Deal with real exercises and challenges
• Learned in Practice and Projects
Method
Systematic Learning
• Theory
• Learned in Lectures, books, WBTs
Alternation between casuistic and systematic phases
Casuistic Introduction
Systematic Analysis
Casuistic Application
Systematic Extension
Casuistic Application
Information
Reflexion
Application
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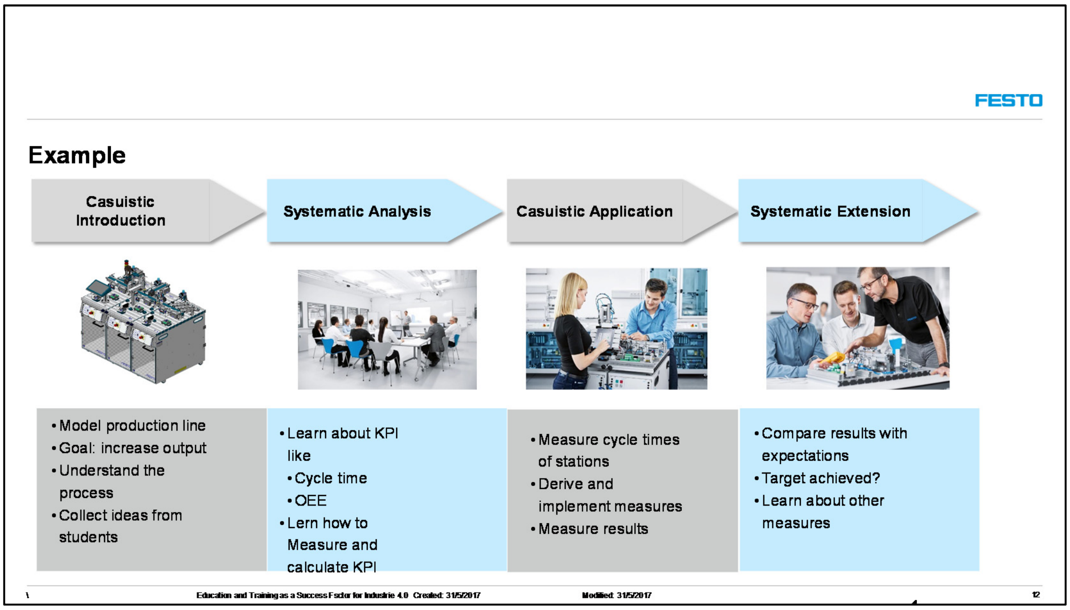
FESTO
Example
Casuistic Introduction
Systematic Analysis
Casuistic Application
Systematic Extension
• Model production line
• Goal: increase output
• Understand the process
• Collect ideas from students
• Learn about KPI like
• Cycle time
• OEE
• Lern how to Measure and calculate KPI
• Measure cycle times of stations
• Derive and implement measures
• Measure results
• Compare results with expectations
• Target achieved?
• Learn about other measures
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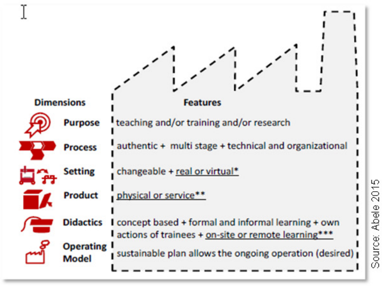
Learning Factories as Didactical Medium

Definition of Learning Factory:

[Eine Lernfabrik]. …ist ein Ort mit realitätsnahem Fabrikumfeld und dir… Pr… [Ab…

A Learning Factory … is a place with realistic Factory environment and direct access to production processes, which enables a problembased and action-oriented learning
[Abele 2010, Translation: R. Pittschellis]



A Learning Factory is a realistic, but for didactical reasons simplified model of real working environments, which allows problem based, project based and action oriented trainings

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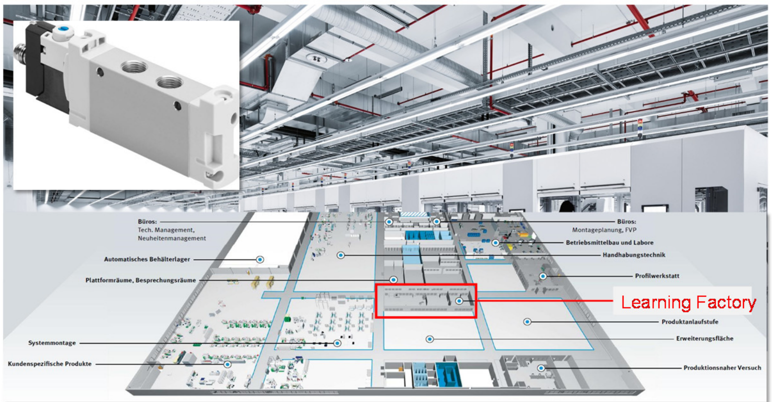
Example 1: Learning Factory as integrated part of the Festo Plant Scharnhausen



Learning Factory in the heart of the factory:

- Learning on demand
- Short training units (30 min)
- Managers as trainers
- Train the trainer concept
- Administration by apprentices
- Covering:
  - Basics (Soldering, screwing, …)
  - Product trainings
  - Automation
  - Organisation (5S, One piece flow,…)

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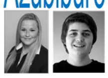
Setup of the Learning Factory Scharnhausen

Seminar Room
- Short theory sessions
- Introductions
- reflections

Training Equipment:
- CP Factory
- Training Bench Energy
- Training Bench Soldering…

Azubibüro



- PC-Workplaces for E-Learning
- Admin via Apprentices

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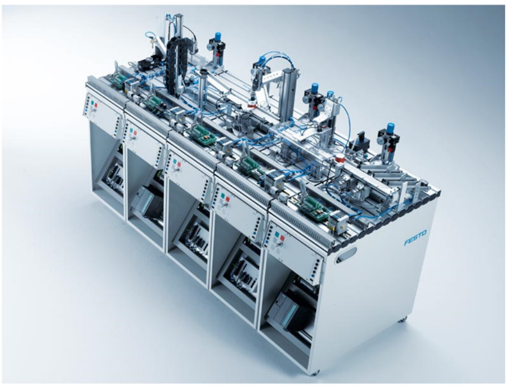
Example 2: Learning Factory for Business Students FH Johanneum (Austria)

Students of Industrial Engineering needs basic knowledge of automation technology and deep understanding of production management

Learn Basics of Automation Technology With MPS
↓
Learn about production related KPI (OEE, MTBF, …)
↓
Measure these KPI with MPS stations
↓
Optimize Performance by technical changes



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Example 3: Industry 4.0 for 15 Vocational Schools in Baden Württemberg

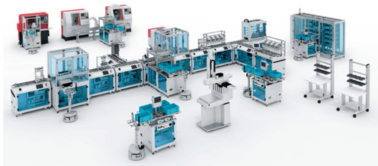
Background

- Baden Württemberg, a federal State of Germany
- Supplier for factories around the world
- Leading innovations in Factory Automation
- Strong industry, strong SME
- Well established partnership Industry – Schools
- High ranking education system

- Industry 4.0 needs well qualified employees!

Framework of the Project

- Equipment for 15 vocational schools in Baden Württemberg with Industry 4.0 Lab
- Budget: 6 Mio. € federal support, plus 6 Mio. € generated by schools and industry
- Sponsored development of didactical concept
- Train the trainer concept for all teachers
- Concept for supporting SME for Industry 4.0



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Example 3: Industry 4.0 for 15 Vocational Schools in Baden Württemberg

Teacher Support

- Mark all I 4.0 topics in curricula
- Develop 6 scenarios for I 4.0
- Teacher training according to the 6 scenarios by specialized teachers
- Forum: www.cp.community.festo.com

Content of Train the Trainer program:

Scenario 1: Product Development / Planning for Industry 4.0

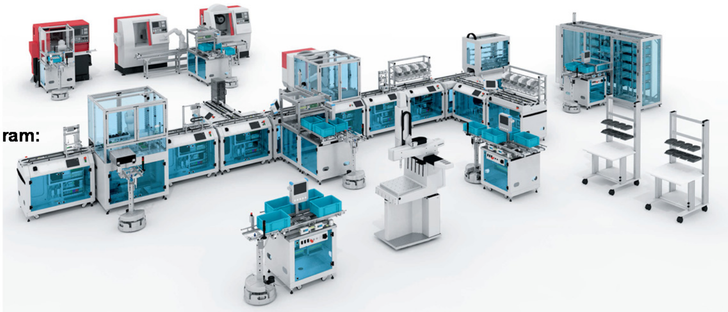
Scenario 2: Flexible Manufacturing

Scenario 3: MES

Scenario 4: Maintenance

Scenario 5: Energy Management

Scenario 6: Networking, Data Security



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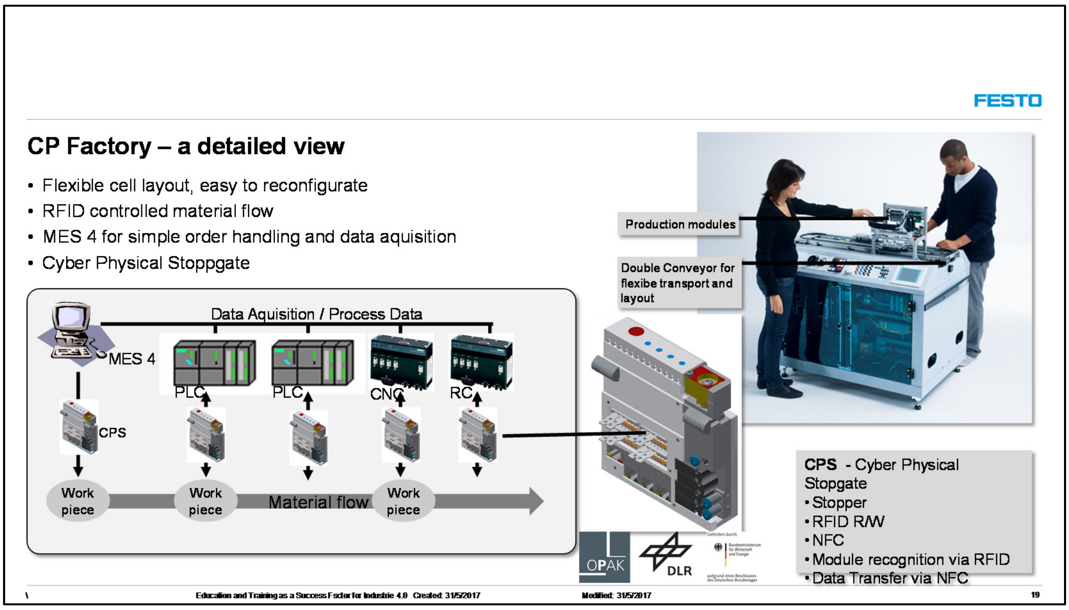
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CP Factory – a detailed view
• Flexible cell layout, easy to reconfigurate
• RFID controlled material flow
• MES 4 for simple order handling and data aquisition
• Cyber Physical Stoppgate
Data Aquisition / Process Data
MES 4
PLC
PLC
CNC
RC
CPS
Work piece
Work piece
Material flow
Work piece
Production modules
Double Conveyor for flexibe transport and layout
CPS - Cyber Physical Stopgate
• Stopper
• RFID R/W
• NFC
• Module recognition via RFID
• Data Transfer via NFC
OPAK
DLR
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Learning Factory for Ressource Efficient Production
•Lecture „Sustainability in Production Engineering"
•Lab Experience: Learning by Research
• Students derives open research questions in the lecture
• Work on these questions in small groups
• Apply in the learning factory
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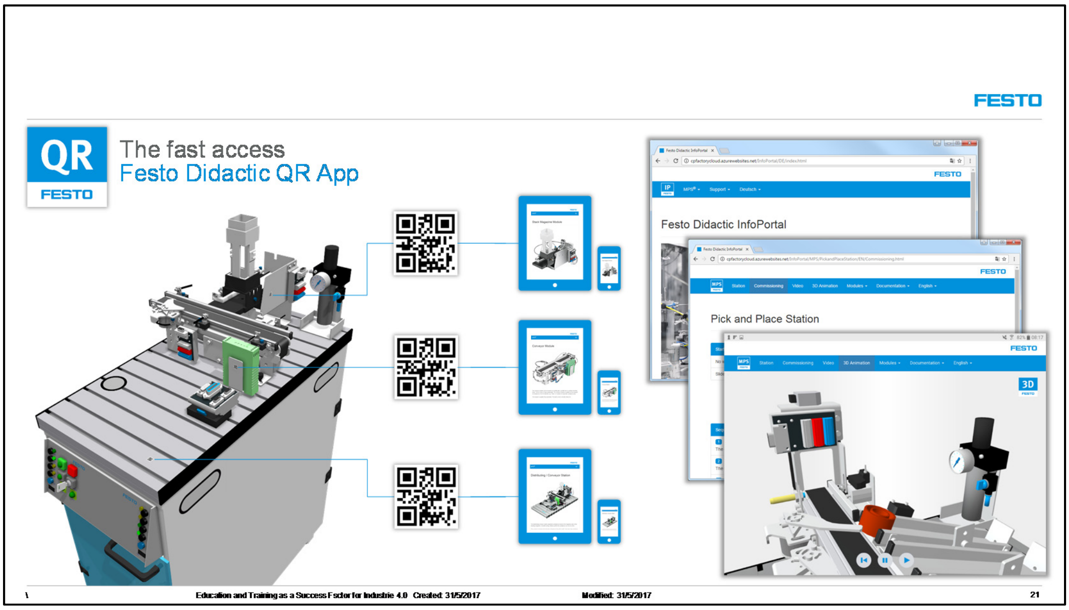
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QR
FESTO
The fast access
Festo Didactic QR App
Festo Didactic InfoPortal
Pick and Place Station
3D
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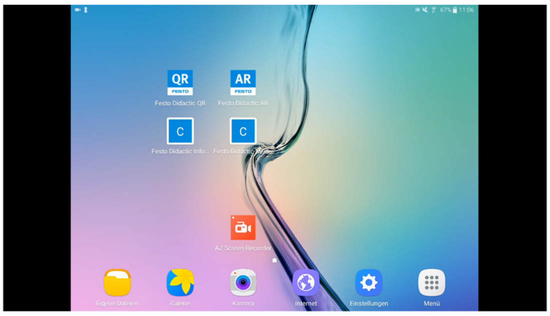
AR FESTO

Intuitive human-machine-interface
Festo Didactic AR App



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VR in Water/Wastewater Training

Von Louis-F. Stahl, CC BY-SA 3.0 de, https://commons.wikimedia.org/w/index.php?curid=20913394

Real Wastewater Plant

EDS Water

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VR simulator for simulating a wastewater treatment plant

Immersive training for water and wastewater professionals

Source: EON, https://www.youtube.com/watch?v=qZr_jaFFsfU

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Eng. Carlos Lino Santiago

Carlos Santiago was born in 1974 and studied Electrical Engineering at the Polytechnic School of the University of São Paulo, Brazil, where he received his diploma in 1997. From 1998 to 1999 he worked at Ford Motor Company of Brazil as an engineering trainee in the Product Development Department. In 1999 he served as Assembly Line Supervisor and Quality Responsible and Special Projects Manager of the Assembly at IVECO S.p.a. in Italy until the year 2001. Between 2001 and 2002 he worked as Product Manager of Fiat Brand and Direct Sales Responsible for logistics at Fiat Auto S.p.a. in Portugal. After some experience in the area, he earned a specialization in Industrial Administration at the Federal University of Paraná, receiving his diploma in 2004. In 2002, he worked for CNH Latin America Ltda as Project Manager, Material Planning Supervisor, Production Manager and Manager of Plant. Between the years 2009 and 2015 he went through several positions of the company CNH in Italy - Plant Manager, Industrial Director and Industrial Director in Brazil. In March 2016, he was invited to the position of director in the Operations area of the Mercedes-Benz do Brasil, responsible for the production of trucks in São Bernardo do Campo (SP) and Juiz de Fora (MG) plants. After a year of acting in this area, he was invited to act as Vice-President of Operations, responsible for the entire operations area of the São Bernardo do Campo, Juiz de Fora plants and parts remanufacturing in Campinas.

carlos_lino.santiago@daimler.com

Mercedes-Benz do Brasil

Having been present in the country for over 60 years, Mercedes-Benz do Brasil, a company pertaining to Daimler Group, is the largest manufacturer and exporter of trucks and buses of Latin America, and leader in vehicles technology for the freight and passengers transport. Currently the company is the single one to produce vehicles of all segments in Latin America: cars, light commercial vehicles (Sprinter and Vito), trucks and bus chassis. The Company has production units of trucks, bus chassis and aggregates in São Bernardo do Campo (SP), cabins and trucks in Juiz de Fora (MG), and cars in Iracemápolis (SP). Further to the Parts and Customer Services unit, Parts Logistic Center and Global Training unit in Campinas (SP), as well as the Technological Development Center, located also in São Bernardo do Campo, which is the largest in South America.

Application of Industry 4.0 technologies in Operations today

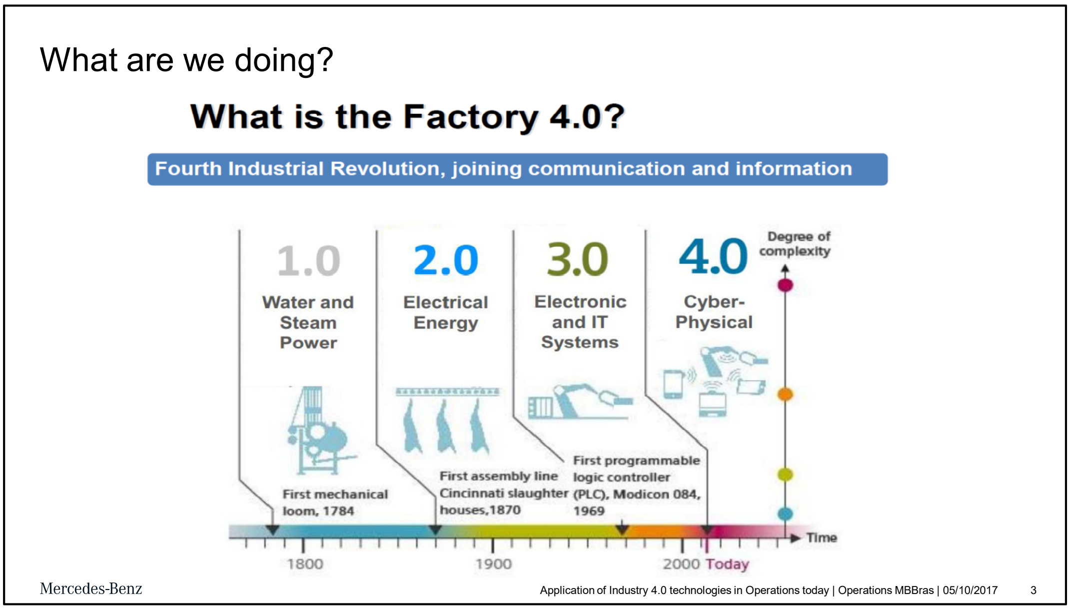
Abstract

The Fourth Industrial Revolution or the Industry 4.0 has been thoroughly studied in the past recent years. Different technologies were assessed in a way to boost efficiency, productivity, automation and take Industrial Operations to the next level. Today, the theory has already turned into practice and several examples of these technologies can be found on the Shopfloor of different production sites. Starting with Process Automation with machine self-control to check if all the safety specifications of a certain product have been reached, achieving practically zero faults to the customers. Summing up with Collaborative Robots working alongside the operators, but performing tasks that are unfit for a human being from a health perspective, reducing injuries and improving employee satisfaction. In addition, merging the data from production, suppliers, operator and robots in one Data Lake and using Analytics and Machine Learning, all the quality issues can be mitigated before the product reaches the end of the line. And also does the robot with multiple sensors in its motors and joints warn the operator when it will need its maintenance, before the breakdown, increasing its uptime. What was before in the books are now a reality and to stay competitive, the operational units must take advantage of these solutions and reinvent themselves.

Keywords

Industry 4.0; Operations; Automation; Collaborative Robots; Data Lake; Analytics; Machine Learning.


Application of Industry 4.0 technologies in Operations today
Carlos Santiago
Piracicaba - October 5th, 2017
Mercedes-Benz
Trucks you can trust


What are we doing?
What is the Factory 4.0?
Fourth Industrial Revolution, joining communication and information
1.0
Water and Steam Power
2.0
Electrical Energy
3.0
Electronic and IT Systems
4.0
Cyber-Physical
Degree of complexity
First mechanical loom, 1784
First assembly line Cincinnati slaughter houses, 1870
First programmable logic controller (PLC), Modicon 084, 1969
Time
1800
1900
2000 Today
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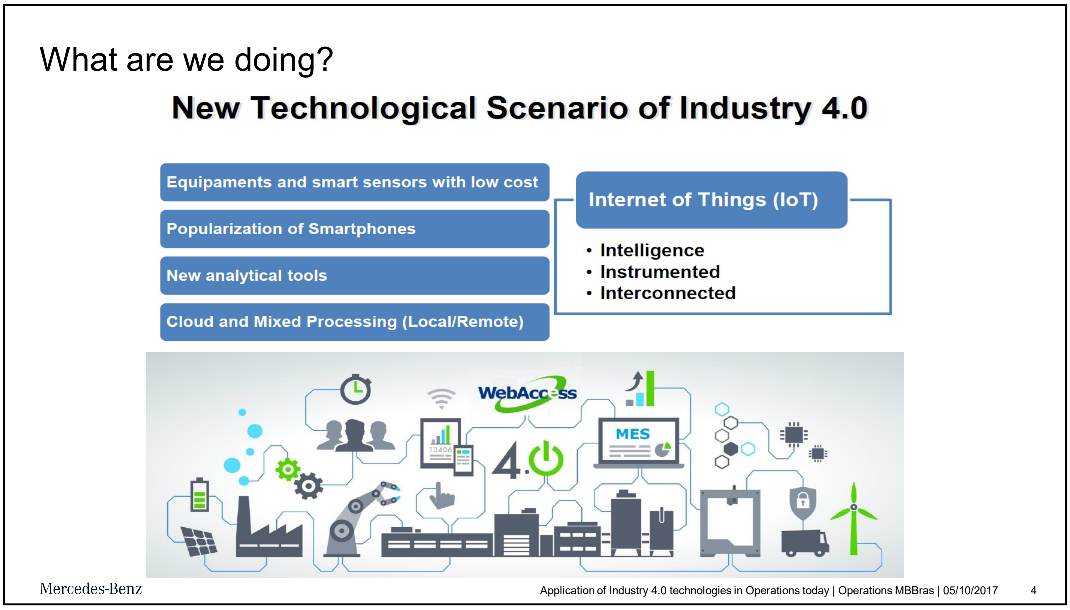
What are we doing?
New Technological Scenario of Industry 4.0
Equipaments and smart sensors with low cost
Popularization of Smartphones
New analytical tools
Cloud and Mixed Processing (Local/Remote)
Internet of Things (IoT)
• Intelligence
• Instrumented
• Interconnected
WebAccess
MES
4.0
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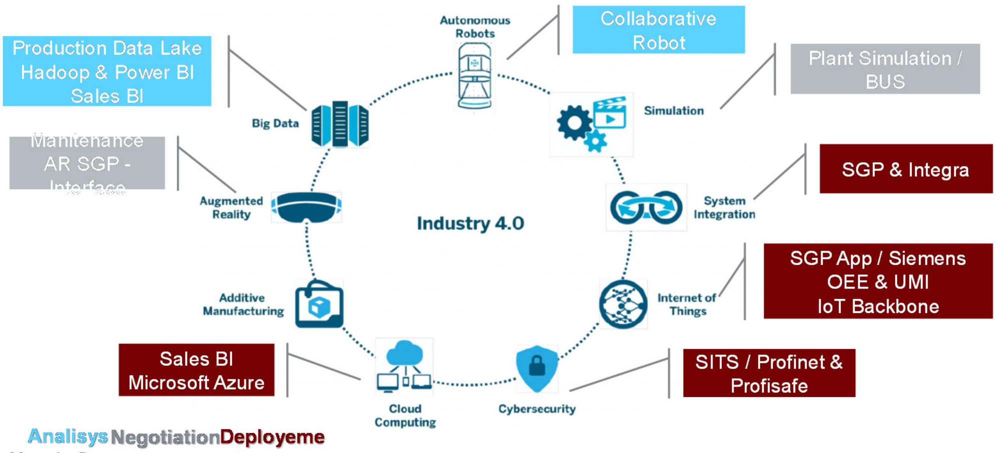
What are we doing?

Facts of Factory 4.0 and IIoT



Analisys Negotiation Deployement

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Agenda

1. Automated AGVs
2. Process control through cameras – Brazil and Germany
3. Real Time Maintenance
4. Manufacturing Execution Systems
5. Collaborative Robots
6. Pick by light
7. Mobile App
8. Big Data Analytics Initiatives

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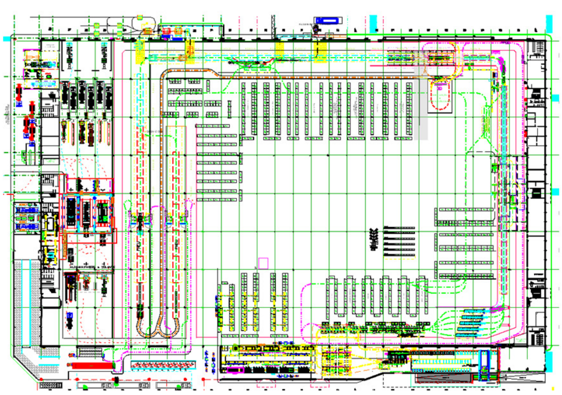
Comparison between concepts - AGV x Carrier lines



Automated Guided Vehicle

- Flexibility of process ✓
- Functional concept ✓
- Diverse routes and possibilities of process ✓
- Low infra-structure necessity ✓
- High technology of equipment ✓

Carrier Chain Line

- Inflexible process ✗
- Functional concept ✓
- Only one route of process ✗
- High infra-structure necessity ✗
- Low technology of equipment ✗

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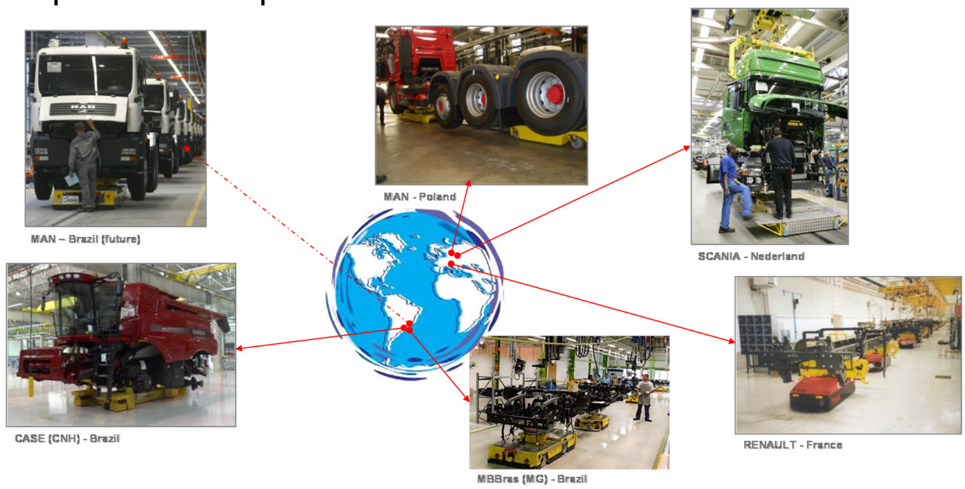
Competitors concept around the world - AGV's line



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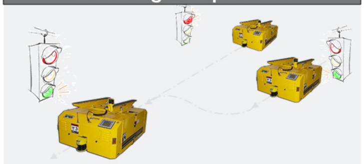
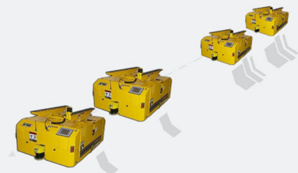
High advantages of AGV line

Teaching new process



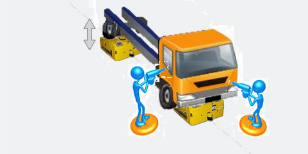
- Possibility to open the assembly line to add an AGV that was in the training area;
- Execute the specific training on-the-job and remove back the AGV for more details;

Recovery of production



- Possibility to recovery the production if any problem happens in the line;
- Possibility to remove the space that was opened for introduction of [illegible] AGV's;

Working ergonomics



- Every AGV (Circuit 2) has a lift capable to elevate the truck in an ergonomic position, depending of the height of worker;
- Allow different workers do the same operation;

Flexibility of new routes

- Possibility to created different routes for the AGV's, depending on our necessity;
- Provide the concept of a higher flexibility of circuits and facilitate to add new processes

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Agenda

1. Automated AGVs
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Process control through cameras – Brazil

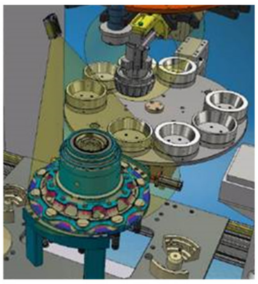
Process control via cameras to check if grease has been correctly applied, otherwise, interrupting the process:

Situation 1:

Without grease

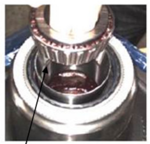
With grease

Red grease applied



Situation 2:

Without grease

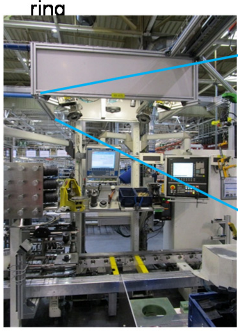


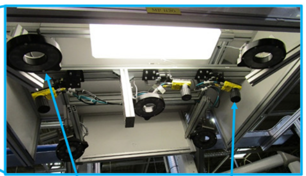
With grease

Red grease applied

Process control through cameras – Germany

Station Equipment to check correct assembly of snap ring





Spot

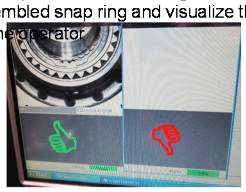
Camera

- 3 Cameras to check correct assembly in 360°
- 5 spots to illuminate the part independent from external influences

1. Operator assembles the snap ring

2. Station will be illuminated to avoid external influences to manipulate the checking result

3. Compares reference images of assembled snap ring and visualize the result for the operator



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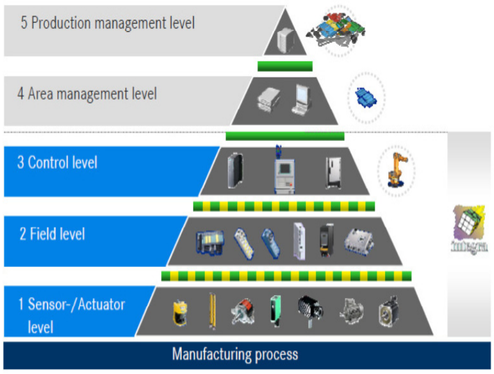
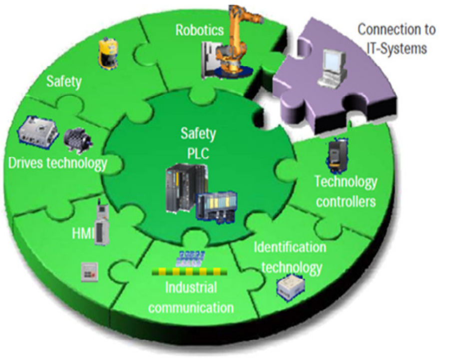
8. Big Data Analytics Initiatives

Global standard of INTEGRA programming architecture

integra – integrated standardization levels 1-3



integra – standardization of components



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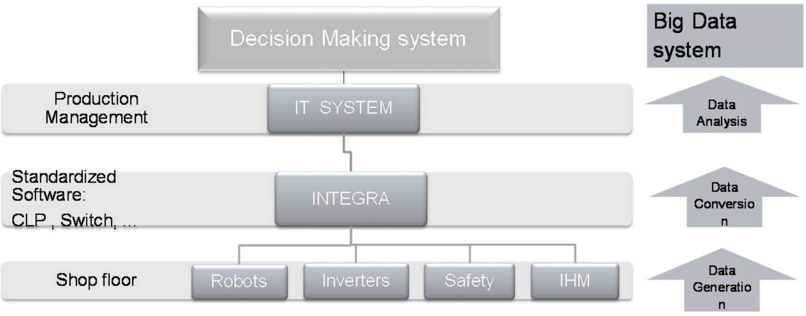
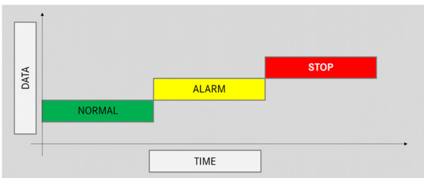
Data workflow for decision making





Benefit: Starting from the monitoring it is possible to replace a component before a critical stoppage

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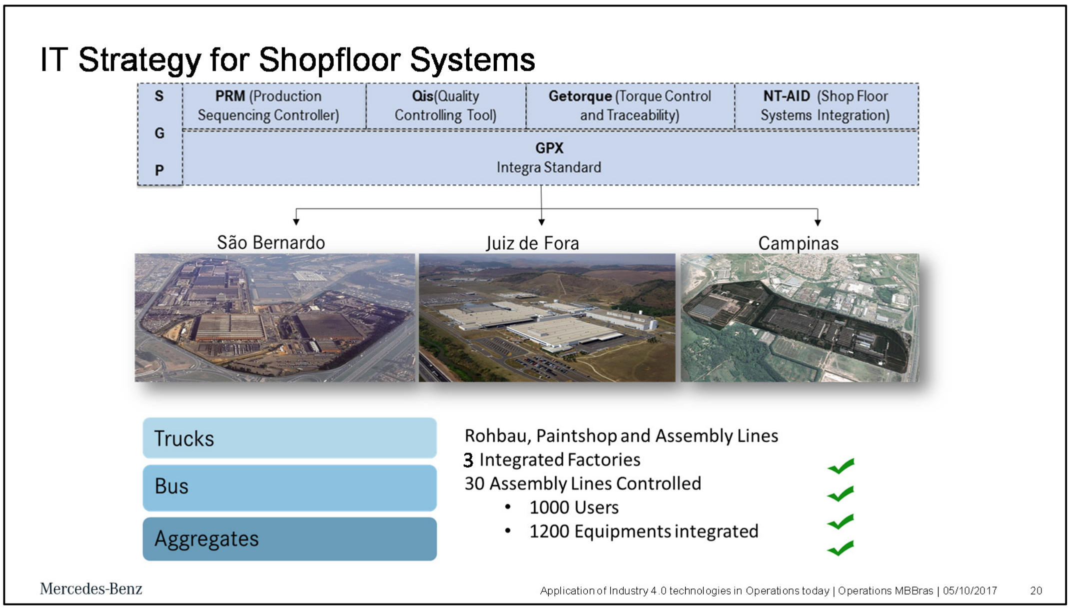
IT Strategy for Shopfloor Systems
S
G
P
PRM (Production Sequencing Controller)
Qis(Quality Controlling Tool)
Getorque (Torque Control and Traceability)
NT-AID (Shop Floor Systems Integration)
GPX
Integra Standard
São Bernardo
Juiz de Fora
Campinas
Trucks
Bus
Aggregates
Rohbau, Paintshop and Assembly Lines
3 Integrated Factories
30 Assembly Lines Controlled
• 1000 Users
• 1200 Equipments integrated
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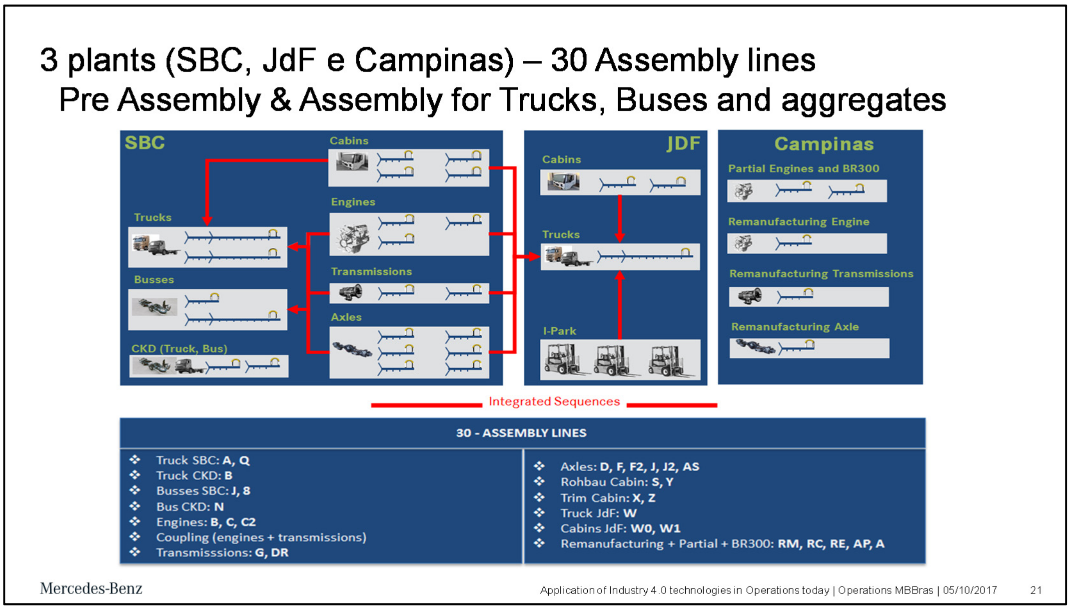
3 plants (SBC, JdF e Campinas) – 30 Assembly lines
Pre Assembly & Assembly for Trucks, Buses and aggregates
SBC
Cabins
Engines
Trucks
Busses
Transmissions
Axles
CKD (Truck, Bus)
JDF
Cabins
Trucks
I-Park
Campinas
Partial Engines and BR300
Remanufacturing Engine
Remanufacturing Transmissions
Remanufacturing Axle
Integrated Sequences
30 - ASSEMBLY LINES
Truck SBC: A, Q
Truck CKD: B
Busses SBC: J, 8
Bus CKD: N
Engines: B, C, C2
Coupling (engines + transmissions)
Transmisssions: G, DR
Axles: D, F, F2, J, J2, AS
Rohbau Cabin: S, Y
Trim Cabin: X, Z
Truck JdF: W
Cabins JdF: W0, W1
Remanufacturing + Partial + BR300: RM, RC, RE, AP, A
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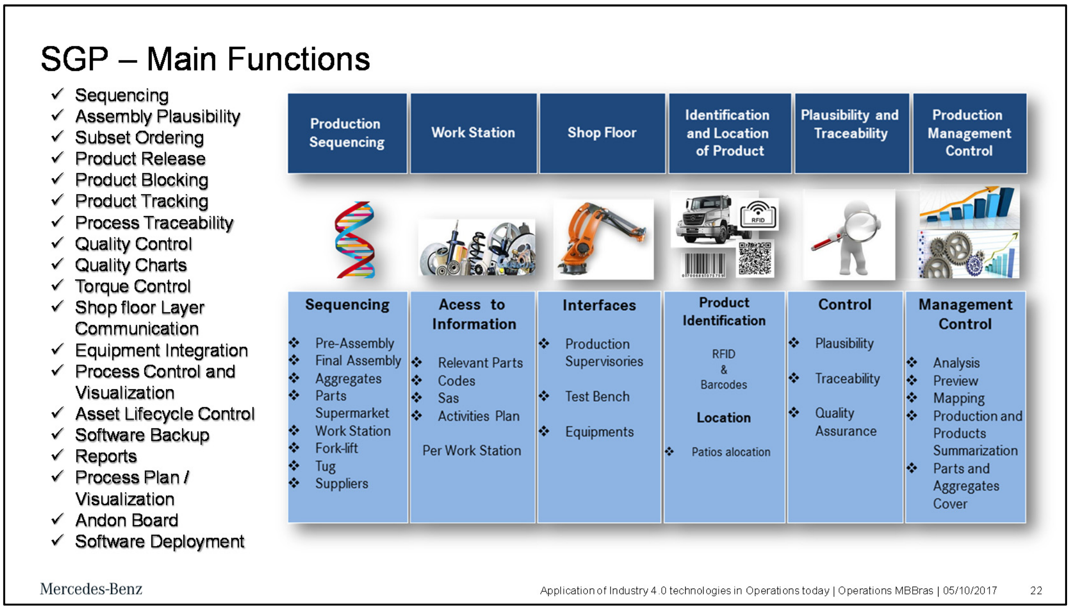
SGP – Main Functions
✓ Sequencing
✓ Assembly Plausibility
✓ Subset Ordering
✓ Product Release
✓ Product Blocking
✓ Product Tracking
✓ Process Traceability
✓ Quality Control
✓ Quality Charts
✓ Torque Control
✓ Shop floor Layer Communication
✓ Equipment Integration
✓ Process Control and Visualization
✓ Asset Lifecycle Control
✓ Software Backup
✓ Reports
✓ Process Plan / Visualization
✓ Andon Board
✓ Software Deployment
Production Sequencing
Work Station
Shop Floor
Identification and Location of Product
Plausibility and Traceability
Production Management Control
Sequencing
Pre-Assembly
Final Assembly
Aggregates
Parts Supermarket
Work Station
Fork-lift
Tug
Suppliers
Acess to Information
Relevant Parts Codes
Sas
Activities Plan
Per Work Station
Interfaces
Production Supervisories
Test Bench
Equipments
Product Identification
RFID & Barcodes
Location
Patios alocation
Control
Plausibility
Traceability
Quality Assurance
Management Control
Analysis
Preview
Mapping
Production and Products Summarization
Parts and Aggregates Cover
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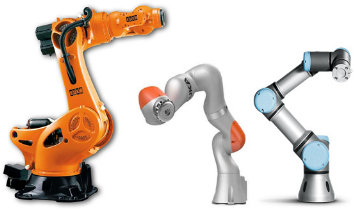
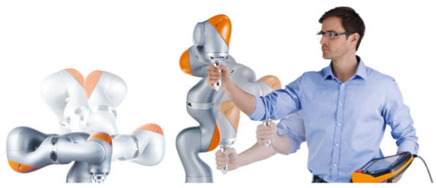
Collaborative Robots

The “Sensitive” Robot



Safety is often central subject to the debate in human-robot collaborative tasks. Technology often outpaces the safety regulatory bodies.

- Safety-rated monitored stop
- Speed and separation monitoring
- Power and force limiting
- Hand guiding



- Collaboration opens new applications for automation
- Collaboration can improve ease-of-use for robots
- User’s application determines which mode of collaboration is suitable
- Risk Assessment is key to determining if safeguards can be removed

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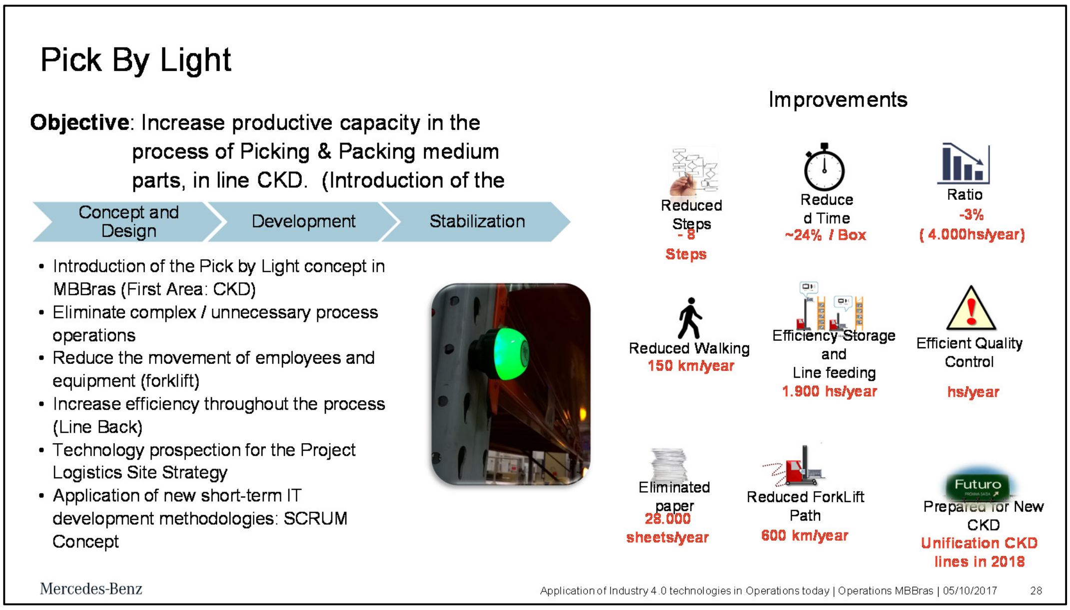
Pick By Light
Objective: Increase productive capacity in the process of Picking & Packing medium parts, in line CKD. (Introduction of the
Concept and Design
Development
Stabilization
• Introduction of the Pick by Light concept in MBBras (First Area: CKD)
• Eliminate complex / unnecessary process operations
• Reduce the movement of employees and equipment (forklift)
• Increase efficiency throughout the process (Line Back)
• Technology prospection for the Project Logistics Site Strategy
• Application of new short-term IT development methodologies: SCRUM Concept
Improvements
Reduced Steps
- 8 Steps
Reduce d Time
~24% / Box
Ratio
-3%
(4.000hs/year)
Reduced Walking
150 km/year
Efficiency Storage and Line feeding
1.900 hs/year
Efficient Quality Control
hs/year
Eliminated paper
28.000 sheets/year
Reduced ForkLift Path
600 km/year
Futuro
Prepared for New CKD
Unification CKD lines in 2018
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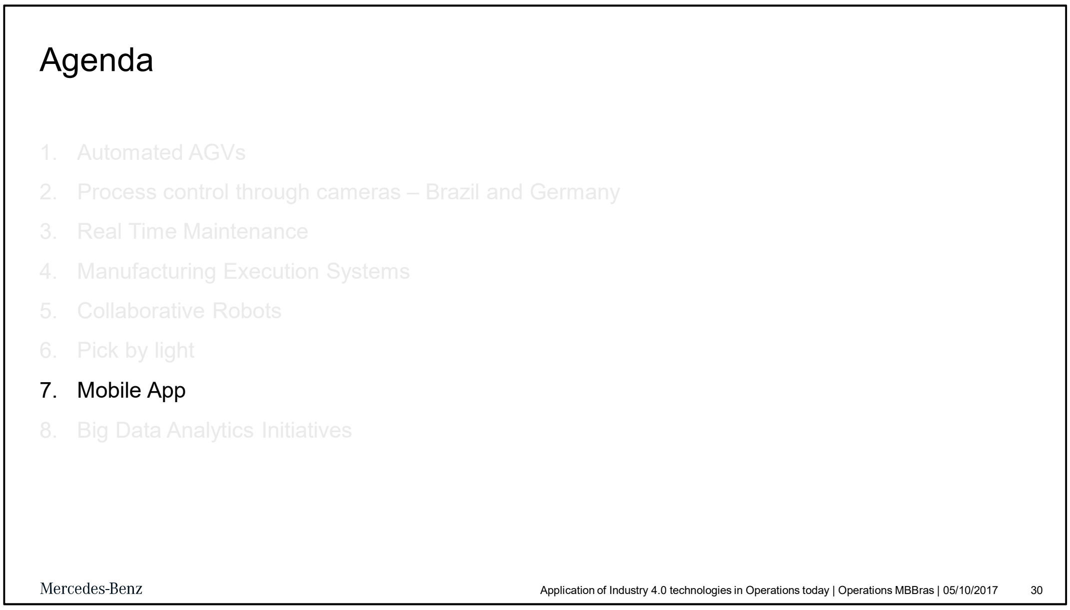
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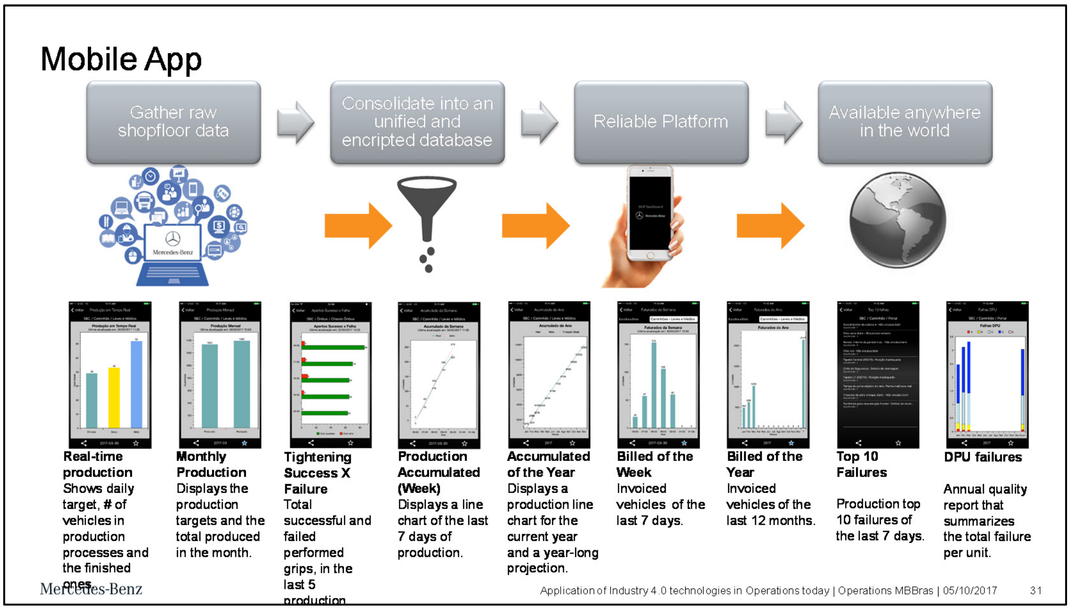
Mobile App
Gather raw shopfloor data
Consolidate into an unified and encripted database
Reliable Platform
Available anywhere in the world
Real-time production
Shows daily target, # of vehicles in production processes and the finished ones
Monthly Production
Displays the production targets and the total produced in the month.
Tightening Success X Failure
Total successful and failed performed grips, in the last 5 production
Production Accumulated (Week)
Displays a line chart of the last 7 days of production.
Accumulated of the Year
Displays a production line chart for the current year and a year-long projection.
Billed of the Week
Invoiced vehicles of the last 7 days.
Billed of the Year
Invoiced vehicles of the last 12 months.
Top 10 Failures
Production top 10 failures of the last 7 days.
DPU failures
Annual quality report that summarizes the total failure per unit.
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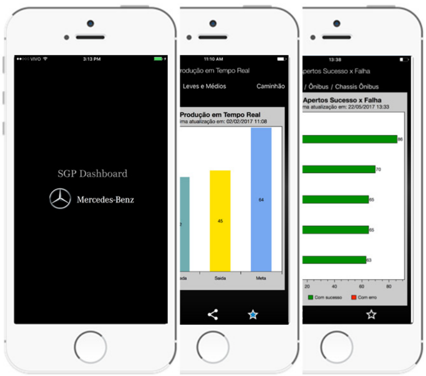
Mobile App

- Thinking of Innovation
- Pratical and Reliable Information for Fast Decisions
- Secure Environment
- Quick Development Using Available Technologies & Infrastructure
- Connected Systems



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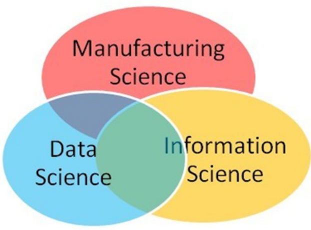
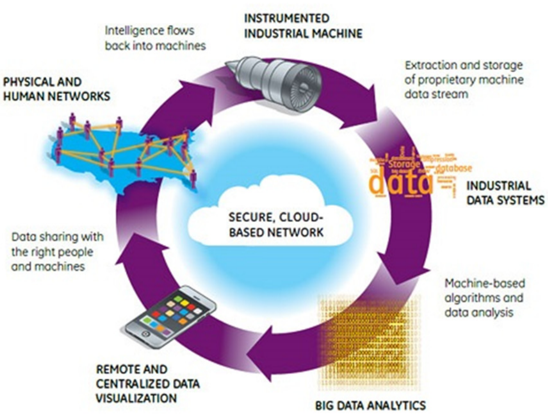
Big Data Initiatives





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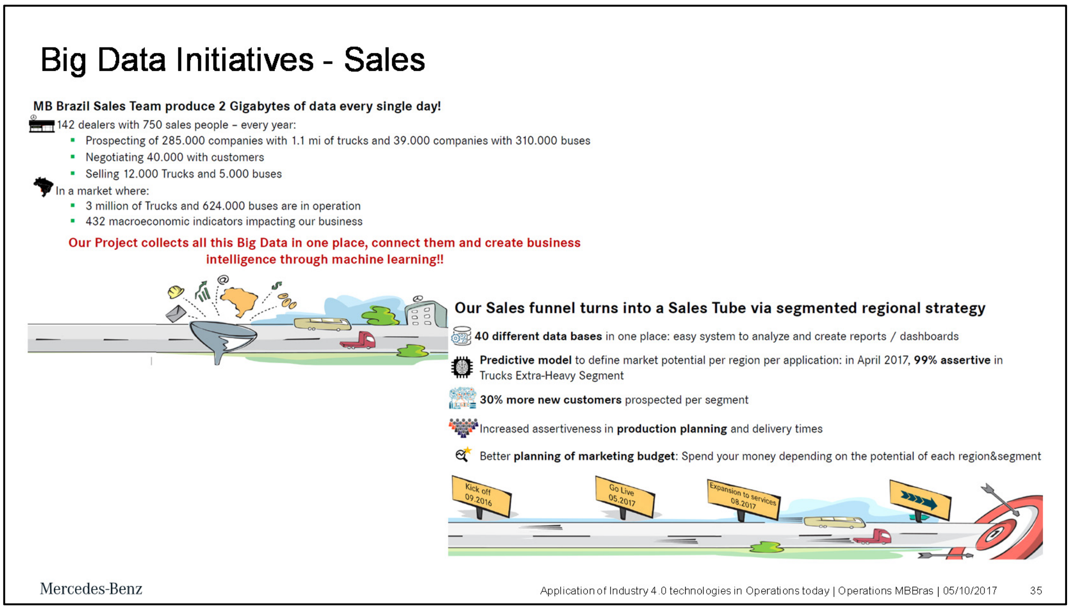
Big Data Initiatives - Sales
MB Brazil Sales Team produce 2 Gigabytes of data every single day!
142 dealers with 750 sales people – every year:
Prospecting of 285.000 companies with 1.1 mi of trucks and 39.000 companies with 310.000 buses
Negotiating 40.000 with customers
Selling 12.000 Trucks and 5.000 buses
In a market where:
3 million of Trucks and 624.000 buses are in operation
432 macroeconomic indicators impacting our business
Our Project collects all this Big Data in one place, connect them and create business intelligence through machine learning!!
Our Sales funnel turns into a Sales Tube via segmented regional strategy
40 different data bases in one place: easy system to analyze and create reports / dashboards
Predictive model to define market potential per region per application: in April 2017, 99% assertive in Trucks Extra-Heavy Segment
30% more new customers prospected per segment
Increased assertiveness in production planning and delivery times
Better planning of marketing budget: Spend your money depending on the potential of each region&segment
Kick off 09.2016
Go Live 05.2017
Expansion to services 08.2017
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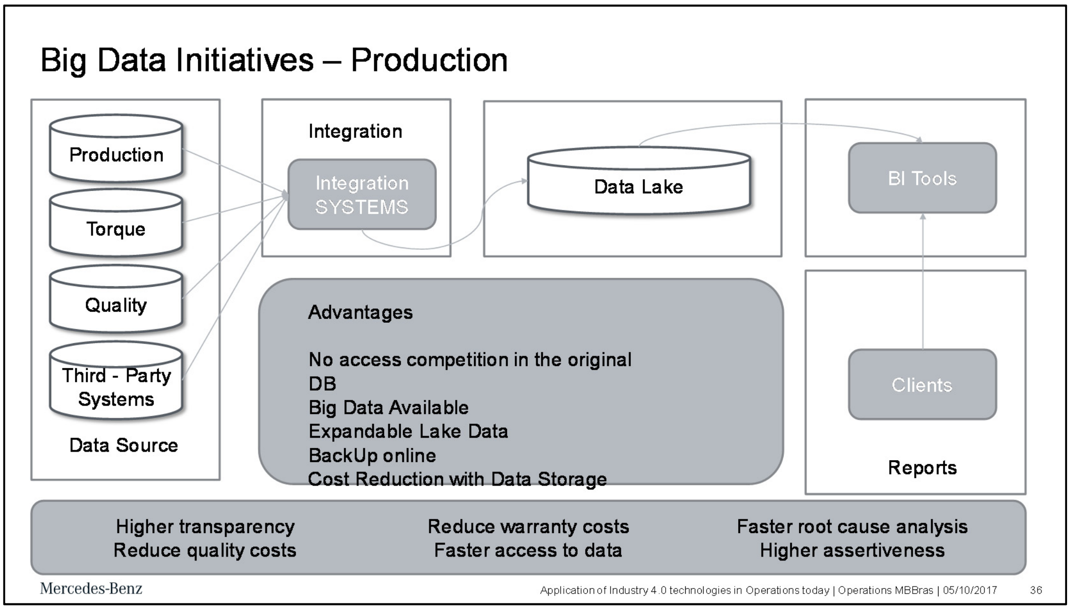
Big Data Initiatives – Production
Production
Torque
Quality
Third - Party Systems
Data Source
Integration
Integration SYSTEMS
Data Lake
BI Tools
Clients
Reports
Advantages
No access competition in the original DB
Big Data Available
Expandable Lake Data
BackUp online
Cost Reduction with Data Storage
Higher transparency
Reduce quality costs
Reduce warranty costs
Faster access to data
Faster root cause analysis
Higher assertiveness
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Thank you for your attention!
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Dr.-Ing. Matthias Weigold

Dr.-Ing Weigold was born in 1977 and studied mechanical engineering at Darmstadt University of Technology, Germany, where he received his diploma in 2002. He received the Dr.-Ing. degree in Mechanical Engineering at Darmstadt University of Technology, Germany in 2008. His thesis „Compensation of the tool deformation during machining with industrial robots" was about a new machine tool concept for milling, drilling and deburring applications based on an industrial robot platform. From 2007 to 2015 he worked at Heidelberger Druckmaschinen AG within the manufacturing division in different functions. As Head of Tool Technology he was responsible for the company-wide development of processes and tool technology and the tool management reorganization. As Head of Engineering he was responsible for the manufacturing innovation management, investment projects and the development and construction of jigs, automation technology and special purpose machines for assembly and manufacturing. He left in 2015 as Head of Engineering and Production Planning for prototype production as well as serial production. Since 2015 he is working at SAP SE within the division of Products & Innovation in the field Industry 4.0. As a product owner "SAP Machine Manufacturing Analytics" he is responsible for a new and disruptive product approach of "Internet based Big Data Analytics for Manufacturing Applications". The interdisciplinary topic of real time data recording, cloud-computing and big data analytics as well as the overall end-to-end integration engineering connects the shop-floor to the global enterprise network. In the last two years, applications for CNC machine tools as well as for industrial robots where developed.

✉ matthias.weigold@sap.com

SAP SE

As the market leader in enterprise software, SAP SE helps companies of any size and sector conduct their business profitably while adjusting continuously to new requirements and enjoying sustainable growth. From the back office to the boardroom, the warehouse to the branch office, and stationary PCs to mobile devices, SAP enables people and organizations to work together more efficiently and utilize business data more effectively than their competitors. Around 300,000 customers now use SAP applications and services to better achieve their goals.

Internet based Big Data Analytics in Manufacturing - a Disruptive Approach for Digitalization of Production Processes

Abstract

By taking advantage of real-time data, companies can gain a strategic advantage in time to value, quality and productivity. This contribution presents an innovative approach of an internet based end-to-end process of big data analytics. The basis is a new method of real-time high speed data recording from a CNC-controller of a machine tool or an industrial robot controller. A new edge gateway functionality is recording the data directly from the real-time fieldbus and communicates the data based on cyber security requirements to SAP HANA® in-memory platform technology. Furthermore, this paper describes the SAP® Machine Manufacturing Analytics application which shows how manufacturing companies from automotive, aerospace and industrial machinery benefit from the web based application to accelerate their process development, reduce quality costs and increase their productivity.

Keywords

Real-time Data Acquisition; Edge and Cloud Technology; Pattern Based Benchmarking; Predictive quality.

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Philipp Raub
SAP-SE

1 Motivation for Big Data Analytics in Manufacturing

The automotive market is being shaped by ever-shorter innovation cycles and a broadening range of available models. Planning horizons are narrowing as well, which significantly reduces the security they are meant to provide. OEMs and component suppliers in this segment thus demand the utmost speed in planning and ramp-up to integrated production solutions. At the same time, flexibility and stability both need to be guaranteed for the foreseeable future [1].

The aerospace industry is a leading sector for innovative process monitoring approaches. The ongoing effort towards a complete digitalization and transparency along the production chain is driven by the fact that OEMs and component suppliers will earn credits to improve the “Probability of Fracture“ (POF) of the produced components. Thus, the maintenance cycles during the operation phase can be enlarged tremendously [2, 3].

However, today much of the process information produced by machine tools and industrial robots is neither utilized nor analyzed systematically. This is because the market lacks solutions that can collect granular data on all the systems in a production line over an extended period, analyze it automatically, and offer corresponding visualizations efficiently.

In the course of the 4th industrial revolution, machine tools and industrial robots are increasingly equipped with additional external sensors. Furthermore, NC controllers of established manufacturers increasingly provide interfaces for real-time acquisition of process signals [5]. Based on gathered information, near real-time analytics not only offer potential for process optimization and root cause analysis in case of process problems but also for quality monitoring. In addition, a comparability between processes, machines and workpieces can be established. This finally opens possibilities for a targeted use of modern analytical methods as well as new partnering and business models.

Based on a typical CNC machining operation in the automotive industry [1] and an industrial robot based welding example used in the aerospace industry [4] SAP® Machine Manufacturing Analytics (in the following SAP MMA) shows how data in a complex production process can be recorded in real-time and analyzed using big data technologies. Thus, opening the door to gain a strategic advantage in time to value, quality and productivity. Essentially, three steps are necessary:

I. Real-time data acquisition

Machine data needs to be recorded in real-time and transferred securely into an appropriate IT infrastructure – a company’s own data center for example – without disrupting the manufacturing process. The SAP approach uses a number of innovative techniques to prove how this interplay between operational technology (OT) and information technology (IT) can be both successful and profitable.

II. Data analysis

With the process data now stored in a high-performance in-memory database such as SAP HANA®, the innovative Industry 4.0 solution SAP® Machine Manufacturing Analytics can analyze it near real-time. SAP MMA makes it possible to optimize and verify workpiece quality along with process performance and stability.

III. Applying and visualizing big data analytics

Meanwhile, systematic data acquisition and analysis open the door to dramatically shorter production startup and process development phases. By innovative, role-based visualization concepts of pattern and animalities analytics new opportunities for the detection of quality issues in near real-time, reduce rework rates and lower appraisal costs are generated by of the SAP MMA core application.

2 SAP® Machine Manufacturing Analytics - real-time data acquisition with MMA Edge

This paper is presenting an innovative approach of big data analytics in discrete manufacturing. The end-to-end-process of big data analytics starts with real-time high speed data recording from the NC-controller by the SAP® Machine Manufacturing Analytics Edge device - in the following MMA Edge. At CNC-machine tools the recording is about 20 real-time variables at the position control loop cycle of 2 Milliseconds. At industrial robot applications the acquisition rate is in the range between 4 and 12 Milliseconds. The recorded data is then being read by the new and innovative MMA Edge component directly from the real-time fieldbus and communicates the data based on cyber security requirements to a private or public cloud based in-memory platform where the new Industry 4.0 applications are running (see figure 1).

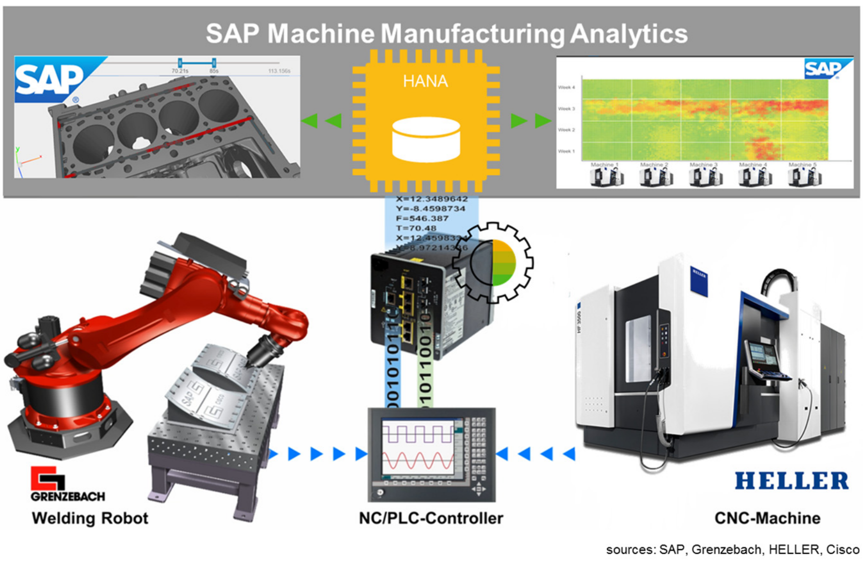


Figure 1: SAP® Machine Manufacturing Analytics – system architecture

For online scenarios, the system will allow the user to control certain aspects of data tracing. Configuration services are provided that will allow the MMA Edge device to obtain information relevant to data capture such as which real-time data to trace, and which non-real-time events to capture. Other contextual information, such as controller specific addressing and trace formats, will be stored at the MMA Core side, but ultimately consumed by edge components. This abstraction layer will maintain machine-agnostic and controller-agnostic functionality in MMA Core application, while providing flexible, centrally managed control of machine/controller specific aspects.

Beside the fact that MMA Edge ensures a high frequency real-time data recording other information such as major events at the HMI (human machine interface) or relevant PLC data are synchronized by a new method. After the recording the contextualization combine design information from the CAD/CAM process, the NC program, NC events with the real-time sensor and process data (see figure 2). Information about the commanded and actual path of the tool and their dynamic behavior e.g. acceleration and jerk is part of data enrichment functionality.

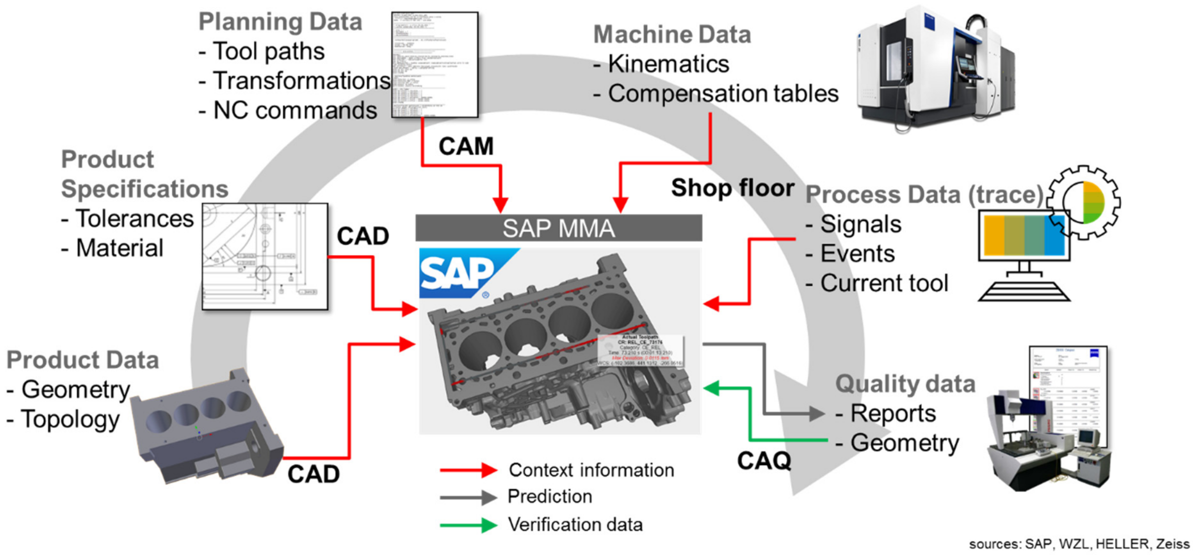


Figure 2: Components of the Big Data Contextualization

3 SAP® Machine Manufacturing Analytics – data analytics

The end-to-end collection of key process data produces quantities of information that can no longer be processed and analyzed using conventional methods. Here SAP® Machine Manufacturing Analytics enable big data comparisons across entire production batches and multiple machines by converting raw sensor data and business data into one context. Its big data analytics functions incorporate visualizations (such as heat maps) and pattern recognition that reveal defects and trends early.

Beside the data enrichment different performance characteristics from the production process are derived. Dynamic profiles (velocity, acceleration and jerk) from the tool center point in space as well as from each single axis and process parameters such as cutting velocity and feet per tooth are calculated.

As an outcome, a single digital context with powerful 3D and 2D visualization was created for the SAP MMA core application to enable contextualization and exploratory data analysis. Another unique component is a multi-directional mapping feature between the NC-program, parameters at time domain as well as the spatial domain based information, making manual adjustments of sensor data to NC program obsolete.

The user and the system itself can create regions of interest which represent key aspects regarding to process stability and quality of the workpiece. By applying thresholds an easy inspection of violations and anomalies is possible and can be further used for immediate feedback to the machine operator or the different engineering departments [5].

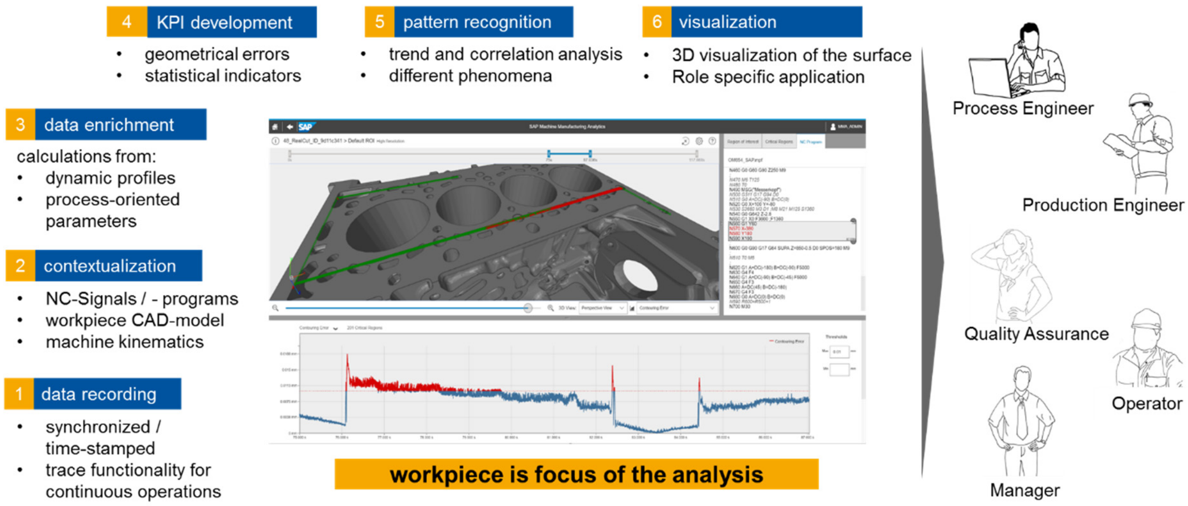


Figure 3: SAP® Machine Manufacturing Analytics - workpiece centric analytics [5]

An additional so called multi-session analysis where the customer can run a pattern based benchmarking of all relevant parameters and performance characteristics from workpieces out of different batches or different machines is the first step into fleet analytics. An example of a visual summary out of five machine tools over four weeks is shown in a 2D heat map (see figure 4). Each pixel at the heat map is representing a specific workpiece by an aggregated colored information. All detailed high resolution information about all process and quality related parameters can be investigated by a deep drill down at any time with the possibilities and power of a private or public cloud based in-memory data base.

SAP MMA can be used to support DMAIC/PDCA workflows: big data visualization helps to identify and define areas of improvement (Region of interest), sensor data from the machine measure process stability, route cause analysis brings those measurements into context with other data such as quality measurements, insights from this analysis are used for process improvements and threshold violation triggered alarms to give instant feedback to the operator or machine to control and monitor the improvement process.

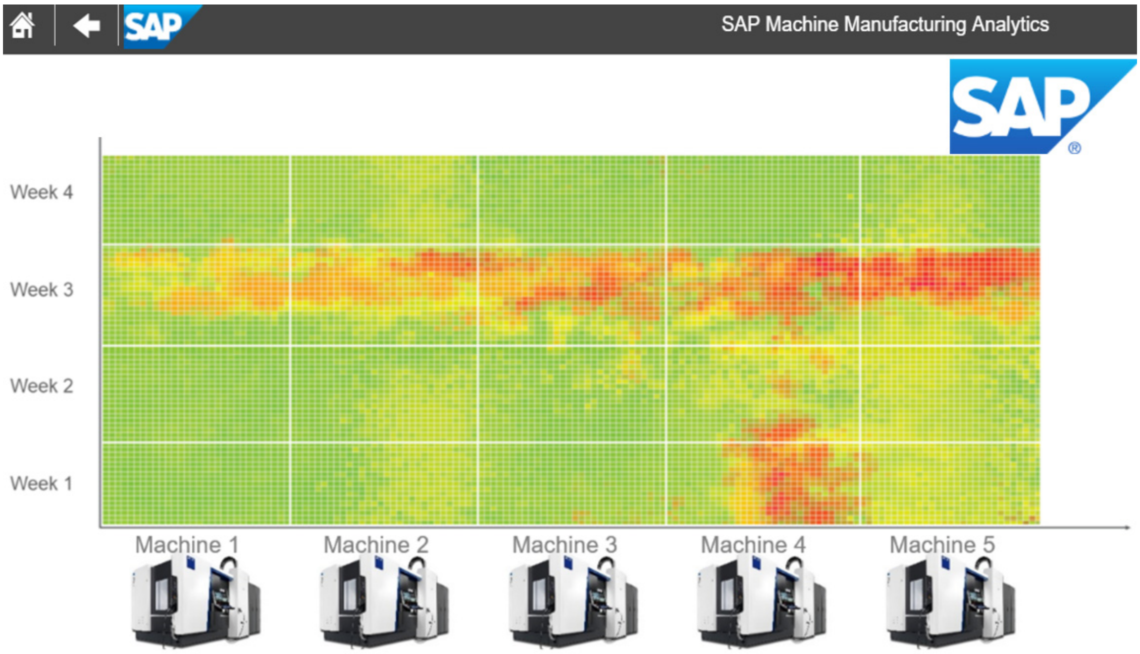


Figure 4: Example of a Fleet Analytics Summary by Heat Map Visualization

4 SAP® Machine Manufacturing Analytics – application

4.1 Two major use cases

SAP® Machine Manufacturing Analytics is currently focused at two major use cases that are aiming at two different goals. The first goal is the reduction of the production engineering effort to accelerate the time-to-market needs. The second goal is to detect quality incidents in near real-time, find the proper root-cause and turning insights into action.

Before series production starts, the technical aspects of various manufacturing processes need to be developed. In addition, manufacturing companies face the challenge of advancing new products to production maturity in ever-shorter ramp-up times. For complex parts, process development – including production ramp-up can take several months before series production actually begins. With the SAP MMA core application, important parameters such as the spindle power and geometrical errors can be visualized based on a 3D model of the workpiece (see figure 3). In addition, other parameters (either recorded directly or derived) can be displayed in time diagrams, which makes it possible to determine optimum process parameters and identify and optimize primary determinants during process development, as well as later on in the ramp-up to series production. MMA is providing analytical tools that drastically reduce the development and ramp-up times for production processes. It also offers the advantage of identifying untapped potential for optimization, which shortens the processing time per workpiece while improving process stability.

At present, quality assurance is always reactive. Inspection and quality assurance efforts for workpieces typically take longer than the manufacturing process of one workpiece itself, which means that only a few characteristics are fully examined or are accessed by taking some samples. In series production set-up, this means that when a quality problem occurs, thousands of parts may have already been affected before non-conformance is being declared. They then require retroactive inspection, which results in significant costs due to inspection effort, rejections and reworking. For a company, this business value is irretrievable lost to the fact of latency as visualized in figure 5. Latency is defined from the moment a quality-related problem occurs until all necessary steps are taken to resolve its consequences [6].

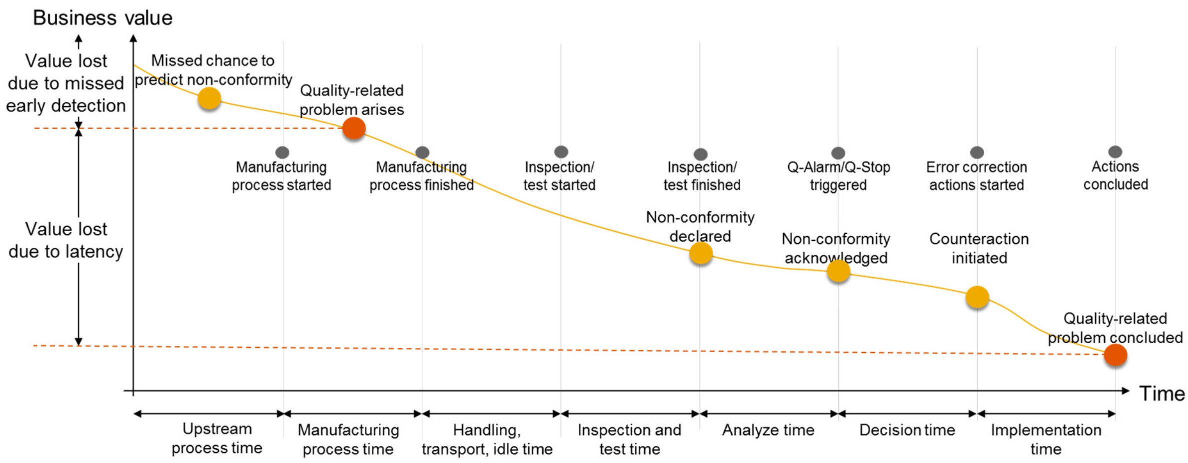


Figure 5: Increase Business Value by Prediction and Reduction of Latencies in Quality Assurance [6] c.f. [7]

SAP MMA offers near-real-time identification of critical deviations like manufacturing anomalies within the moment of manufacturing process. This makes it possible to respond immediately and correct quality issues before they become a problem, and enabling corrective actions to be taken early to solve the problem. Instead of merely taking random samples, this approach ensures 100% inspection of all workpieces and constitutes a key step towards achieving zero-defect production.

By applying machine learning techniques and scalable computation power SAP MMA can be used in future to predict non-conformity even before the quality problem actually arises. As shown in figure 5, this enables additional real business value to any manufacturing process and will dramatically reduce cost of bad quality.

4.2 Role based visualization

An essential advantage of a cloud-based realization is the fact that a worldwide and device independent access to all analytical functions and to the user interface is possible. Whether directly on the HMI (human machine interface), at work stations at the planning and supervising department or with smartphones and tables during a boarding procedure at the airport. All different users within the company receiving near real time information and getting support. Moreover, the different roles are equipped with different access rights and user specific analytical functions and a different user interface.

The process engineer can investigate all details during the development process. He can set-up rules, create regions of specific interest and set specific thresholds and baseline characteristics for the upcoming series production. Production engineers, workers or quality assurance are able to access different characteristics and can do a deep drill down in root cause analyses without operating with several different applications. The workpiece and machine independent transparency – always workpiece centric – are summarized by user specific dashboard application where the content is updated seconds after the operation has happened.

5 SAP® Machine Manufacturing Analytics – summary and outlook

Today's lack of tools capable of analyzing design and real process data in a single context leads to longer ramp up times and significant manual effort is required to match and contextualize actual machine, tool and workpiece related data. SAP MMA helps reduce process development time and effort and ensure a completely new process transparency over batches and several machines. Secondly the lack of ability to detect quality issues as soon as they occur leads to higher costs as more rework is required, material and time wasted. Therefore, SAP® Machine Manufacturing Analytics helps detect quality issues in near real-time, reduce rework rates and lower external and internal quality costs. The current development is aiming towards the prediction of workpiece quality inline while the parts are being machined.

At different customers the MMA Edge solution is integrated into their CNC-machines and industrial robots the MMA Core application and their analytical functionality is tested. These results enhancing them to support the latest possibilities in factory IT now expect future collaboration with machine tool manufacturers, robot manufacturer, automation experts and IT experts like SAP to include machine technology, network integration and competent partners in digitalizing their production processes.

6 References

[1] Weigold M., Raub P., et al.; 'Big Data Analytics in Manufacturing - Real-Time Analysis of Production Processes with SAP, Cisco and HELLER'; Partner Brochure; AMB Stuttgart; 2017

[2] Eckstein M.; ‘Zustands- und Prozessüberwachung bei der Fertigung von Flugtriebwerken‘; Vertiefungsseminar ‘Prozess- und Zustandsüberwachung für die Fertigung von Turbomaschinen‘, WZL RWTH Aachen; 2016

[3] Weigold M.; ‘Big Data Analytics in Manufacturing - Cloud-basierte Prozessanalysen’; Vertiefungsseminar ‘Prozess- und Zustandsüberwachung für die Fertigung von Turbomaschinen‘, WZL RWTH Aachen; 2016

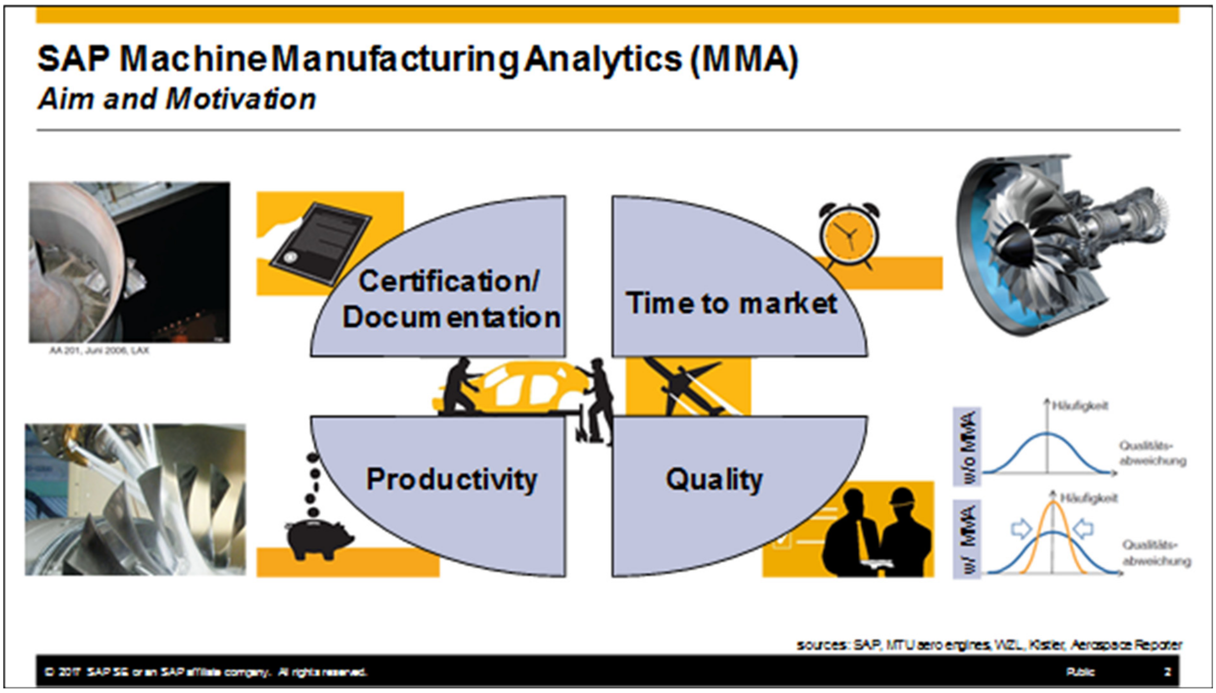
[4] Weigold M., Raub P., et al.; ‘Big Data Analytics in Manufacturing - Cloud-based analysis of the friction stir welding process with SAP, Cisco and Grenzebach‘; Partner Brochure; HMI Hannover; 2016

[5] Brecher C., Wellmann F., Queins M., Weigold M., et al.; ‘Value and Potentials of Model-Based Analytics‘; Aachener Werkzeugmaschinen Kolloquium (AWK); WZL RWTH Aachen; 2017

[6] Raub P.; ‘Cloud Computing For Manufacturing Operations to Predict Work Piece Quality’; Master Thesis; KIT Karlsruhe; 2017

[7] Schuh G., Anderl R., Gausemeier J., et al.; ‘Industrie 4.0 Maturity Index: Managing the Digital Transformation of Companies’; Herbert Utz Verlag; 2017


Internet based Big Data Analytics in Manufacturing -
a Disruptive Approach for Digitalization of Production Processes
22nd International Seminar on High Technology – Challenges of the 4th Industrial Revolution
October 5th 2017, Teatro UNIMEP, Piracicaba, Brazil
Dr. Matthias Weigold, SAP SE
SAP


SAP Machine Manufacturing Analytics (MMA)
Aim and Motivation
AA 201, Juni 2006, LAX
Certification/
Documentation
Time to market
Productivity
Quality
w/o MMA
w/ MMA
Häufigkeit
Qualitäts-
abweichung
sources: SAP, MTU aero engines, WZL, Kistler, Aerospace Reporter
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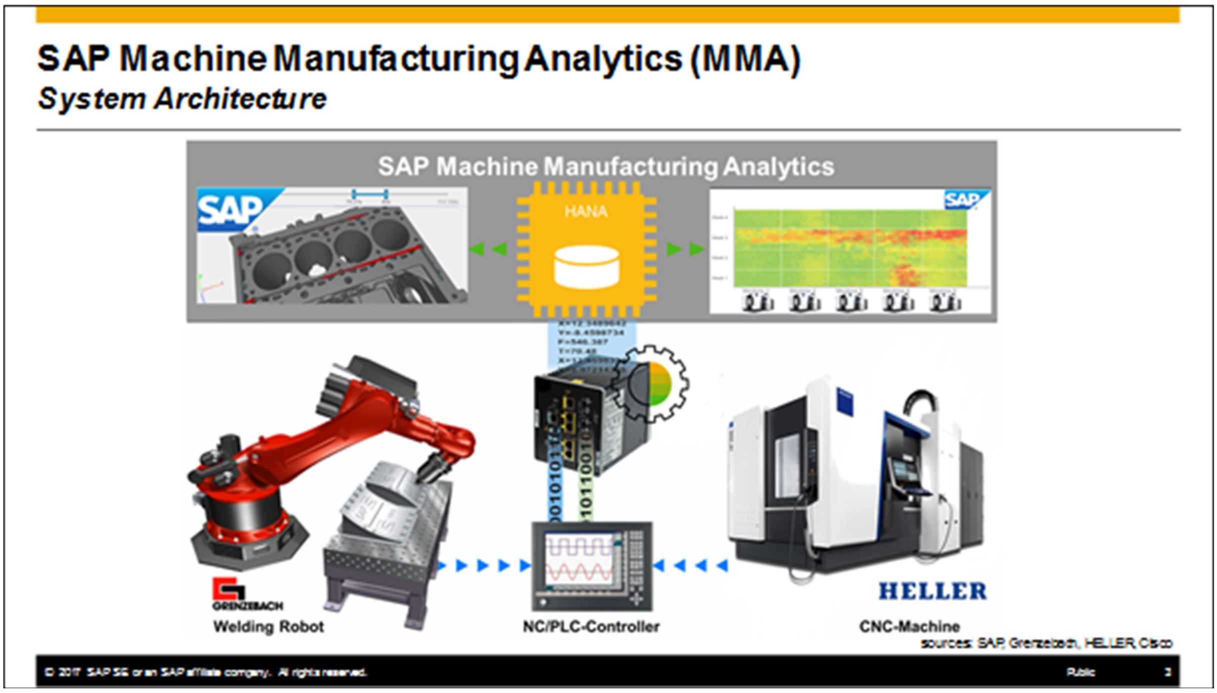
SAP Machine Manufacturing Analytics (MMA)
System Architecture
SAP Machine Manufacturing Analytics
SAP
HANA
SAP
GRENZEBACH
Welding Robot
NC/PLC-Controller
HELLER
CNC-Machine
sources: SAP, Grenzebach, HELLER, Cisco
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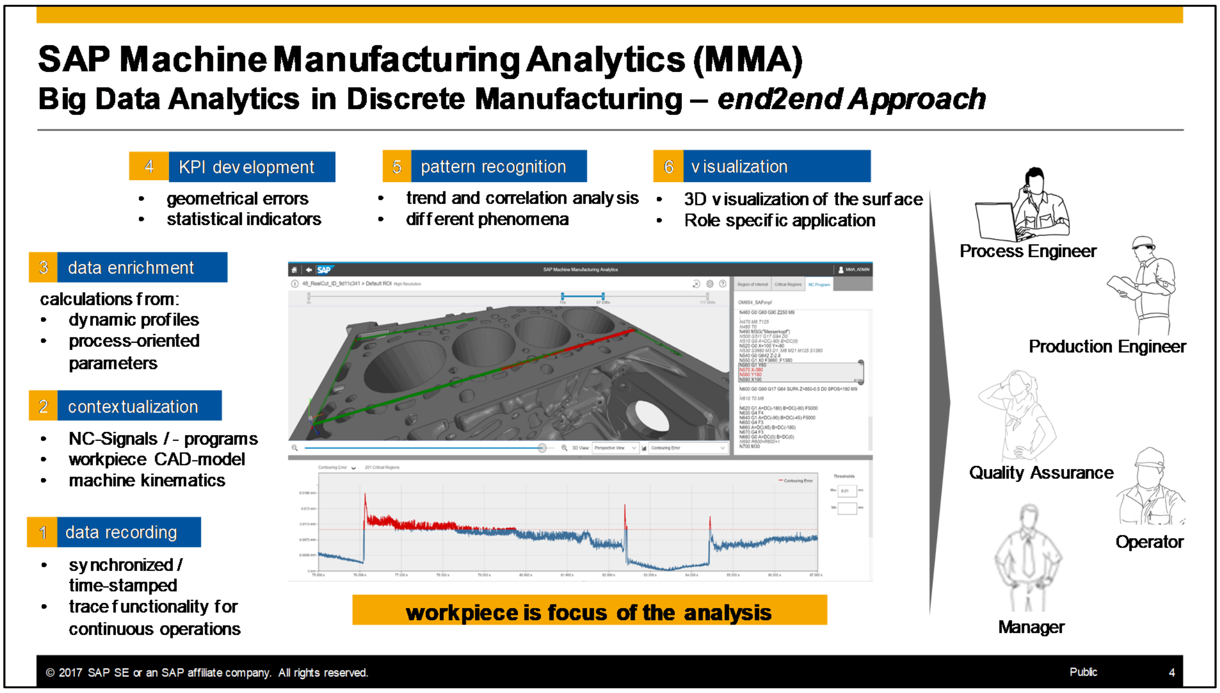
SAP Machine Manufacturing Analytics (MMA)
Big Data Analytics in Discrete Manufacturing – end2end Approach
4 KPI development
• geometrical errors
• statistical indicators
5 pattern recognition
• trend and correlation analysis
• different phenomena
6 visualization
• 3D visualization of the surface
• Role specific application
3 data enrichment
calculations from:
• dynamic profiles
• process-oriented parameters
2 contextualization
• NC-Signals / - programs
• workpiece CAD-model
• machine kinematics
1 data recording
• synchronized / time-stamped
• trace functionality for continuous operations
workpiece is focus of the analysis
Process Engineer
Production Engineer
Quality Assurance
Operator
Manager
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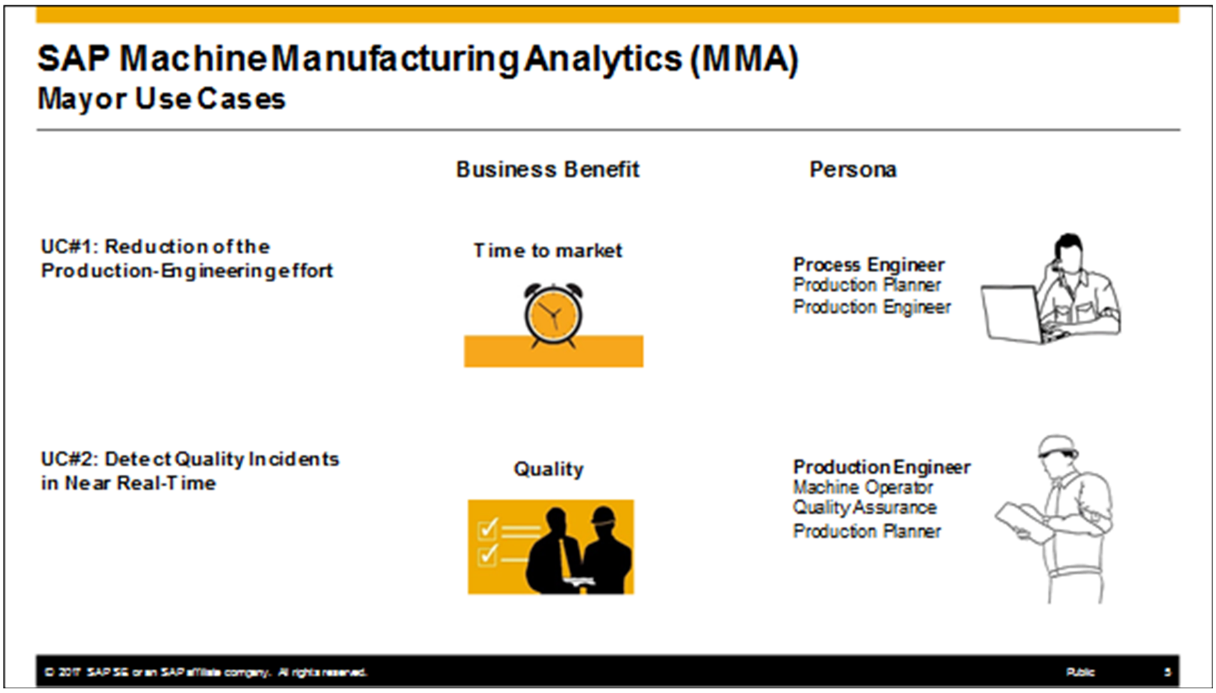
SAP Machine Manufacturing Analytics (MMA)
Mayor Use Cases
Business Benefit
Persona
UC#1: Reduction of the Production-Engineering effort
Time to market
Process Engineer
Production Planner
Production Engineer
UC#2: Detect Quality Incidents in Near Real-Time
Quality
Production Engineer
Machine Operator
Quality Assurance
Production Planner
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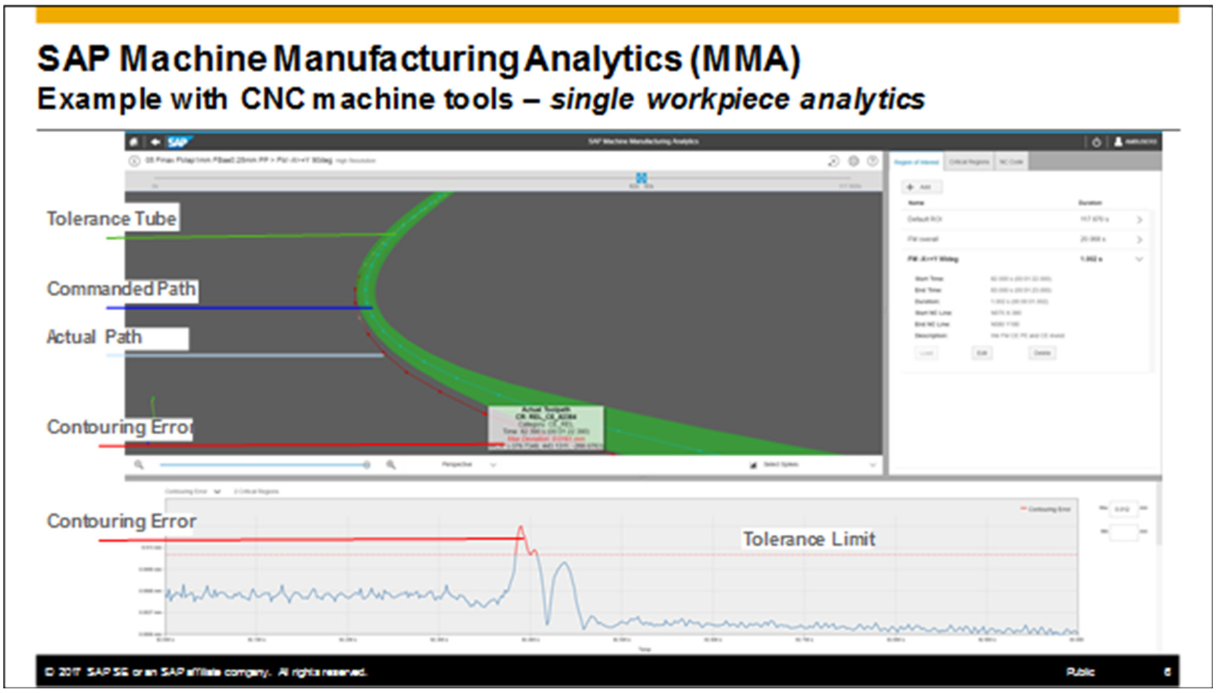
SAP Machine Manufacturing Analytics (MMA)
Example with CNC machine tools – single workpiece analytics
Tolerance Tube
Commanded Path
Actual Path
Contouring Error
Contouring Error
Tolerance Limit
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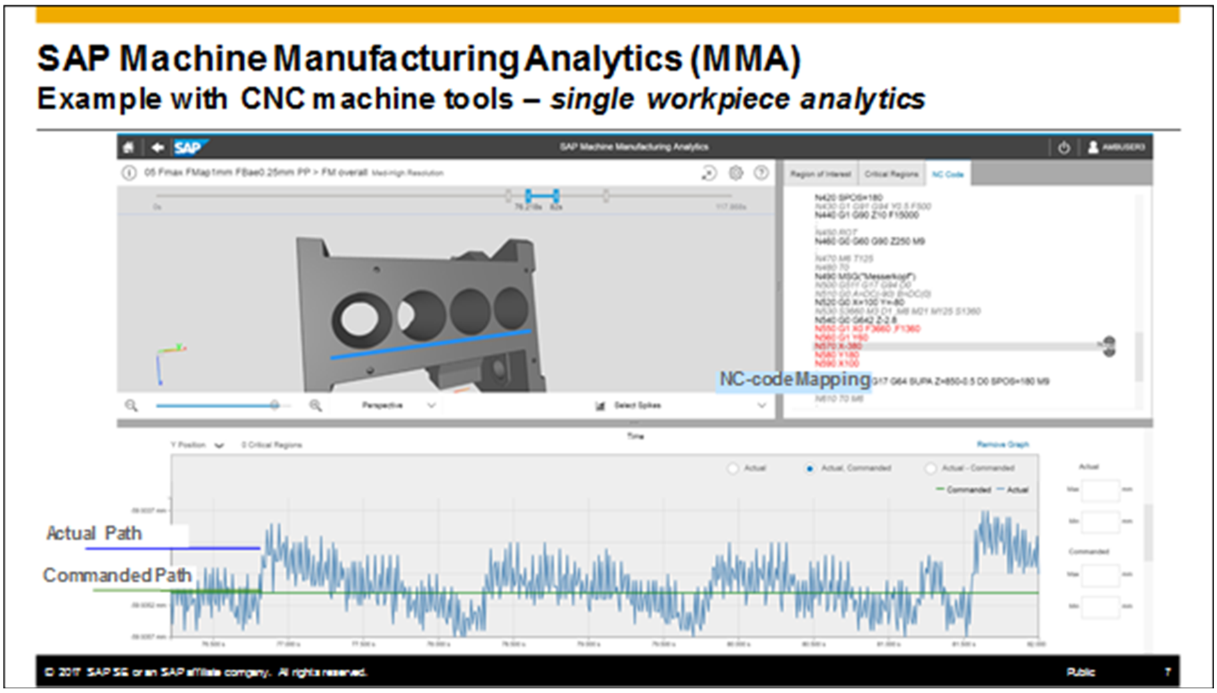
SAP Machine Manufacturing Analytics (MMA)
Example with CNC machine tools – *single workpiece analytics*
SAP Machine Manufacturing Analytics
NC-code Mapping
Actual Path
Commanded Path
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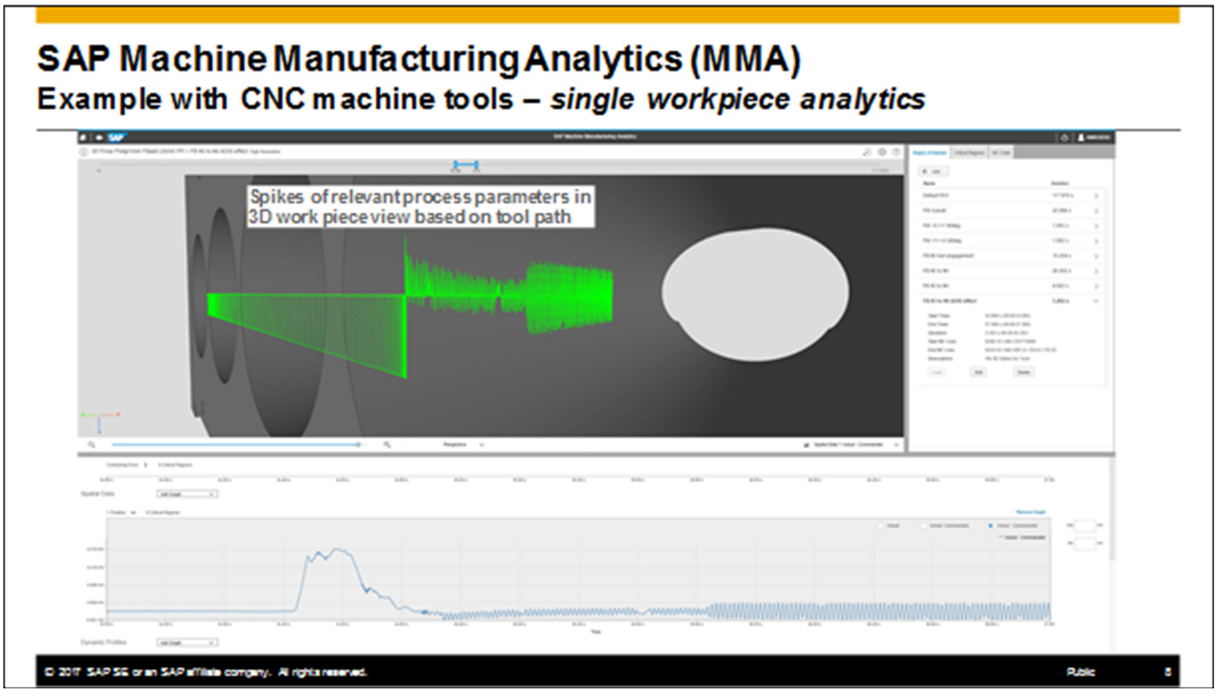
SAP Machine Manufacturing Analytics (MMA)
Example with CNC machine tools – *single workpiece analytics*
Spikes of relevant process parameters in 3D work piece view based on tool path
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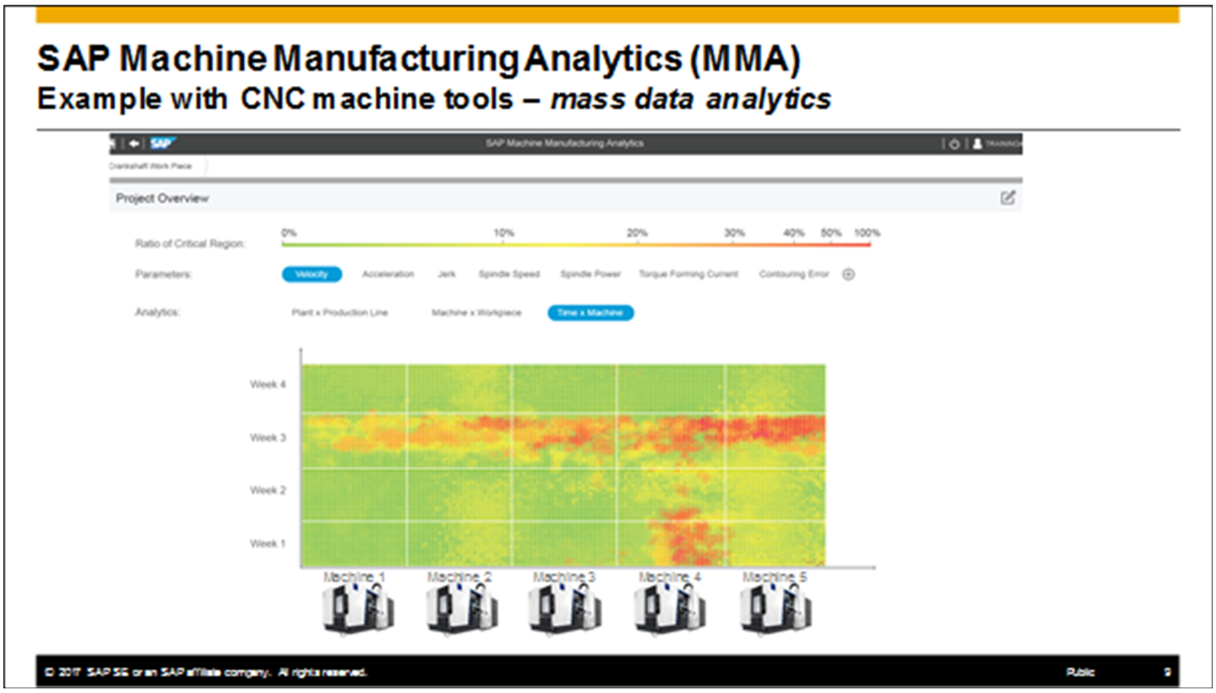
SAP Machine Manufacturing Analytics (MMA)
Example with CNC machine tools – *mass data analytics*
Project Overview
Ratio of Critical Region:
0% 10% 20% 30% 40% 50% 100%
Parameters:
Velocity
Acceleration
Jerk
Spindle Speed
Spindle Power
Torque Forming Current
Contouring Error
Analytics:
Plant x Production Line
Machine x Workpiece
Time x Machine
Week 4
Week 3
Week 2
Week 1
Machine 1
Machine 2
Machine 3
Machine 4
Machine 5
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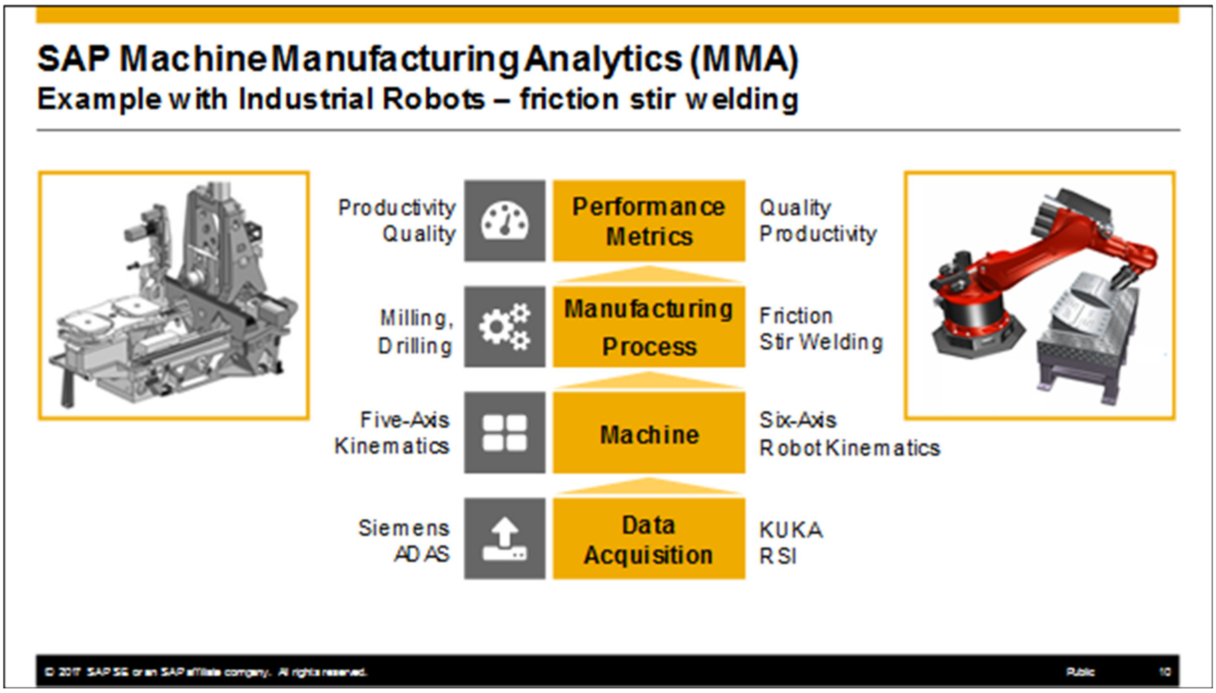
SAP Machine Manufacturing Analytics (MMA)
Example with Industrial Robots – friction stir welding
Productivity
Quality
Performance Metrics
Quality
Productivity
Milling,
Drilling
Manufacturing Process
Friction
Stir Welding
Five-Axis
Kinematics
Machine
Six-Axis
Robot Kinematics
Siemens
ADAS
Data Acquisition
KUKA
RSI
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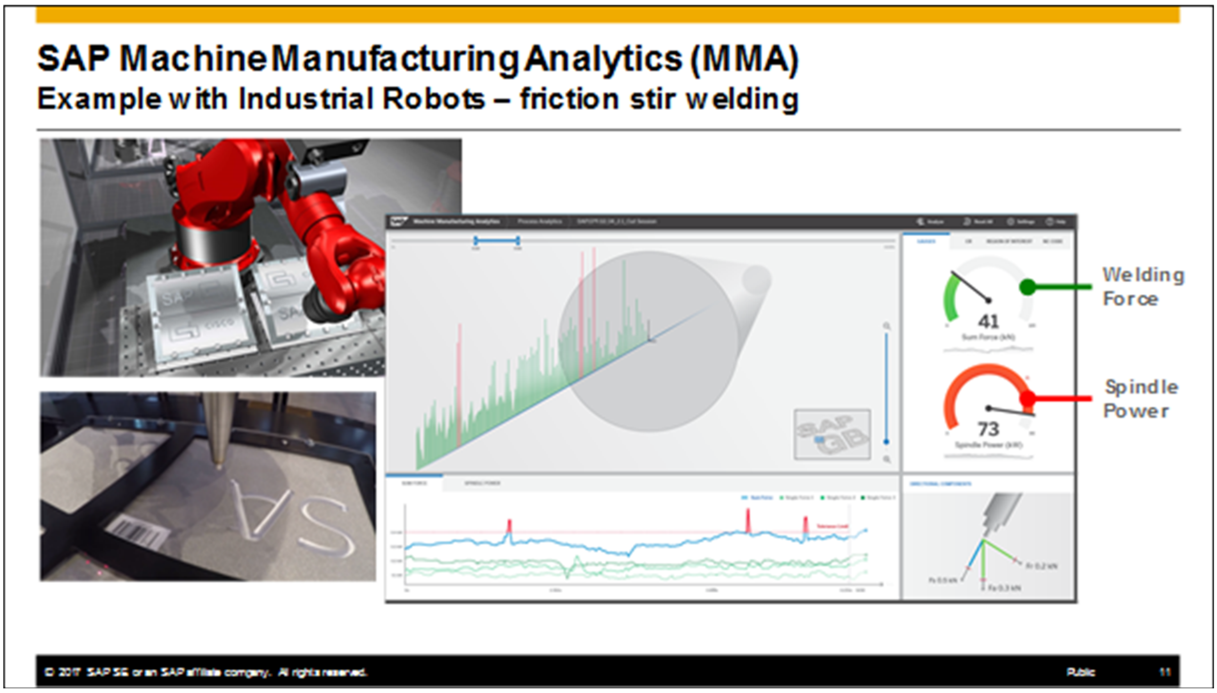
SAP Machine Manufacturing Analytics (MMA)
Example with Industrial Robots – friction stir welding
Welding Force
Spindle Power
41
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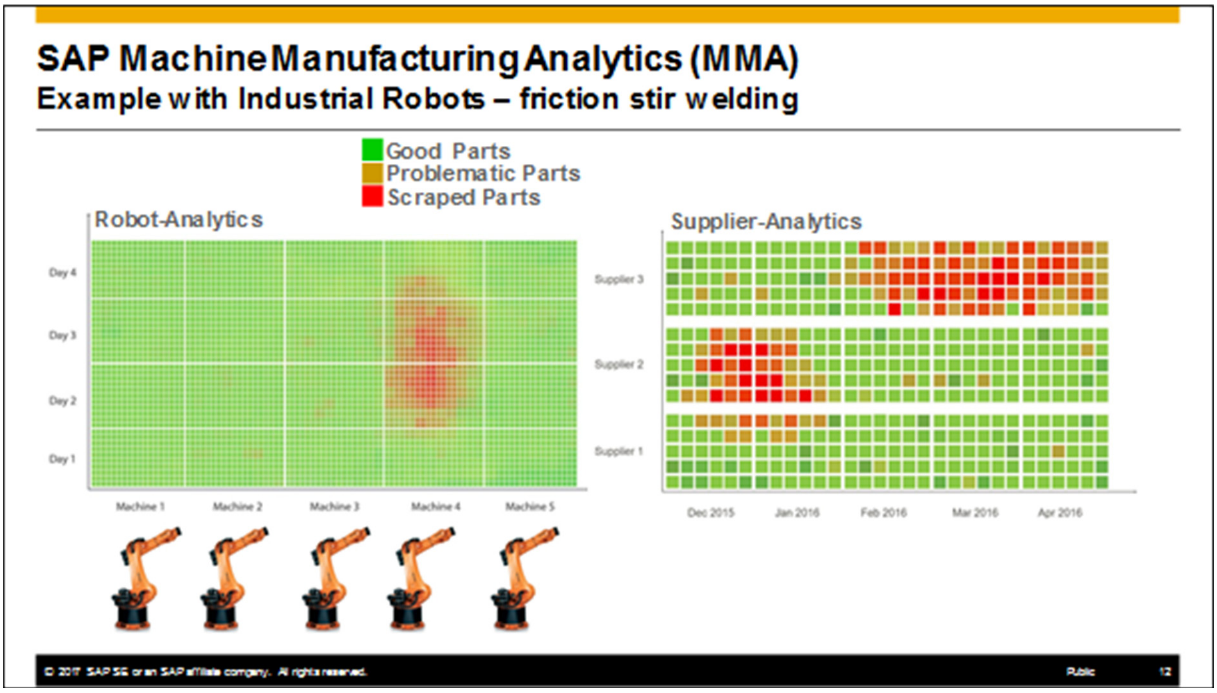
SAP Machine Manufacturing Analytics (MMA)
Example with Industrial Robots – friction stir welding
Good Parts
Problematic Parts
Scraped Parts
Robot-Analytics
Supplier-Analytics
Day 4
Day 3
Day 2
Day 1
Machine 1
Machine 2
Machine 3
Machine 4
Machine 5
Supplier 3
Supplier 2
Supplier 1
Dec 2015
Jan 2016
Feb 2016
Mar 2016
Apr 2016
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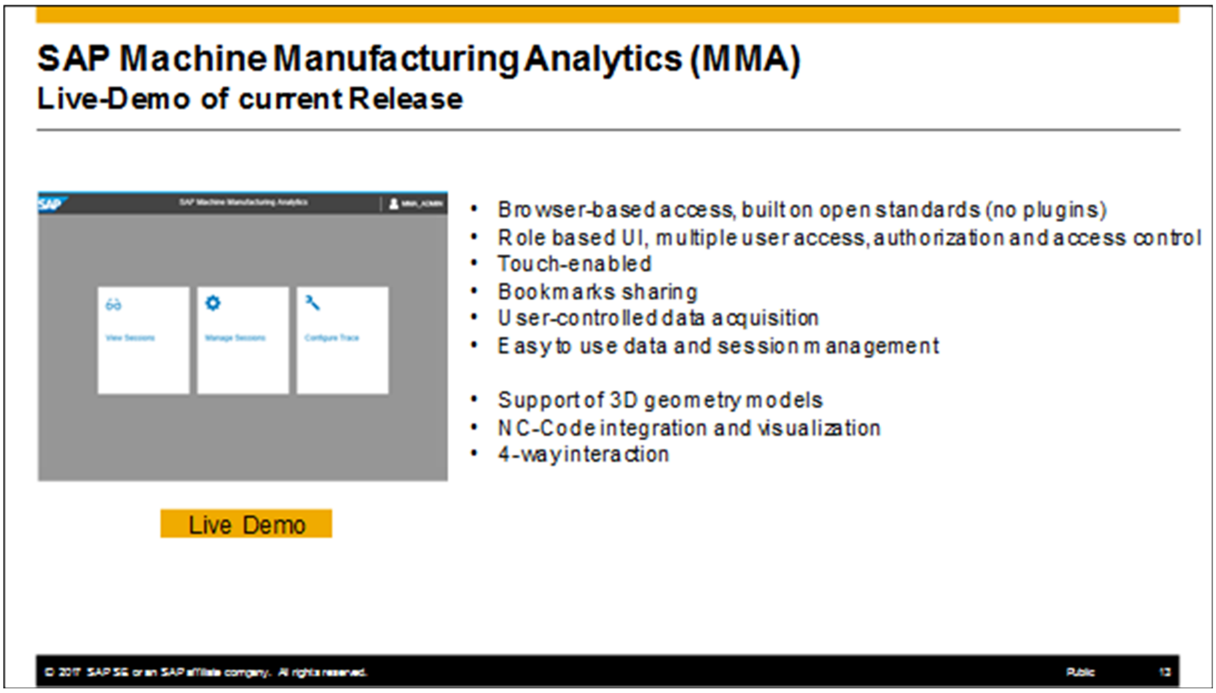
SAP Machine Manufacturing Analytics (MMA)
Live-Demo of current Release
Browser-based access, built on open standards (no plugins)
Role based UI, multiple user access, authorization and access control
Touch-enabled
Bookmarks sharing
User-controlled data acquisition
Easy to use data and session management
Support of 3D geometry models
NC-Code integration and visualization
4-way interaction
Live Demo
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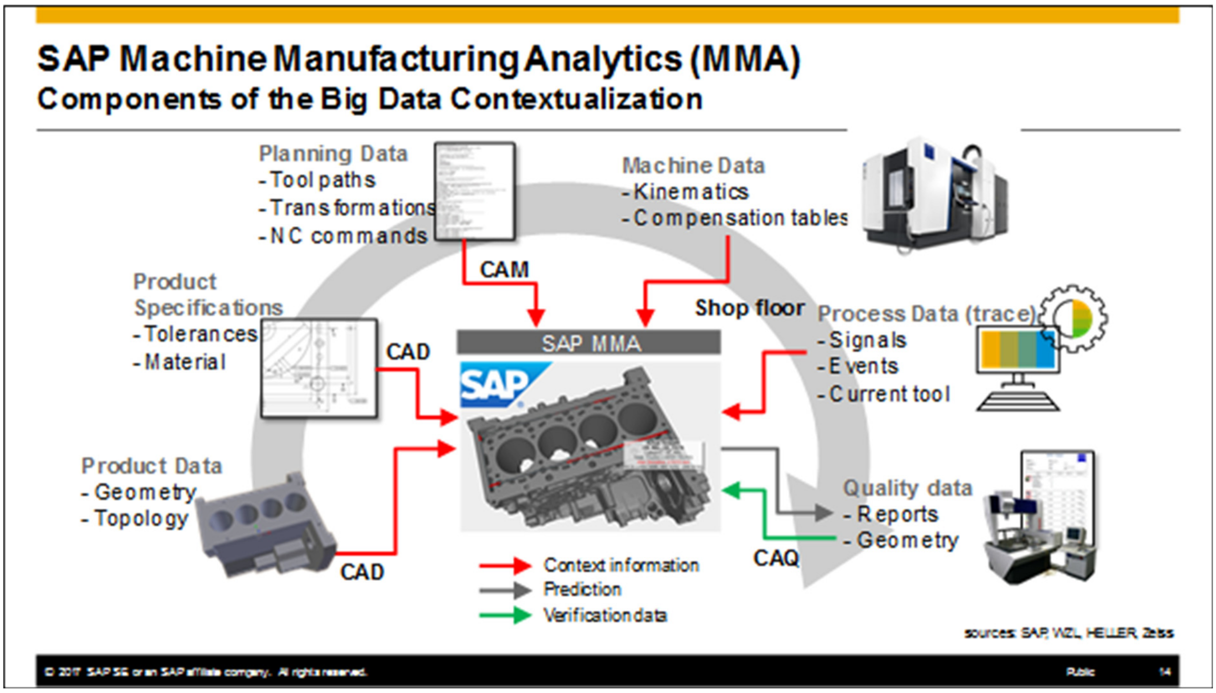
SAP Machine Manufacturing Analytics (MMA)
Components of the Big Data Contextualization
Planning Data
- Tool paths
- Transformations
- NC commands
Machine Data
- Kinematics
- Compensation tables
Product Specifications
- Tolerances
- Material
CAM
Shop floor
Process Data (trace)
- Signals
- Events
- Current tool
CAD
SAP MMA
Product Data
- Geometry
- Topology
Quality data
- Reports
- Geometry
CAD
CAQ
Context information
Prediction
Verification data
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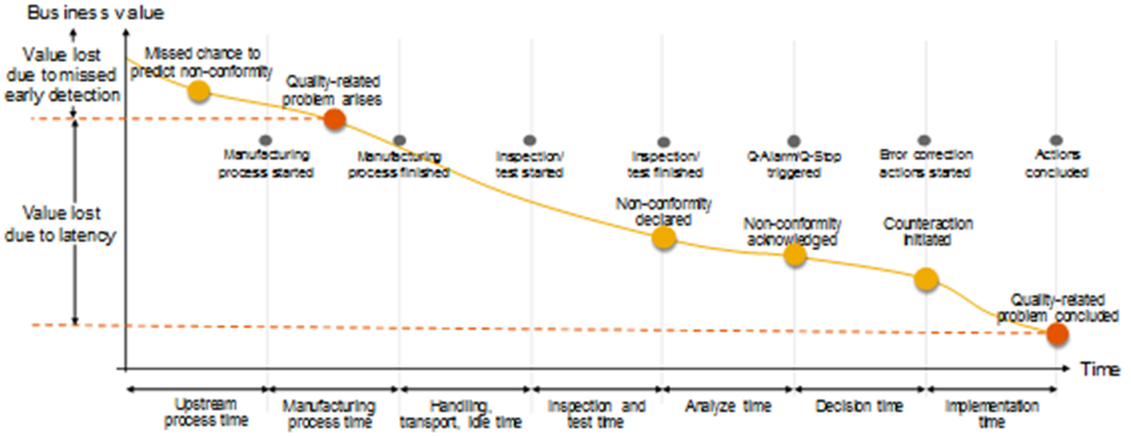
SAP Machine Manufacturing Analytics (MMA)
Prediction and Reduction of Latencies in Quality Assurance



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SAP Machine Manufacturing Analytics (MMA)
Summary

SAP MMA is focused on customers in the **automotive industry, aerospace and industrial machinery & components**
Main users are Process Engineers, Production Engineers, Machine Operators and Quality Assurance

Whose primary focus is:
1. faster production ramp-up
2. detect quality incidents in serial production in near real time
3. automated analysis of productivity losses and potentials

SAP MMA is a **real-time analytics application** to gather **real insights from the manufacturing process** within seconds after the production of a workpiece was executed

This product provides:
1. **contextualization of NC program with regard to spatial and time based context**: 3D/2D/NC-Code interaction
2. **workpiece based 3D-visualization of main indicators**: KPI's such as geometrical tolerance
3. **pattern based benchmarking/analytics**: visualize digitized data from multiple production workpieces

Unlike our competitive environment:
Control / Automation supplier: our solution runs **different CNC-controllers** and moreover **Industrial Robots**
Monitoring solutions: our solution is capable of analysing **complete fleets for duration > days and weeks**

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Dr.-Ing. Edmond Bassett

Dr.-Ing. Edmond Bassett was born in 1977 in Damascus, Syria. Graduated as mechanical engineer specialized in production technology at the University of Damascus. He completed his master degree in 2007 at the Leibniz Universität Hannover, specialized in mechanical design. From 2007 to 2012 worked Dr. Bassett at the institute of Institute of Production Engineering and Machine Tools of the Leibniz Universität Hannover and finished his reteach activities with a dissertation on the topic of tailored cutting edge microgeometries.In 2013 started his career at DMG MORI AG in the central development department. Since 2016 by GILDEMEISTER Drehmaschinen GmbH (associated company of DMG MORI) leading the technology development and turn-mill experience center of DMG MORI in Bielefeld.

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DMG MORI

The DMG MORI group is a leading producer worldwide of cutting machine tools. Our range of products includes high-tech turning and milling machines, as well as Advanced Technologies, such as Ultrasonic, Lasertec and Additive Manufacturing, as well as automation and complete technology solutions for the Automotive, Aerospace, Die & Mold as well as Medical industries. Our APP-based control and operating software Celos and innovative digital products enable us to shape *Industrie 4.0*. We also support our customers with a wide range of training, repair, maintenance and spare part services covering the entire machine life cycle. As a “Global One Company” with over 12,000 employees, together with our Japanese partner, DMG MORI Company Limited, we are present in 79 countries around the world. A total of 157 national and international locations are in direct contact to our customers.

DMG MORI

With “Open Connectivity” to adaptive production

Abstract

The trend of digitization, driven by Industry 4.0, is significantly changing the general mindset of people who work in production organizations. Machine tool manufacturers are adapting IIoT-Solutions to their machines to help the customer reach higher levels of productivity and efficiency. On this path of digital transformation both machine tool manufacturers and their customers improve their digital readiness and work on sharpening a picture beyond this trend. In this paper the challenges of a successful adaption of IIoT-solutions in production organizations will be discussed based the wide market experience of DMG MORI. As the world's leading manufacturer of machine tools, DMG MORI supports its customers, especially SMEs, on their path to complete digitization with the help of the CELOS® app-supported system and with other intelligent software solutions.

Keywords

CELOS®; Industry 4.0; Apps; Digital Factory; Digitization; Smart Machines; IT-Security; SMEs.

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1 Introduction

The trend of digitization, driven by Industry 4.0, is significantly changing the general mindset of people who work in production organizations. Machine tool manufacturers are adapting IIoT-Solutions to their machines to help the customer reaching higher levels of productivity and efficiency. On this path of digital transformation both machine tool manufacturers and their customers improve their digital readiness and work on sharpening a picture beyond this trend.

The digital transformation process requires facing real challenges improving the connectivity level, adapting new processes and applying data analytics. DMG MORI has identified this paradigm change and started the digital transformation since 2013 with CELOS®, an app-supported system with unique multi-touch operation. Since then and after more than 10.000 CELOS-machine installations DMG MORI is moving the next steps towards open connectivity, in order to help its customers adapting the digital factory in reality.

In this paper the challenges of a successful adaption of IIoT-solutions in production organizations will be discussed based on the wide market experience of DMG MORI, as the world's leading manufacturer of machine tools. DMG MORI is supporting its customers, especially SMEs, on their path to complete digitization with the help of the CELOS® app-supported system and with other intelligent Software Solutions.

2 On the Path Of Digitization - from a vision to the reality

The metalworking industry has identified the need of a digital transformation to solve the target conflict regarding production time, cost and quality. The market success in the future relies essentially on the digitization throughout the organization. This includes connecting smart machines and enabling horizontal and vertical integration of information streams in the production organization.

Figure 1: With CELOS® on the path of digitization

A possible first step of digitization is to check the status quo of the “digital readiness” of the organization. Some test models, e.g. VDMA Readiness Check, can be applied to evaluate the personal and infrastructural assets of the company. In order to move the vision into reality the company should “think big and start small”. This means to keep focus on implementing complete processes, while starting with small digitization projects, e.g. having a tool management system connected to a tool presetting device with direct link to machine tools. Such a step requires the definition of needed data interface between existing IT-Systems and a first evaluation of the data quality in order to define a realistic time line of the digitization project. Next steps will follow fast, when technical details will be discussed between production engineers and IT-experts. E.g. process workflows must be visualizes and standardized. Rules and user rights should be defined. These steps will be more challenging to SMEs with limited IT-resources or the ones depending on external expertise. In other words it is important to develop standardized, lean but yet user-specific and flexible digitization solutions to SMEs.

Once the benefits and the first positive results of digitization steps are clear, the biggest change in mindset of the customer will emerge concerning the corporate IT infrastructure in the digital factory. Today, IT is rather seen as a cloudy cost factor. The job is not done buying the license, but software maintenance and updates are even more (compared to the initial purchase) seen as a painful distortion of budget and infrastructure. This point of view will change completely.

3 Challenges in the digital transformation of a manufacturing organization

Digitization of end-to-end processes has high potential to increase the efficiency of manufacturing organizations. Nevertheless, starting such a transformation process brings up the challenges of harmonizing the workflow as well as standardization of the generated working data, e.g. between shop floor and office floor.

At first, manufacturing and the computer industry have established quite diverse cultures and different ways to solve problems over decades. While the IT professional might be used to “just perform a quick update”, in production environments the approach “never touch a running system” has proven to be more constructive. But, on the foundation of common ground a solution can be approached: neither perfect manufacturing processes nor immaculate software products happen to ‘fall from the sky’, even less at their first appearance. In both industries, there is usually an iterative way of incremental improvements that lead to the desired solution. The IT software update may be compared to a carefully revised NC-program: its next “version” delivers less tool wear and improved chips, while the software update gives new features and improved stability. Of course, any changes to machinery on the shop floor – and software is always vital part of that machinery – must be taken very carefully, so that risks are minimized. On the software side, this means use of comprehensive and state-of-the-art methods of quality assurance, and on the production side, software maintenance must be seen as a mandatory and recurring action.

A second potential disagreement may arise from diverging conceptions of the product lifecycle. While a machine tool is usually meant (and able) to work decades, in the software industry product life spans of a few years or even a few months are standard. However, a productive operation of the machine must be possible also after years of usage. In order to accomplish this, production software has to be built very modular and it is advisable to rely on common and broadly implemented IT standards (such as OPC UA).

Also, there is a different way of selling the product: machines are very likely to be leased or bought, while software is preferably rented on the basis of a monthly fee. The local maintenance personnel cannot provide this service, so this means that continuous payments and service level agreements are mandatory. This business model is already very well-known from ERP-systems, but now it is expanded into production itself.

In general, a common misunderstanding shall be clarified: the digitalization of production does neither start nor terminate with just a digital twin or a smart machine, but it is rather based on transparent and well-thought enterprise processes. Not only selected machines, but the whole enterprise’s processes and its IT infrastructure have to be made capable. Also today’s bouquet of “classic” production optimization strategies remains valid: digitalization is not a replacement for a Lean process, but it may expand and improve this process.

4 Solutions and next steps of implementation

To meet the requirements of digitalization, it is of prime importance that the input and output of a process are measurable. As an example, sorted parts on a palette ease a clear identification, compared to a box full of unsorted parts. Discrete processes may be represented more easily than continuous or overlapping processes etc. Following next steps can be summarized as a general road map of implementation.

4.1 Improved Connectivity:

DMG MORI approached the next step on the path of digitization by building CELOS® with modular and open IT architecture and a scalable structure of connectivity while focusing on E2E processes (Figure 2). Processes like: order management, planning, programming and machining are assisted by special apps on CELOS®. In order to achieve the required level of connectivity the CELOS® netBOX has been developed, an Iot-Connector between machines and CELOS® manufacturing network. Now it will be possible to connect older non-CELOS machines and also machines of other manufacturers.

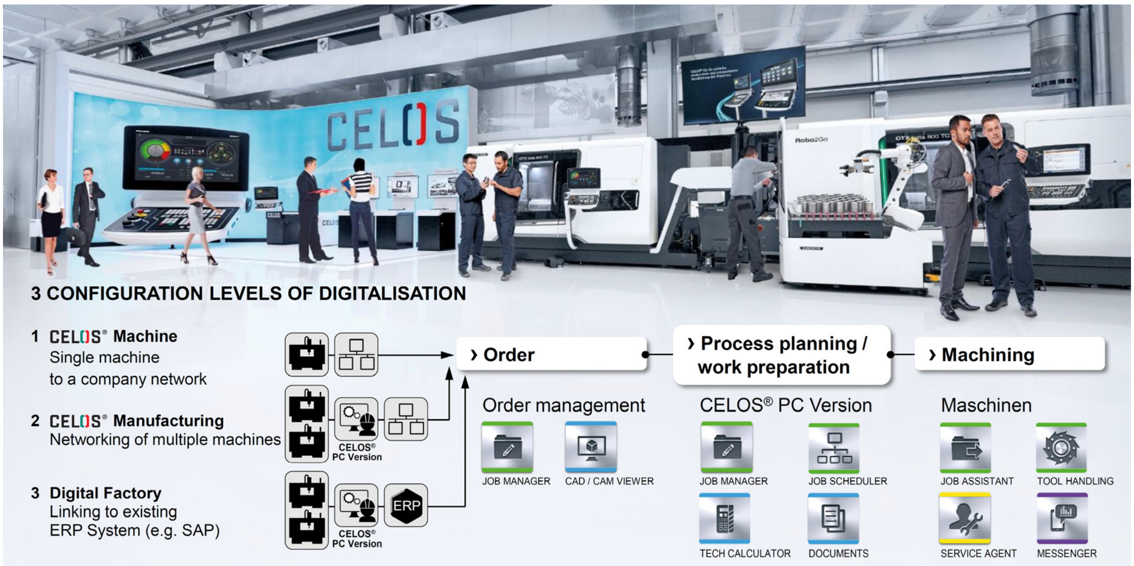


Figure 2: Configuration levels of digitizsation

4.2 Smart Machines:

Smart CELOS® machines still have advantages against non-CELOS machines regarding measuring, visualizing and analyzing the generated manufacturing process data. They can be considered as milestones on the road to digital transformation - a symbiosis of mechanics, electronics and information technology. Integrated sensors for temperature, forces, fluid levels and vibrations deliver the current status of machine tool core components as well as of the production process. By use of the "Condition Analyzer" app it is possible to evaluate the sensor data and set warning and alarm signals to give the current machine and process status. The collected data are brought together in a superordinate cloud architecture. Connecting machines on the shop floor to other production lines or even to other machines of the company worldwide, a cross-machine and cross-plant evaluation of the generated data can be conducted with the aid of special algorithms. This enables a qualified forecast of potential events of damage, for example on the spindle, using the submitted data and determined "behavioral patterns".

Figure 3: Configuration levels of digitization

Another app, "Performance Monitor", analyzes the machine's availability and allows an intuitive detection of machine downtimes. The machine operator will be enabled to give feedback regarding the causes of down time, e.g. wrong material pallet delivered (Figure 3). In total, today there are already 26 apps on CELOS supporting machine operators.

4.3 Starting the vertical and horizontal integration:

Thanks to its open architecture CELOS® allows the exchange of information with higher-level structures (vertical integration) in addition to its benefits in the shop floor area (horizontal integration). The sum of both integration strategies is the real step forward towards the digital factory, a vision with no more unscheduled machine downtimes and only the highest possible machine availability.

A direct impact on maintenance processes can be achieved through such integrations. Figure 4 demonstrates how the "Service Agent" app interacts with the "Condition Analyzer", analyzes warnings and sends messages to machine operators and maintenance departments. It also reminds on pending maintenance tasks. After that, these messages can trigger an order process of spare parts just in time. Logistical and economical benefits of such a scenario are well known in the automotive industry and it will find more acknowledgment in SMEs.

Figure 4: Efficient maintenance processes in the digital factory

One other example of a vertical and horizontal integration in metal cutting corporations is adapting a digital tooling process. DMG MORI offers modular solutions to help customers to get the required information on availability of cutting tools in the organization (digital CAD-models and physical tools in storage). These information are essential for high efficient job preparation steps, which usually are conducted either by a separate staff group or by the machine operating personnel. The target is "No more searching and waiting for tools and setup equipment". This works by managing all the tool information in one database and provide this to all departments involved in getting the machining job done. The process can be conducted as following: CAD/CAM Department can get the programming order from managing departments or ERP-Systems. They search for available tools in the database, and apply them in programming if suitable to the machining strategy. If there are no suitable digital tools available, the programmer can download the tool CAD models from the integrated cloud library. Such a tool cloud library includes digital catalogs of most of tool manufacturers and is continuously increasing its capability. The required tools will be now installed in the user-library and thus become available together with its technology information to other users of the organization. The order process of the tool can be now trigged. After a 1:1 simulation of NC-programs the machine operator can assemble the required tools, which are now reserved for the specific order in the tool storage. Its position is also well known and defined. Its life-time information is saved in the database. After the assembly, the tools must be measured by a pre-setting machine, which is connected to the database of the tool. On this way, the real dimensions of the assembled cutting tool (diameter, length, cutting edge) will overwrite the nominal values in the databank and be instantly available on the CELOS® machine. All what the machine operator has to do now is to use a code scanner or a RFID-reader on the machine to install the right tool in the right position of the tool magazine. This way, the job preparation will be much more efficient especially for SMEs, which do not have the big capacity to install a department specialized doing only job preparation.

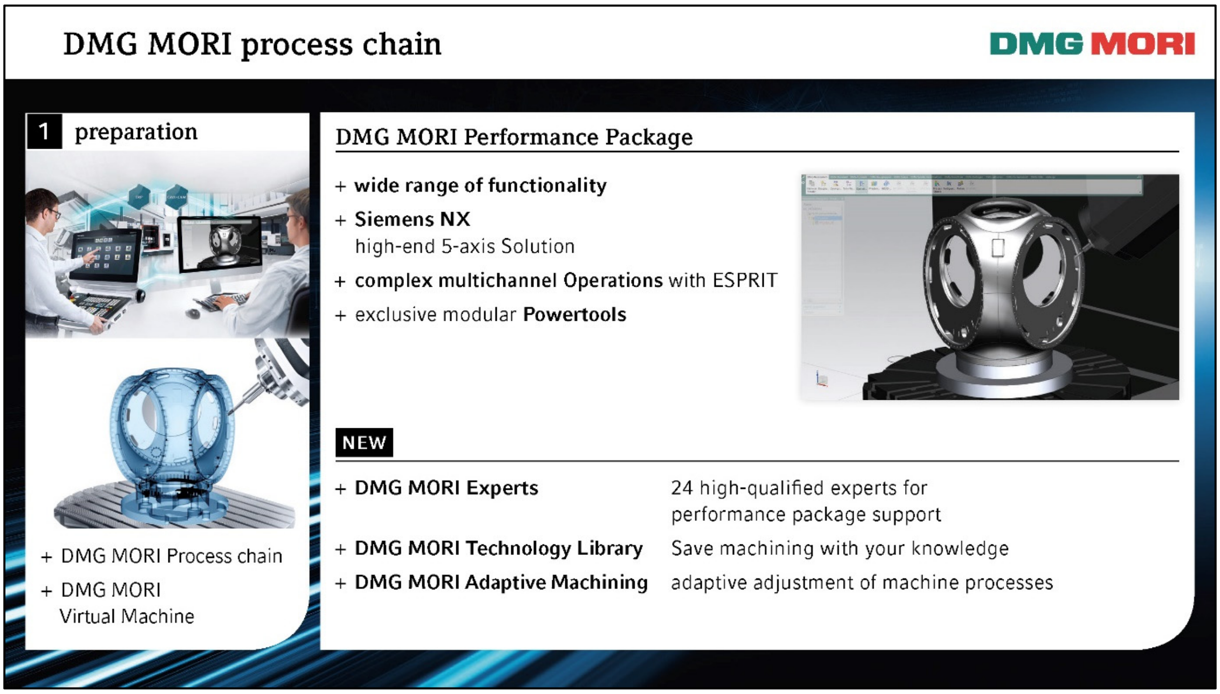
5 Summary

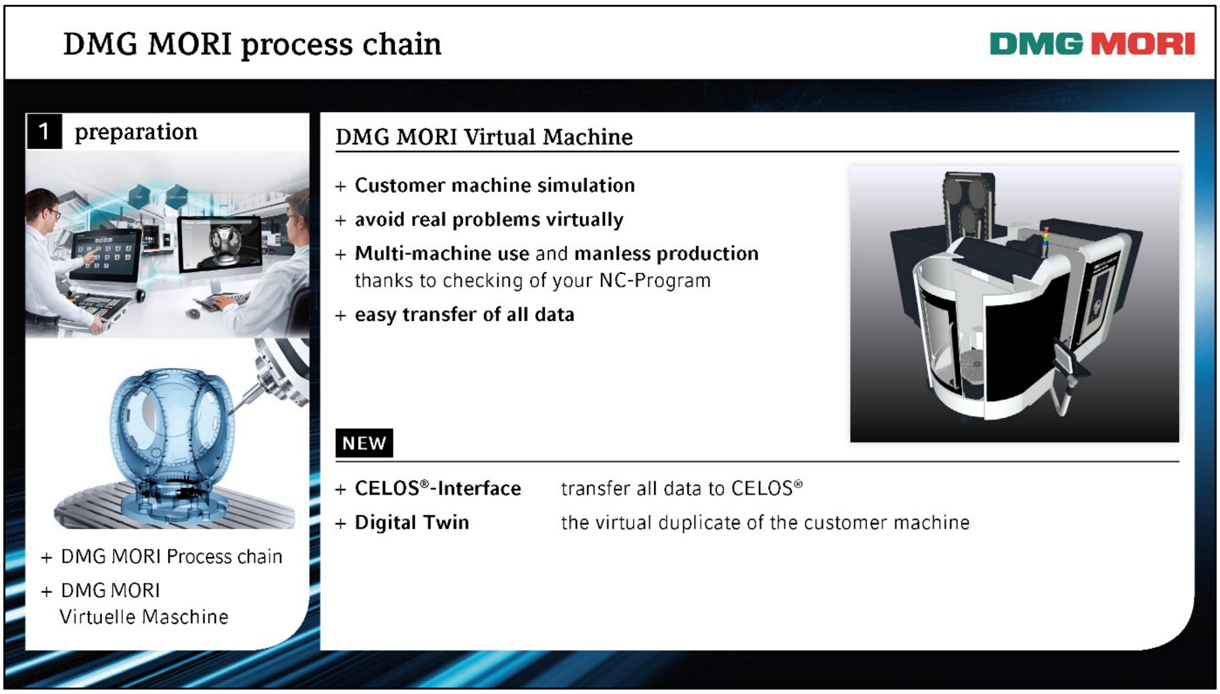
Changing the general mindset of people working in production organizations will emerge through realizing the big benefits of digitization. Since two different cultures are now have to be working together and understand each needs, it is clear to have some differences until real synergies will come out.

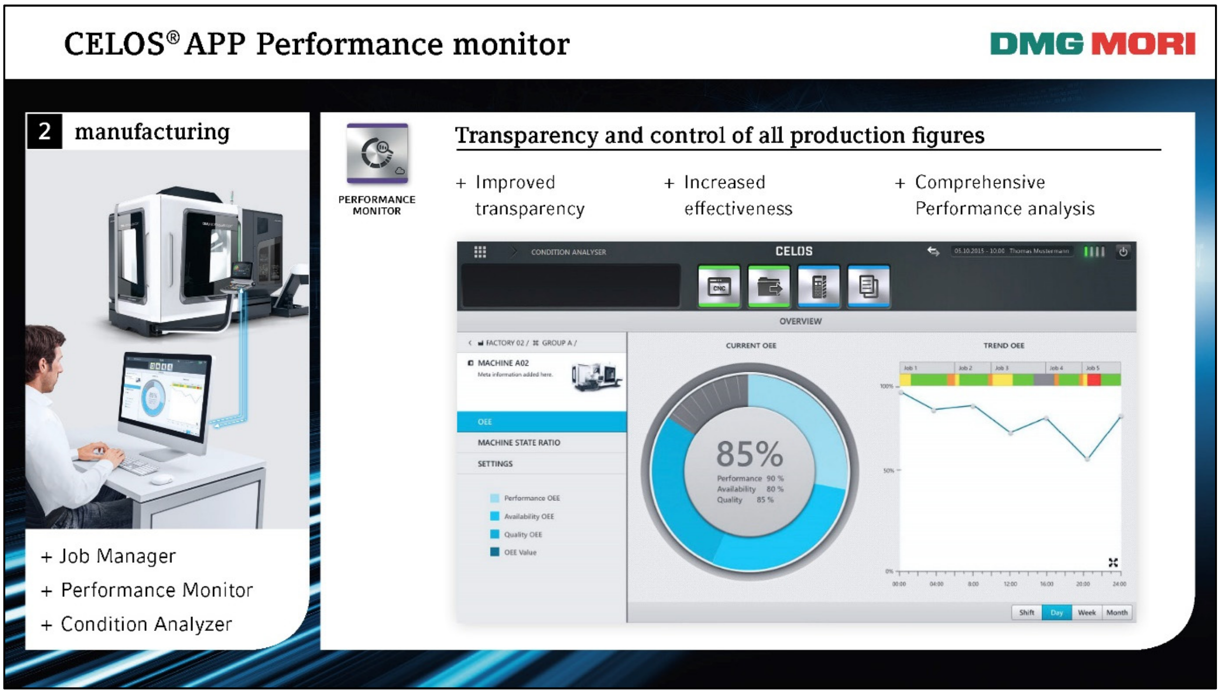
SMEs of metal cutting industries have limited IT capacities in usual, so they need a full support of machine manufacturers. DMG MORI, as the world's leading manufacturer of machine tools, is taking an active role supporting digitization of its customers. With CELOS® as an open connectivity platform the first steps on the path of digitization can be done. Small focused projects, though with focus on end-to-end processes, can be started to roll out the digitization process throughout the corporation. Existing products of DMG MORI will help reaching this target. They allow the vertical and horizontal integration of machine tools in the manufacturing organization. Powerful specific apps, like “Condition Analyzer” or “Performance Monitor” with the help of the CELOS® netBOX are some examples of these.

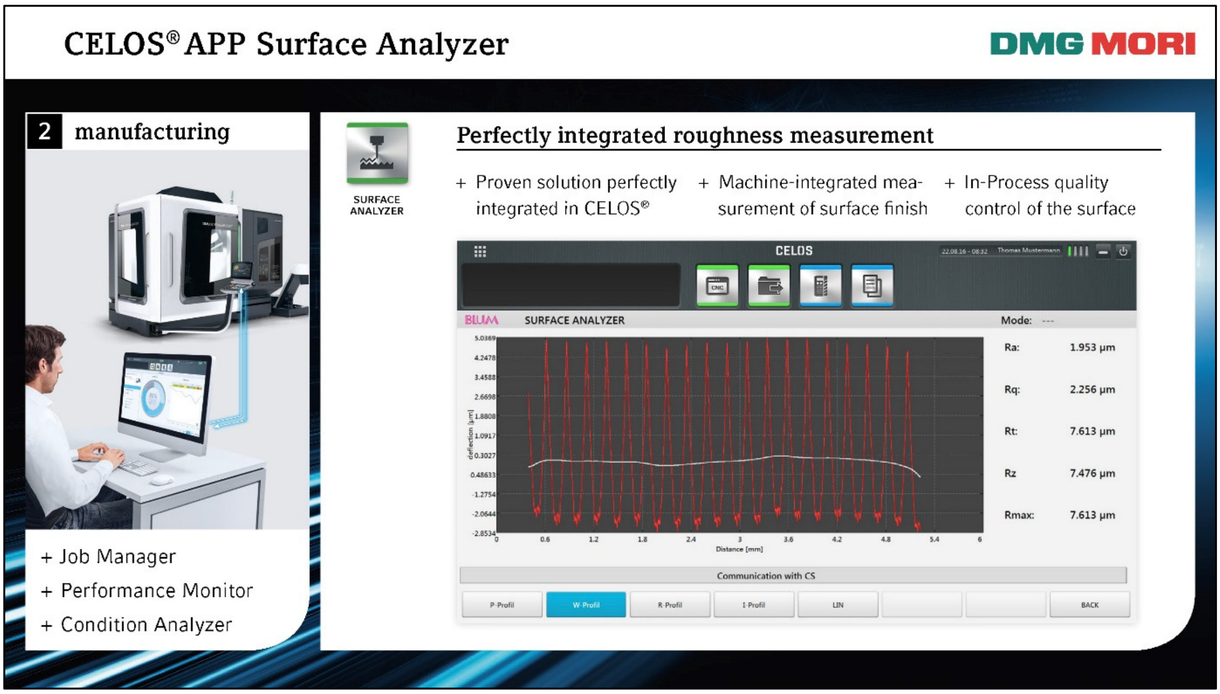

Digital Factory
Path of digitization
PATH OF DIGITIZATION
› EXCELLENCE IN PRODUCTION
Digital Factory
› INTELLIGENT WORKFLOW
CELOS® Manufacturing
› MORE THAN JUST SMART
CELOS® Machine
DMG MORI

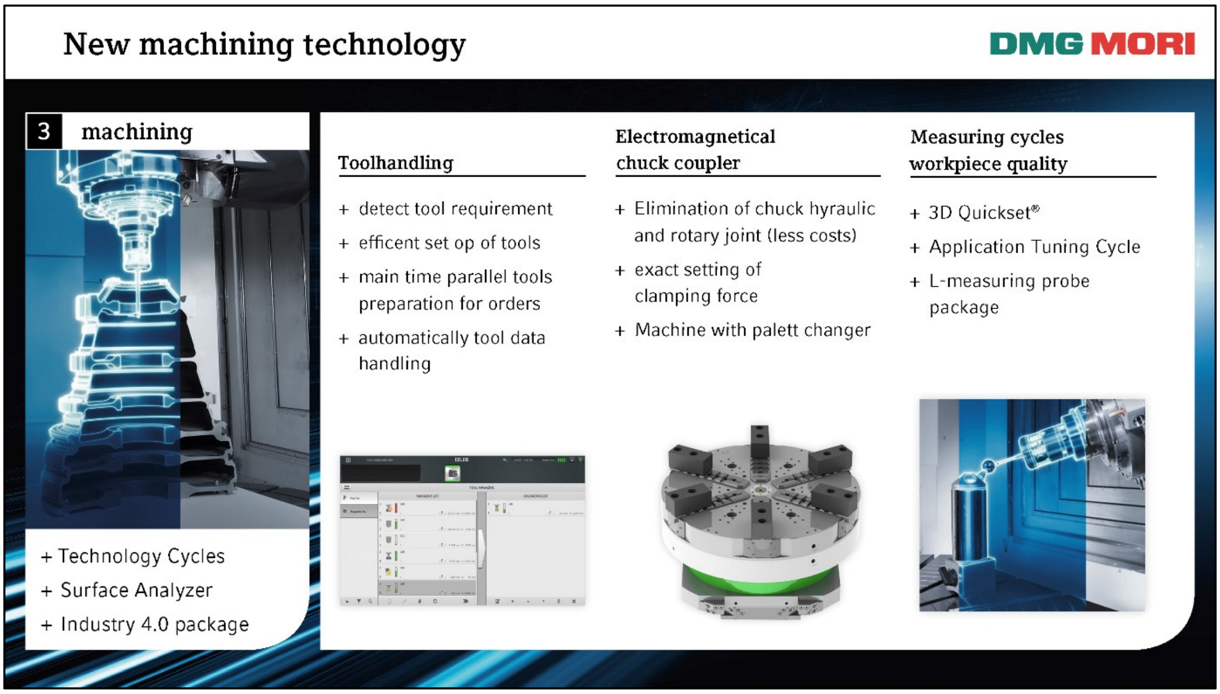

CELOS® Manufacturing
DMG MORI
1 preparation
2 manufacturing
3 machining
4 service
+ DMG MORI Process chain
+ DMG MORI Virtual Machine
+ Job Manager
+ Performance Monitor
+ Condition Analyzer
+ Technology Cycles
+ Surface Analyzer
+ Industry 4.0 package
+ Service Agent
+ Developer
+ Update

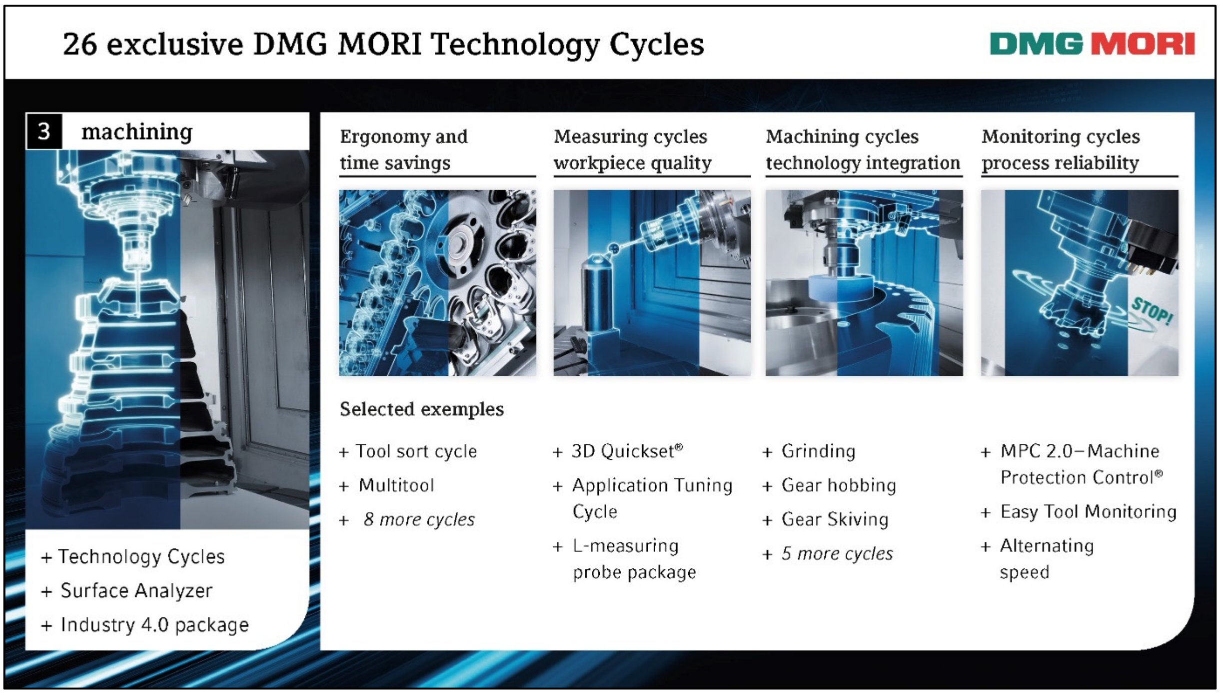

DMG MORI process chain
DMG MORI
1 preparation
+ DMG MORI Process chain
+ DMG MORI Virtual Machine
DMG MORI Performance Package
+ wide range of functionality
+ Siemens NX high-end 5-axis Solution
+ complex multichannel Operations with ESPRIT
+ exclusive modular Powertools
NEW
+ DMG MORI Experts — 24 high-qualified experts for performance package support
+ DMG MORI Technology Library — Save machining with your knowledge
+ DMG MORI Adaptive Machining — adaptive adjustment of machine processes

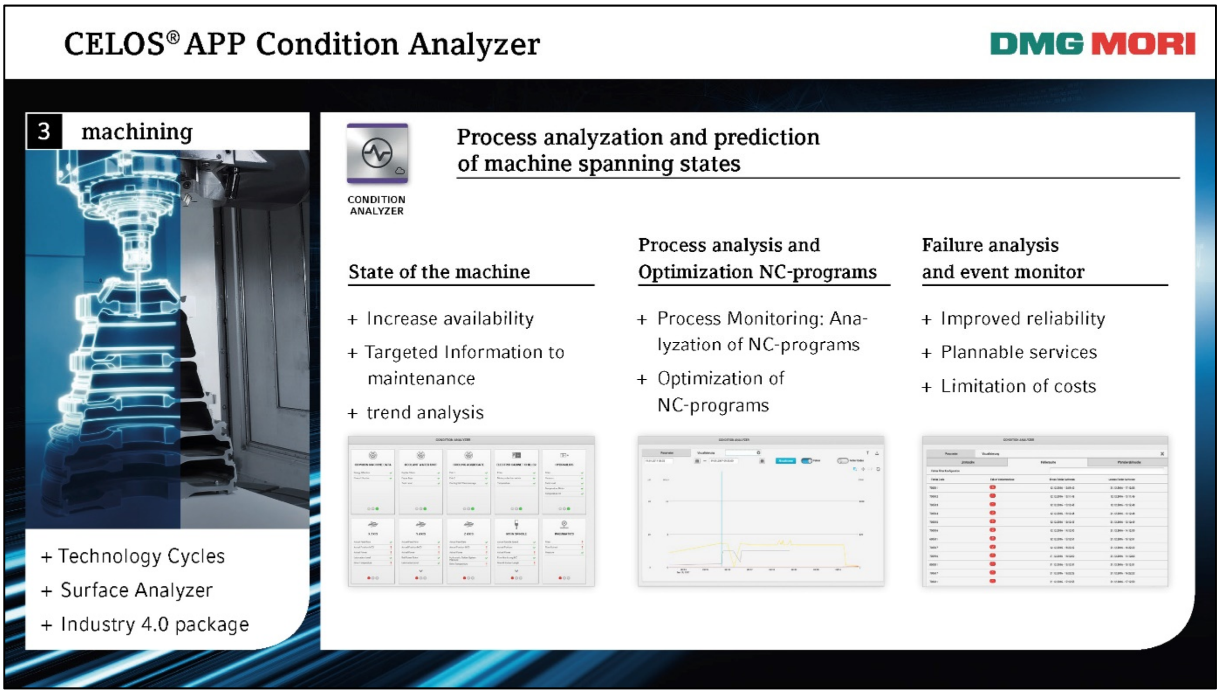

DMG MORI process chain
DMG MORI
1 preparation
+ DMG MORI Process chain
+ DMG MORI Virtuelle Maschine
DMG MORI Virtual Machine
+ Customer machine simulation
+ avoid real problems virtually
+ Multi-machine use and manless production thanks to checking of your NC-Program
+ easy transfer of all data
NEW
+ CELOS®-Interface — transfer all data to CELOS®
+ Digital Twin — the virtual duplicate of the customer machine

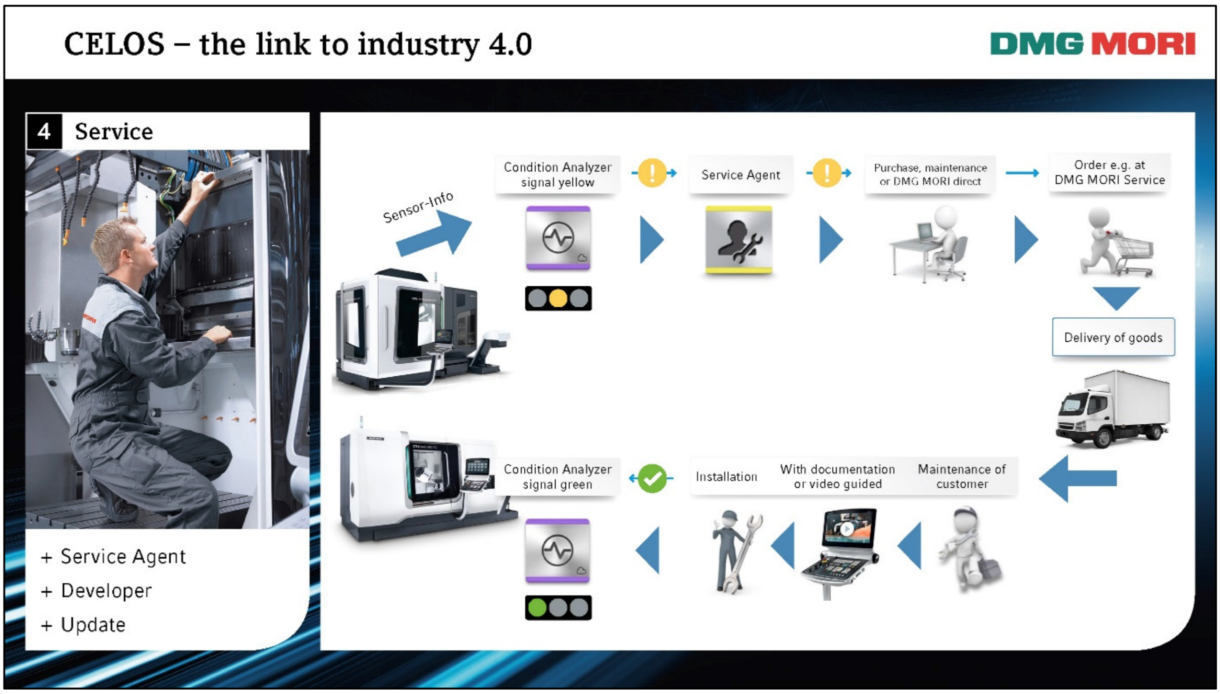

CELOS® APP Performance monitor
DMG MORI
2 manufacturing
PERFORMANCE MONITOR
Transparency and control of all production figures
+ Improved transparency
+ Increased effectiveness
+ Comprehensive Performance analysis
CELOS
OVERVIEW
CURRENT OEE
TREND OEE
85%
+ Job Manager
+ Performance Monitor
+ Condition Analyzer


CELOS® APP Surface Analyzer
DMG MORI
2 manufacturing
SURFACE ANALYZER
Perfectly integrated roughness measurement
+ Proven solution perfectly integrated in CELOS®
+ Machine-integrated measurement of surface finish
+ In-Process quality control of the surface
CELOS
SURFACE ANALYZER
Ra: 1.953 µm
Rq: 2.256 µm
Rt: 7.613 µm
Rz 7.476 µm
Rmax: 7.613 µm
+ Job Manager
+ Performance Monitor
+ Condition Analyzer


New machining technology
DMG MORI
3 machining
+ Technology Cycles
+ Surface Analyzer
+ Industry 4.0 package
Toolhandling
+ detect tool requirement
+ efficent set op of tools
+ main time parallel tools preparation for orders
+ automatically tool data handling
Electromagnetical chuck coupler
+ Elimination of chuck hyraulic and rotary joint (less costs)
+ exact setting of clamping force
+ Machine with palett changer
Measuring cycles workpiece quality
+ 3D Quickset®
+ Application Tuning Cycle
+ L-measuring probe package


26 exclusive DMG MORI Technology Cycles
DMG MORI
3 machining
+ Technology Cycles
+ Surface Analyzer
+ Industry 4.0 package
Ergonomy and time savings
Measuring cycles workpiece quality
Machining cycles technology integration
Monitoring cycles process reliability
STOP!
Selected exemples
+ Tool sort cycle
+ Multitool
+ 8 more cycles
+ 3D Quickset®
+ Application Tuning Cycle
+ L-measuring probe package
+ Grinding
+ Gear hobbing
+ Gear Skiving
+ 5 more cycles
+ MPC 2.0–Machine Protection Control®
+ Easy Tool Monitoring
+ Alternating speed


CELOS® APP Condition Analyzer
DMG MORI
3 machining
CONDITION ANALYZER
Process analyzation and prediction of machine spanning states
State of the machine
+ Increase availability
+ Targeted Information to maintenance
+ trend analysis
Process analysis and Optimization NC-programs
+ Process Monitoring: Analyzation of NC-programs
+ Optimization of NC-programs
Failure analysis and event monitor
+ Improved reliability
+ Plannable services
+ Limitation of costs
+ Technology Cycles
+ Surface Analyzer
+ Industry 4.0 package


CELOS – the link to industry 4.0
DMG MORI
4 Service
Sensor-Info
Condition Analyzer signal yellow
Service Agent
Purchase, maintenance or DMG MORI direct
Order e.g. at DMG MORI Service
Delivery of goods
Condition Analyzer signal green
Installation
With documentation or video guided
Maintenance of customer
+ Service Agent
+ Developer
+ Update

Eng. Rafael Zanini

Rafael Zanini was born in 1985 and studied computer engineering at the University of São Paulo (USP), Brazil, where he graduated as best student in 2007. He concluded his MBA on Strategic Project Management at Fundação Getúlio Vargas (FGV) on 2013 and he is currently doing his MSc in Computer Science at University of Campinas (Unicamp). Working for Chemtech since 2006, he has worked as systems engineer, solution architect, team leader, business developer, project manager and recently he has been acting as Sales Manager, responsible for the whole Industrial IT area within the company. Working as a consultant for different projects in China, UAE, South Africa and Germany, he is currently active on different digitalization initiatives on Siemens and his customers, giving several lectures about Digitalization on workshops and automation events. Rafael has worked as technical manager for different types of automation, system integration and digitalization projects for metals and mining, food and beverages, chemicals and petrochemicals and utilities industries, delivering innovative solutions and systems for mission critical projects. Being an Agile practitioner and enthusiast, he is a certified Scrum Master since 2010, Project Management Professional (PMP) since 2012 and SAFe Agilist since 2015. Rafael is also one of the founders and former vice-president of Cursinho Prof. Chico Poço, a Non-Governmental Organization (NGO) dedicated for providing education for low-income students, where he teaches physics until today.

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Chemtech

Founded in 1989, Chemtech is the Brazilian company specialized on Engineering Projects, Consulting Services and Industrial IT solutions. Chemtech can deliver state of the art technologies for different industrial segments and for different countries all around the world. Being part of Siemens since 2001, Chemtech's experience gathers more than 4.000 projects for process industries such as Oil & Gas, Chemicals & Petrochemicals, Metals & Mining, Generation, Transmission and Energy Distribution. With HQ in Rio de Janeiro (RJ), Chemtech has a high skilled team on its offices in Belo Horizonte (MG), Salvador (BA) and São Paulo (SP).

chemtech
A Siemens Business

Using the Digitalization Master Plan as a tool for implementing a Smart Manufacturing (Industry 4.0)

Abstract

Industry 4.0 comes as the new industrial revolution for completely disrupt the way we create and produce on industry, rather on the discrete manufacturing or process industries. Digital technologies such as digital twins, cyber-physical systems, artificial intelligence, big data analytics, 3D printers and several different technologies create a complete new vision with tremendous potential for increasing the efficiency, transparency and quality in the industry, reducing dramatically the costs and time to market. However, this whole new world of potential and initiatives comes also with a lot of questions about which path to follow and which projects should be prioritized, leading companies to a complete confusion and frustration about which investments to make and what benefits they can really have with the Industry 4.0 concept. This work presents a structured methodology called Digitalization Master Plan, developed by Chemtech/Siemens as a solution to stablish a clear roadmap towards digitalization, starting from a digital maturity check model, going through all identified digitalization opportunities, mapping the related costs, technical feasibility and expected returns of investment. This work also shows some real reference cases of implementing this methodology, presenting concrete digital projects and returns for process and discrete manufacturing industries.

Keywords

Industrie 4.0; Smart Manufacturing; Digitalization; Digital Twins; Integrated Engineering; Integrated Operations.

1 Introdução

Digitalization is the key concept that drives our daily lives nowadays. It is present all around us, on the way we interact socially, the way we buy and consume products and services, the way we use transportation, the way we work and consume information and entertainment. It is a wide concept brought to us through the digital technologies that have revolutionized the world since the beginning of the Internet and the usage of smart devices.

When we use all this potential applied to industries, there is a completely new world of opportunities and possibilities. Technologies such as digital twins, cyber-physical systems, artificial intelligence, big data analytics, 3D printers and several different technologies create a complete new vision with tremendous potential for increasing the efficiency, transparency and quality in the industry, reducing dramatically the costs and time to market.

In 2010, the German government has sponsored the creation of a new concept called "*Industrie 4.0*", which summarizes all these possibilities and gives this new digital revolution a new name and visibility. According to [1] and [2], the whole concept of *Industrie 4.0* relies on the application of Digitalization and Cyber-Physical Systems for bringing up new levels of productivity, efficiency and disruption of the value chains all over industries.

The main goal of *Industrie 4.0* is to fundamentally improve value chains all over the product lifecycle, from engineering to operations, from products to plants, from suppliers to end consumers. However, the way to do it is not always clear. Usually, most measures implemented in many industries are still only based on pilot projects, which often seems as only technological and feasibility studies rather than concrete implementations of *Industrie 4.0* concepts. This happens because most companies are still trying to identify their own resources, their own systems and culture, so then be able to research for new opportunities and possibilities. In addition, the daily activities and business needs ultimately consume all their resources and initiatives, and pilots are often left by their own chance, since they usually overlook key aspects of its implementation such as a company's organizational structure and culture, focusing only on the needs of one specific area within the company.

As a result, the changes are often only small and evolutionary and not disruptive as they should be, and usually they fail to reflect the organization's actual processes and business needs. Trying to solve this, Acatech – German National Academy of Science and Engineering - presented in [1] its recommendations for implementing the strategic initiative *INDUSTRIE 4.0*, mostly based on focusing on three features of *Industrie 4.0:*

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

Despite the practical focus of these strategic recommendations, they still lack the appropriate support for companies to start their own journey towards a digital transformation process. They still do not know which technologies they should start investigating, which systems and processes they have already implemented and how they can create a consistent digitalization vision for the whole company. In addition, most CEOs and CFOs still lack the visibility of how much this transformation will cost and what are the tangible and business benefits that they can extract from this digital transformation, leaving them with no other option than just fostering and sponsoring a few isolated opportunities that can improve the efficiency and transparency of some key functional areas, but that lack the impact of creating an unified vision for the whole company.

2 The Digitalization Master Plan (DMP)

Trying to solve some of these questions, Chemtech, a Brazilian Siemens Company, has adapted its well-known methodology for Automation and Instrumentation Master Plans to drive its customers to a new level of digitalization. The Digitalization Master Plan (DMP) is the consulting methodology that aims to identify process improvement opportunities, technologies and people skills that can be improved or upgraded in order to help customers to extract all the business value from Digitalization while implementing their journey towards *Industrie 4.0.*

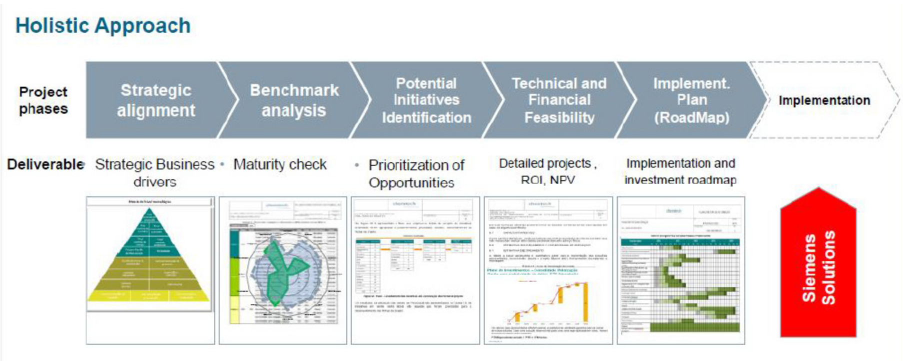

Figure 1: The Digitalization Master Plan Methodology

In order to do so, the DMP begins with the its alignment with all other strategic plans already defined for the company, interacting with them to promote process improvement on already identified bottlenecks and pain points. Therefore, the DMP considers not only existing identified opportunities, but also new ones, all grouped together in a way that provides a global overview through time, linking them to strategic goals and improvement process.

The strategic objectives are then mapped to market best practices for each technological perspectives, which allows to identify the gaps are based on technology, processes and people skills, which shall be developed in order to achieve the desired level of maturity and performance.

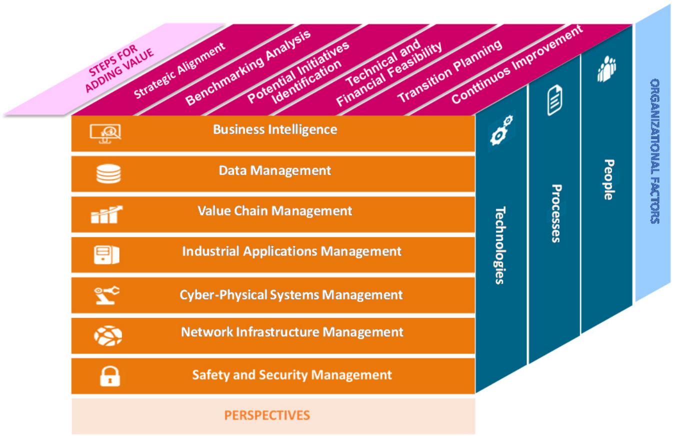

Figure 2: The Digitalization Master Plan "Cube" - Technological Perspectives

The improvement opportunities are then prioritized according to their cost, expected returns and implementation complexity and schedule, allowing the best opportunities from a business perspective to be identified. Once defined, these opportunities are planned and included on the five-year roadmap, which ultimately gives the company a clear view of the path to be followed and the plan to be executed for each one of the opportunities.

Once developed, the advisory plan should be reviewed at least annually, in order to incorporate any changes in the strategic context and the evolution of technology and progress of the implementation plans. Figure 1 presents a comprehensive perspective of the whole process, while Figure 2 shows the technological perspectives that are evaluated during the Master Plan execution.

2.1 Digitalization Master Plan Steps

The process of developing an advisory plan consists of the following major steps:

1. Strategic alignment;
2. Data gathering and analysis;
3. Interviews and workshops;
4. Benchmarking;
5. Opportunity Identification & Prioritization;
6. Roadmap definition;
7. Personnel Planning;
8. Investment Planning (Budget);
9. Final Presentation.

The concepts and tasks for each step are detailed on the following sections.

2.1.1 Strategic Alignment

This step includes the identification of company's board business objectives and targets in order to guide the proposal of technology solutions opportunities. Activities such as interviews with the directors, key operational management levels and existing strategic plans analysis should be considered during this phase.

The strategic alignment should be developed in such way to reference multiannual targets of the operational Units. It also gives a clear vision of the business targets and goals that the Digitalization Advisory Plan should address.

2.1.2 Data Gathering and Analysis

The data gathering and analysis phase is done to support the identification of opportunities for improvement with the application of technologies. The data gathering consists of extracting and analyzing data available on:

- Production plans;
- IT infrastructure and architecture diagrams;
- Automation infrastructure and architecture diagrams;
- History of business performance indicators involving production, quality, specific consumption of raw materials, operational income, accidents, etc.;
- Loss profiles, Downtimes reports, Failure analysis reports, etc.;
- Personnel Capacity table and job operation map together with activity worksheets versus allocated time;
- Bottlenecks analysis and production chain.

All these documents are often spread on text files, spreadsheets, reports and all types of written and digital Medias. It is important that key people from all areas are involved on this data gathering, so all relevant information is presented to the assessment leaders.

2.1.3 Interviews and workshops

To identify problems faced by the area, interviews and meetings should be conducted aiming the involvement and sharing of improvement ideas with the teams involved in the production process. Descriptions of the opportunities raised must be specific and the scope well-defined. Where available, statistical processes performance data to which the opportunities identified are linked shall be included.

The opportunities identified in this step will provide subsidy to the prioritization step.

2.1.4 Opportunities Identification and Prioritization

From the identified opportunities in the previous steps, a classification process shall be performed based on prioritization methodology. In this analysis, the adherence between the performance and technology gaps shall be considered. The prioritization process shall take into account all strategic drivers aligned on the first steps, balancing opportunities according to its investment, expected returns, effort, complexity and proposed schedule. Opportunities classified as "To Implement" may be detailed in latter phases to detail its scope on future engineering projects.

2.1.5 Roadmap

The objective of the Roadmap is to present a consolidated view of projects planned to be executed according to the prioritization. The Roadmap allows the visualization of the evolution over time and consolidated dimensions evaluated in the Advisory Plan.

2.1.6 Investment Planning (Budget)

The Advisory Plan should consider, separately, the major current and planned expenses (including staff) in the medium term, considering all the possible costs with engineering, support and maintenance. Besides that, each opportunity defined inside the roadmap will have its cost estimated, in a way to make sure that the annual budget fits the strategic goals defined for the Advisory Plan.

2.1.7 Final Presentation

The advisory plan shall be presented to managers and directors of the units in order to ensure the expected strategic alignment. The presentation usually includes:

- Goals of the Advisory Plan;
- Advisory Plan Benefits;
- Prioritized opportunities;
- Evaluated Projects;
- Digitalization Roadmap;
- Investment and Return Estimations (Return of Investment).

2.2 Deliverables and Results

It is expected that at the end of each step a unique deliverable (or document) is generated, consolidating all the findings and information developed on each step. According to the proposed methodology, the DMP produces the following deliverables:

Table 1: List of DMP Deliverables

Methodology Step	Deliverables	Description
Strategic Alignment	Project Plan / Strategic Drivers List	Document with key definitions of how the project shall be managed and coordinated, and a list of key goals and strategic drivers.
Data Gathering and Analysis	Organizational Assets Inventory	Excel spreadsheet containing the main organizational assets of the company, such as equipment, teams, systems, documents, operating procedures, etc.
Interviews and Workshops	Technical Process Overview	Technical report containing descriptive of the process, flowcharts, photos and information collected during the visits to the site.
	Maturity Matrix	Based on the findings, the maturity matrix is developed as a spreadsheet showing the current maturity scores, the desired scores and the expected scores after the implementation of the identified opportunities.
	Actual Architecture (AS IS)	Document with the logical view of the current architecture of automation and existing systems in the plant.
Opportunities Identification and Prioritization	Prioritized Opportunity List	Spreadsheet containing the main digitalization opportunities mapped for the plant. These opportunities are grouped into projects and prioritized.
Project Evaluation	Economic and Technical Feasibility Studies	Project sheets that summarizes the feasibility analysis for top priority projects.
	Future Architecture (TO BE)	Document with the logical vision of the proposed architecture for automation and digital systems in the plant.
Investment Planning	Cash Flow and Investment Plan	Based on company's budget
Roadmap / Final Presentation	Digitalization Roadmap and Project book	Spreadsheets in Excel / Technical report with the consolidated view of the investments and descriptive of the projects proposed for the Digital Master Plan

3 Practical Example of the Digitalization Master Plan

In order to evaluate and test its own methodology, Siemens has sponsored the execution of the DMP methodology on one of its own factories in Brazil. The main goal of the project was to evaluate the current maturity level of a Power Capacitor Plant and to transform it into a Benchmark reference for all Siemens plants in Brazil.

As specific goals, the Project aimed to identify a clear vision for the future investments on the plant, defining all the steps necessary for their implementation and development as well as the budget for the digital transformation of the plant.

Due to its strategic importance, it was crucial that the plant efficiency could be raised up by the application of state-of-the-art technologies. As automation and digitalization technologies are the basis for Industry 4.0 concepts, the project main purpose was to identify the Industry 4.0 initiatives that could increase the productivity, reduce operational costs, increase product quality and production flexibility, and reduce the time-to-market and production times.

The DMP shall be used as the main reference for future human resource and capital resource planning in the future, promoting technological evolution and sustainability for the plant. The digitalization maturity planning horizon is for five years, from 2017 to 2022.

The current existing automation assets and base are composed by isolated control and supervisory systems, which are not integrated into an automation network. Each area computes its own information based on spreadsheets or legacy systems, that must be manually synchronized and merged together in order to produce consolidated reports for managers and shift leaders. Each area has its own KPIs and targets, which are manually monitored on a daily, weekly and monthly basis. The current level of digitalization only allows managers to take corrective actions upon deviated KPIs, making it difficult to anticipate production problems or deviations. Most data are available on shared spreadsheets, filled up manually by operational staff.

Based on the proposed maturity model, the biggest identified gaps were around automation network infrastructure, manufacturing execution systems, maintenance management systems and the integration between different assets and smart equipment.

All production bottlenecks were identified and validated using a digital twin of the plant, simulating all operational tasks and times, allowing the consultant team to identify all bottlenecks for given scenarios. All scenarios were modeled and simulated using Siemens Plant Simulation software. Based on these scenarios, it was possible to simulate process re-design scenarios, considering different number of staff, shifts and teams. It was also possible to evaluate project returns and expected increase on productivity levels, which allowed us to calculate project overall returns.

The final prioritized opportunity list contains 56 mapped opportunities, grouped into 17 different projects – which sums up a total investment of almost 6.5 million (BRL) to be executed within a five-year roadmap. The project portfolio generates a NPV of over 5 million (BRL), with an average project payback of 1.6 years.

Projects are categorized over different areas, and grouped according to it's importance to the plant. Different initiatives and projects were identified, and some of them are listed below:

- Engineering management:
  - Usage of engineering collaboration platform for documents and workflows integration.
- Operatinos Intelligence and Manufacturing Operations Management:
  - Implementation of MES and Visual Management Dashboards;
  - Implementation of Advanced Planning and Scheduling system integrated to MES and SAP.
- Maintenance management:
  - Implementation of Maintenance platform integrated to engineering and MES.
- Product traceability:
  - Implementation of product digital twin and traceability along the production chain.
- Robotized production cells:
  - Automation and robots for manual production lines.
- Quality system Integration:
  - Online quality inspection and predictive quality models.

All projects were evaluated from technical and economical perspectives, validating the expected returns based on current costs and expected increase over productivity, efficiency and cost reductions.

4 Digitalization Maturity Check Model

Recently studies from Acatech [3] have proposed an *Industrie 4.0* Maturity Index, which defines a proposed methodology for assessing and defining a digitalization strategy for companies. However, before this study was even published, the maturity check model used on the DMP project by Chemtech was based on a mix approach between existing maturity models based on [4] and also based on the Chemtech's own model for digitalization technological perspectives. The first reference gives a straightforward evaluation criteria for ISA-95 activities model for MOM applications, while the second reference allows to evaluate innovative opportunities and systems.

The maturity assessment was based on the information gathered during the site assessment, interviews and workshops, allowing the consultant team to evaluate the current situation of the automation and digital systems on the plant.

The maturity model was based on the following perspectives:

- Digitalization Technological Perspectives: based on Chemtech's methodology, the following digital perspectives were evaluated;
- Production/Inventory/Quality/Maintenance Operations Management: based on the four pillars of ISA-95, all the tasks and activities were evaluated according to the proposed MESA model for MES maturity [4];
- Automation: based on automation standards and maturity models;
- Field devices: based on automation and instrumentation standards and maturity models.

MESA proposed an evaluation similar to existing software models, such as CMMi, with the following levels of maturity:

- Level 1 – Initial;
- Level 2 – Managed;
- Level 3 – Defined;
- Level 4 – Quantitatively Managed;
- Level 5 – Optimizing.

Chemtech has adapted those levels to fit a more digital-focused approach, incorporating key aspects of Industry 4.0 to the levels of maturity, according to the following ones:

- Level 1 – Spontaneous: processes are done mostly with the use of manual mechanisms or with local support of spreadsheets and other generic tools, but without following a corporate standard;
- Level 2 – Methodical: processes are repeatable, possibly with consistent results. Not all processes and tools are documented, but there are defined templates and data can be shared;
- Level 3 – Administrative: processes and tools at this level are well defined with documented standards for all activities and shared across all organizational groups.

Subgroups may tailor their processes from organization standards or use their own specific tools when needed;

- Level 4 – Tool supported: processes are supported with specialized and standard tools for each area and function group; however, different tools do not share or collaborate with each other on a transparent way, only through customized or limited interfaces;
- Level 5 – Integrated: processes are supported with specialized tools which can communicate and share information based on open standards, bringing the possibility for insights based on correlated data analysis;
- Level 6 – Autonomous: processes are driven by autonomous machines that can interact with the existing systems and database, providing automatic insights and prescriptive actions based on predictive models and data analytics.

Based on these criteria, the results for the assessed plant are shown on Figure 3.

Based on these results, it was possible to evaluate the technological areas with biggest gaps that should be correctly addressed in order to improve the plant's digitalization maturity. Therefore, after the initial gap analysis, it was possible to identify more than 75 opportunities, which were then filtered and prioritized into 56 opportunities and then grouped into 17 projects.

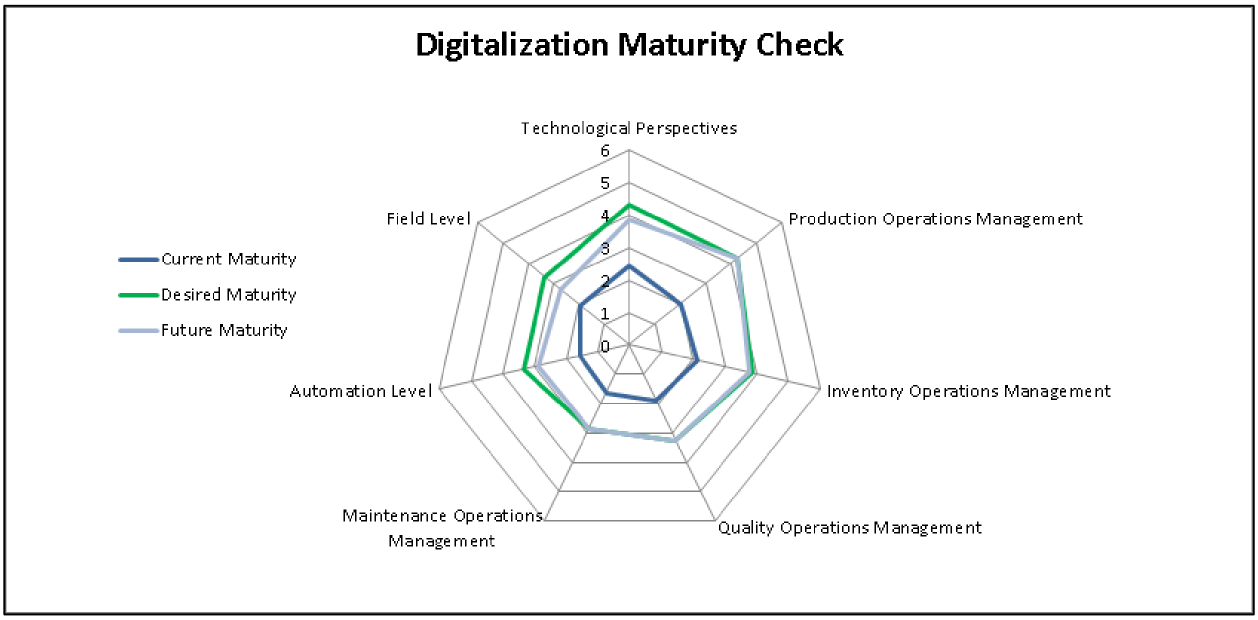

Figure 3: Digitalization Maturity Check

5 Opportunity and Project Evaluation

Based on the identified gaps and opportunities, it was created a list of all opportunities so they could be discussed and prioritized based on operational and management teams comments and decisions. The responsible for each area were constantly involved during this process, so that everybody could have the same level of understanding of each opportunity, its benefits and its implications to the existing processes.

Each one of the opportunities was evaluated based on the following information:

- **Business driver**: high level business need identified on the strategic alignment that can be improved with this specific opportunity;
- **Areas**: define the functional areas impacted by this opportunity;
- **Type**: define the opportunity type: 1 – Data Acquisition, 2 – Production Control, 3 – Manufacturing Management, 4 – Data Integration, 5 – Process Improvement, 6 – Data Analytics;
- **Project Name;**
- **Included on Roadmap**: a flag that indicates if the project was included on the final roadmap;
- **Technological Perspectives**: indicates which of the digitalization technological perspectives are affected by the project;
- **Technical complexity**: indicates if the opportunity is complex and hard to be implemented;
- **Investment**: estimates the total cost to implement the opportunity;
- **Potential Returns**: estimates the level of return expected;
- **Weighted Score**: indicates a calculated based on a weighted score based on opportunity complexity, impact, investment and expected return. This score is used for prioritizing the opportunity.

After the opportunity identification and classification according to its business drivers, they are all grouped into projects according to their types and technological perspectives, in such a way that makes sense to put them into the same project. For this implementation, all the 75 opportunities were filtered and prioritized, generating 56 priority opportunities that were grouped into 17 projects.

Each project than get a specific Project Charter, describing the project vision, scope, premises and affected areas and stakeholders. Projects are than technical evaluated, so they can be estimated in terms of cost and return. By the end of project conceptual and feasibility studies, it is possible to also prioritize and rank projects, according to the following project information:

- Project Name;
- Affected Areas and Stakeholders;

- Type;
- Technological Perspective;
- Current Situation: describe the current context on the plant that required the implementation of such project;
- Project Goals: describe project high-level goals;
- Project Scope: a brief description of project scope;
- Estimated Costs: a brief description of estimated costs (includes services, equipment, software and hardware);
- Estimated Returns: a brief description and rationale about the expected returns, based on reduced costs, increased productivity or increased revenue.

Besides all this information, each project is planned and analyzed according to its predecessors, so it is possible to define a logical sequence of projects and an initial roadmap. The additional fields are:

- Expected Start Date;
- Duration;
- Expected Capex Investment;
- Expected Opex Investment;
- Expected Return (Anually);
- Net Present Value (NPV);
- Simple Payback.

It is important to mention that all investment estimates are executed at FEL1 project level, where the Business Opportunity is identified and for which a cost estimate, denominated "Budget Order of Estimate", corresponding to classes 5/4 of AACEI (Association for the Advancement of Cost Engineering International), with an error margin typically between -30% and +50%.

It is possible that during the project execution, some projects are pre-selected as strategic projects, so they are evaluated at conceptual level, which then can make it possible to estimate the costs at FEL 2 level, or Conceptual Design Phase, in which the process design is defined, allowing a better detailing of the Budget, called Preliminary Budget, which corresponds AACEI Class 3, with a margin of error typically between -15% to +30%. However, this is only done for specific projects that are already identified as critical and top priority projects.

Once all information is generated, it is possible to create the initial Roadmap, based on the technical and economical feasibility of each Project. This is a step that needs to be refined over and over, according to other external inputs from different stakeholders. Many criteria can affect a project date and expected schedule, such as plant planned shutdowns, or planned maintenance periods, market demand and many other factors. The roadmap is then discussed with different stakeholders and areas, so they can all be aligned about project sequence and proposed schedules.

For the DMP generated for Siemens Capacitor factory, only 15 projects were considered top priority and were defined on the digitalization roadmap. Despite of being economically and technically feasible, the remaining two projects were left outside the roadmap mainly because of its investment level and complexity, which were too high to the standard Capex investment parameters accepted by the organization.

6 The Digitalization Roadmap

The roadmap alignment phase can take a long time depending on company organization and complexity. In most companies, investment projects are planned by a central PMO area, responsible for mobilizing project resources, project managers and teams. The DMP projects should consider not only the desired Industry 4.0 vision for the company, but should also incorporate ongoing and existing project initiatives, premises and restrictions, in a way that all projects are allocated and understood by all stakeholders. This step is usually handled through quick interactive sessions, where projects are briefly introduced to stakeholders and then they are quickly evaluated according to its importance and complexity to fit on the existing organization.

It is important to mention that the whole team that participates on the DMP process must be aligned and excited with the proposed projects and opportunities, and they should be specially excited about the Industry 4.0 vision that is desired for the company. This is achieved by involving top executives (C-level, directors, top managers) and making them engaged with the whole DMP concept and what it represents. The company must feel at the end of this process that they have come up with their own ideas and plans about digitalization, and that all ideas were heard and considered during this process.

During the review of the digitalization roadmap for its Power Capacitor factory, different areas from Siemens were involved, including corporate IT, corporate strategic planning, legal, procurement and many other areas within the organization. After a few rounds, the final roadmap is the one presented on Figure 4. The projects marked in green are considered the top priority projects and were detailed to the Conceptual Design level.

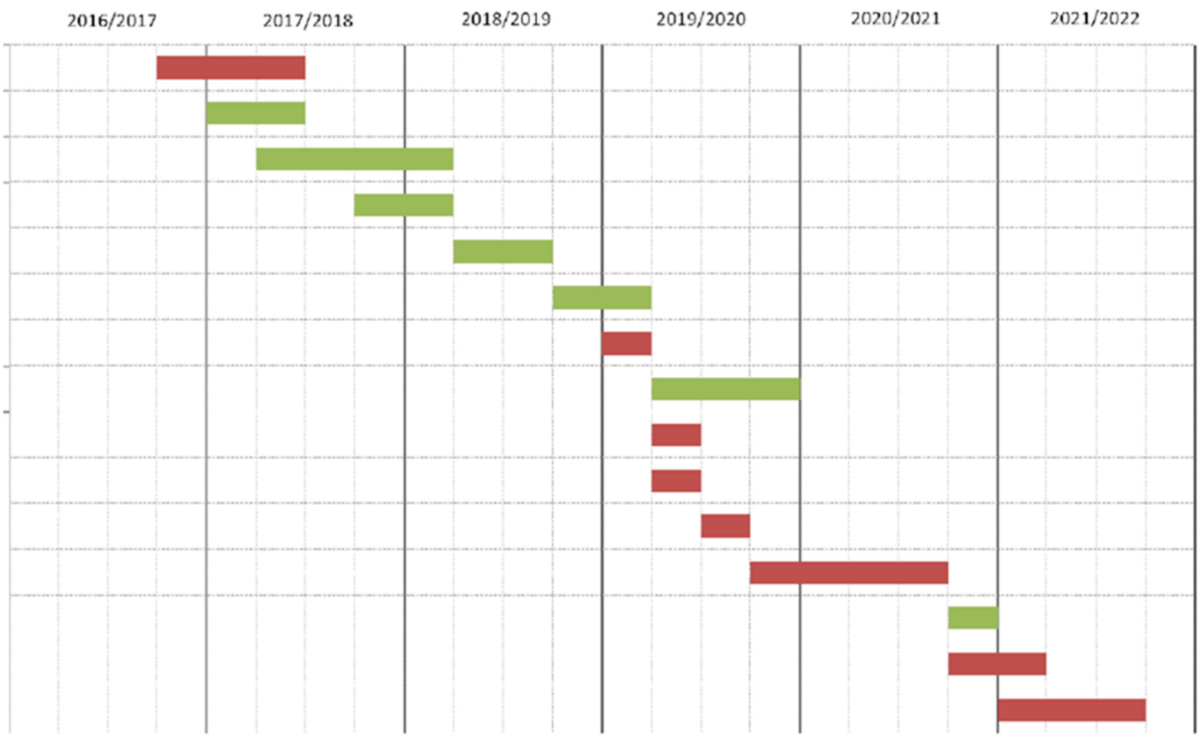

Figure 4: Final Digitalization Roadmap

Figure 5 represents the expect cash flow analysis, considering the expected project Capex and Opex investment plan and expected returns. It is important to mention that some of the projects were brought to the beginning of the roadmap due to their high expected return, which made it possible to finance the next projects with the expected margin and profit increase. So it is also important to consider company's capital availability and limitations, in order to create a economically feasible roadmap. Otherwise, companies may be overwhelmed with so many projects and initiatives that they can hardly continue with the DMP implementation due to lack of resources, money or even focus.

As we can see on the cash flow analysis, the overall payback of the DMP only occurs after 4 years of implementation, but is important to see that the overall investment budget kept limited to a certain amount of money that the company decided that was suitable and feasible for its investments plan.

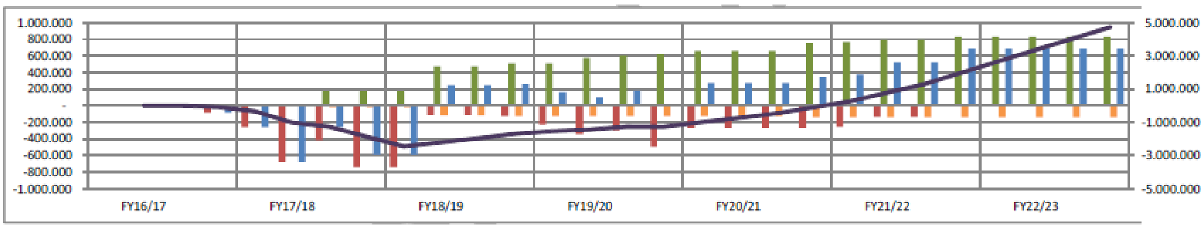

Figure 5: Expected Cash Flow

7 Summary

The *Industrie 4.0* initiative has created a new industry awareness about how the digitalization can have a huge impact on industrial companies. Redesigned processes and operations based on digitalization can bring industries to a complete new level of productivity, efficiency, flexibility and quality, all that using the same amount of assets and resources, but with a greater productivity and profitability.

Industrie 4.0 has significantly impact not only on discrete manufacturing industries, but also on all process industries, rather innovating the way companies design their processes and plants, or the way companies interact with each other and bring more value from their connected networks and supply chains. *Industrie 4.0* is bringing a complete new level of competitiveness, as companies can now be completely synchronized and integrated through the usage of top digital technologies. Operational intelligence is increased, as new ways of making decision based on real-time and predictive information are available, making it even harder for the companies that do not embrace *Industrie 4.0* to its full potential.

This article presents a consultative approach that can be used for creating a digitalization roadmap that can drive companies to oversee the buzzwords and abstract concepts from *Industrie 4.0* to concrete implementation projects, with tangible returns and a clear vision for the future. The presented methodology was already evaluated and put to prove on existing factories and plants, showing not only that is a consistent approach but that digitalization can bring concrete value to companies and industries.

This contribution also presents a maturity model that can be applied not only for specific MES implementation projects, but that can also consider digitalization impacts and effects over the whole processes and organizations, creating distinguished levels of maturity regarding digitalization concepts.

Future work is creating a vertical framework that can better assess the Digitalization maturity levels for each and every industry, allowing companies to better understand industry benchmarks and best practices. This would be extremely useful, as most of technologies that are applicable or relevant to one specific industry most times are not that relevant or important for other industries, which may generate inconsistent maturity levels when compared to each other. In this way, a customized evaluation criteria and maturity model would make such evaluations much more adherent to specific processes and verticals.

8 Acknowledgements

The author wants to thank Siemens for sponsoring the execution of the Digitalization Master Plan methodology on its own factories, allowing the author and Chemtech to validate their proposed and existing methodology. Many thanks in particular to the team that participated on the project development, as well as the supporting areas within Siemens that made relevant considerations and collaborated for the success of the project implementation.

The author also wants to thank the collaboration of all other partners that contributed to the development of the project, and that have used Siemens simulation and digital twin tools to validate the proposed models and processes with a quantitative and relevant approach.

9 References

[1] Forschungsunion, acatech, Recommendations for implementing the strategic initiative INDUSTRIE 4.0, www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf, April 2013

[2] Forschungsunion, acatech, Cyber-Physical Systems, http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Publikationen/Stellungnahmen/acatech_POSITION_CPS_Englisch_WEB.pdf, December 2011

[3] Günther Schuh, Reiner Anderl, Jürgen Gausemeier, Michael ten Hompel, Wolfgang Wahlster (Eds.), Industrie 4.0 Maturity Index, http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Publikationen/Projektberichte/acatech_STUDIE_Maturity_Index_eng_WEB.pdf , May 2017

[4] MESA, MESA MOM Capability Maturity Model Version 1.0, WHITE PAPER #53, April 2016

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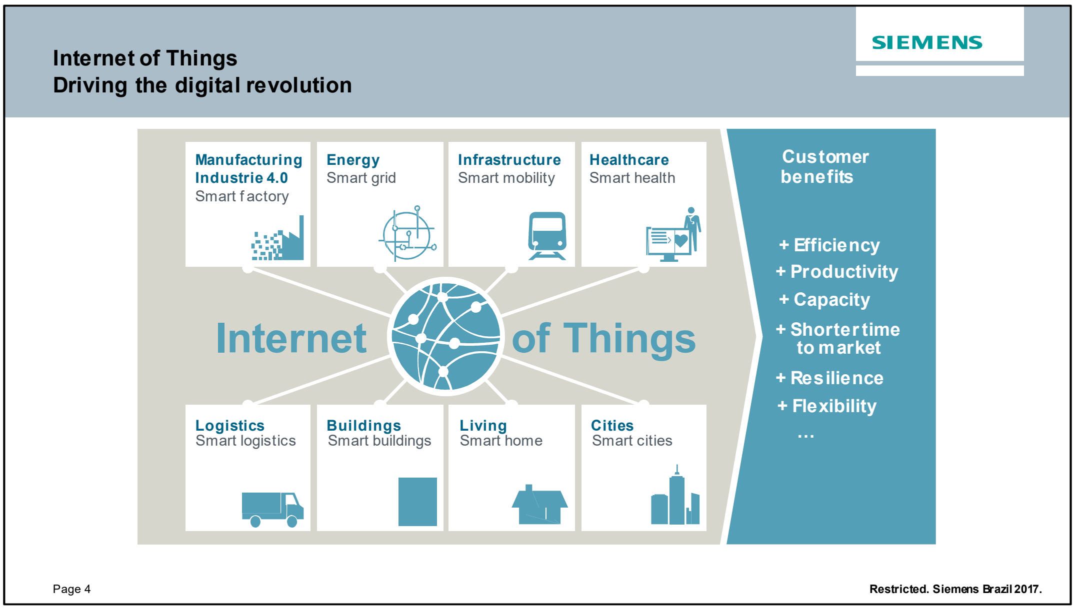
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Internet of Things
Driving the digital revolution
Manufacturing
Industrie 4.0
Smart factory
Energy
Smart grid
Infrastructure
Smart mobility
Healthcare
Smart health
Internet
of Things
Logistics
Smart logistics
Buildings
Smart buildings
Living
Smart home
Cities
Smart cities
Customer benefits
+ Efficiency
+ Productivity
+ Capacity
+ Shorter time to market
+ Resilience
+ Flexibility
...
Page 4
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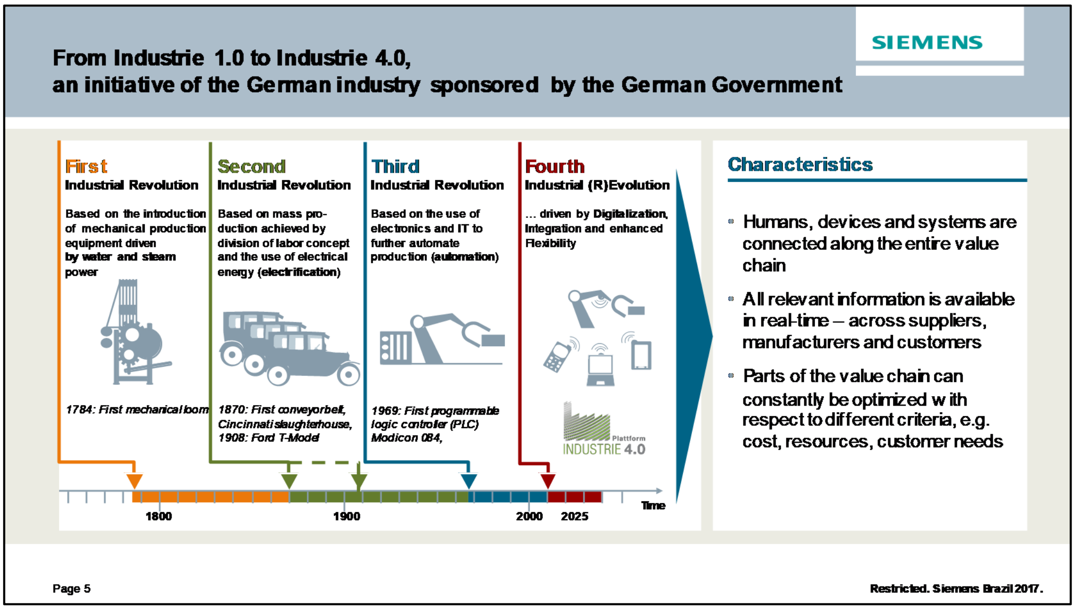
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From Industrie 1.0 to Industrie 4.0,
an initiative of the German industry sponsored by the German Government
First
Industrial Revolution
Based on the introduction of mechanical production equipment driven by water and steam power
1784: First mechanical loom
Second
Industrial Revolution
Based on mass production achieved by division of labor concept and the use of electrical energy (electrification)
1870: First conveyor belt, Cincinnati slaughterhouse, 1908: Ford T-Model
Third
Industrial Revolution
Based on the use of electronics and IT to further automate production (automation)
1969: First programmable logic controller (PLC) Modicon 084,
Fourth
Industrial (R)Evolution
... driven by Digitalization, Integration and enhanced Flexibility
Plattform INDUSTRIE 4.0
1800
1900
2000
2025
Time
Characteristics
Humans, devices and systems are connected along the entire value chain
All relevant information is available in real-time – across suppliers, manufacturers and customers
Parts of the value chain can constantly be optimized with respect to different criteria, e.g. cost, resources, customer needs
Page 5
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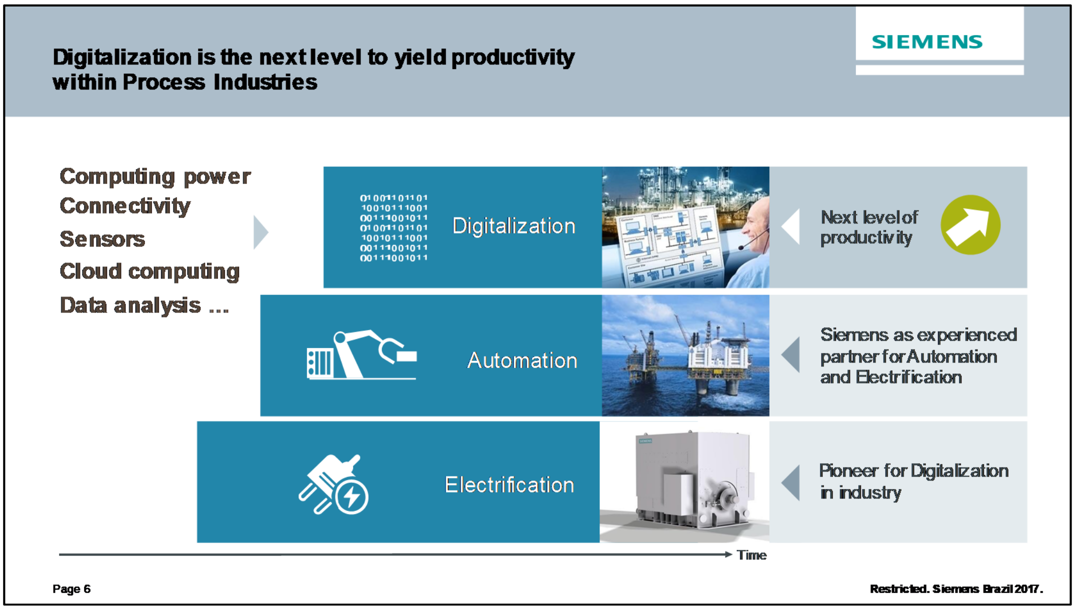
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Digitalization is the next level to yield productivity
within Process Industries
Computing power
Connectivity
Sensors
Cloud computing
Data analysis ...
Digitalization
Next level of productivity
Automation
Siemens as experienced partner for Automation and Electrification
Electrification
Pioneer for Digitalization in industry
Time
Page 6
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Generating customer benefits is our key priority

Industry trends

Efficiency
- Resource and energy efficiency
- Demanded product/quantity
- …

Flexibility
- Individualized mass production
- Volatile markets
- …

Quality
- Closed-loop quality
- Traceability
- …

Time-to-market
- Fast innovation
- More complex products
- Lifecycle Management
- …

Security

HSSE – Health & Safety | Environment | Regulations/Standard | …

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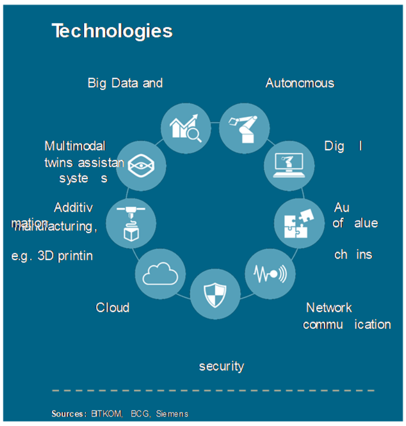
Smart Manufacturing
Industrie 4.0 is the next level



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Digitalization is key to provide answers to future challenges in industry

Future challenges in industry

- Shorter **time to market**
- **Increased flexibility** in volatile, heterogonous, global markets
- Optimized **productivity**
- Energy and resource **efficiency**
- Mitigation of **demographic change**
- Continuous, **safe and reliable operations**

DIGITALIZATION

Research areas

- **Horizontal integration** of the value-add networks
- **Vertical integration** and networked production systems
- Seamless **integration of the engineering** along the entire life-cycle
- **Cyber Physical Systems (CPS)**
- **Reference architecture model**
- Integration of **human creativity and innovativeness**

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The Journey towards Digitalization

Holistic Approach

Project phases	Strategic alignment	Benchmark analysis	Potential Initiatives Identification	Technical and Financial Feasibility	Implement. Plan (RoadMap)	Implementation
Deliverable	Strategic Business drivers	Maturity check	Prioritization of Opportunities	Detailed projects, ROI, NPV	Implementation and investment roadmap	Siemens Solutions

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Digitalization through a prioritized masterplan

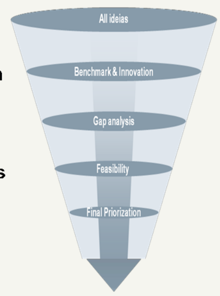
Project goals

Improve **Industry** profitability by applying new **Digitalization** solutions

- **Increase productivity**, efficiency and quality
- **Reduce costs**
- **Maximizing efficiency** of capital allocation
- Establishment of a **highly integrated** value chain
- **Improve security** and mitigate physical and **cyber security** risks

Deliverables

- Collection of all **business drivers** regarding automation, IT, regulatory / safety and energy efficiency
- Drivers **priorities** by estimated impact based on Industry benchmarks and innovation
- Main **gaps** per driver
- Identified opportunities with ensured **technical and financial feasibility** and best financial KPIs
- A **prioritized investment plan** for sustainable, mid and long-term improvement (ROI, NPV)
- **5-years master plan** that fully translates strategic directions into implementable actions, by industrial area



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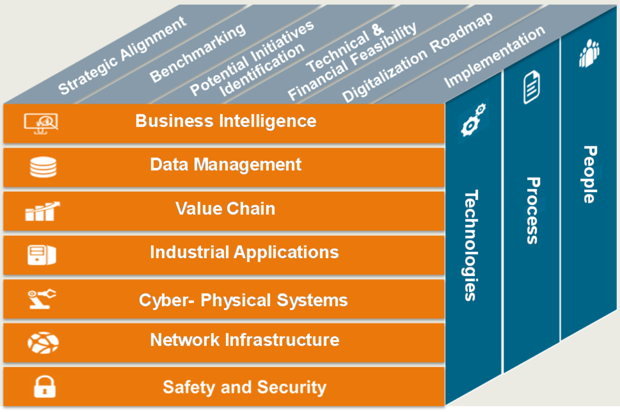
The digitalization methodology includes three perspectives

Holistic approach

- Three perspectives of Chemtech's digitalization methodology are **applied along the full value chain** and include
  - Proven consulting approach
  - Technological perspectives
  - Organizational aspects
- Each technological category consists of **several technologies**
- Flexible adaption and **focus** based on the individual **customer needs**



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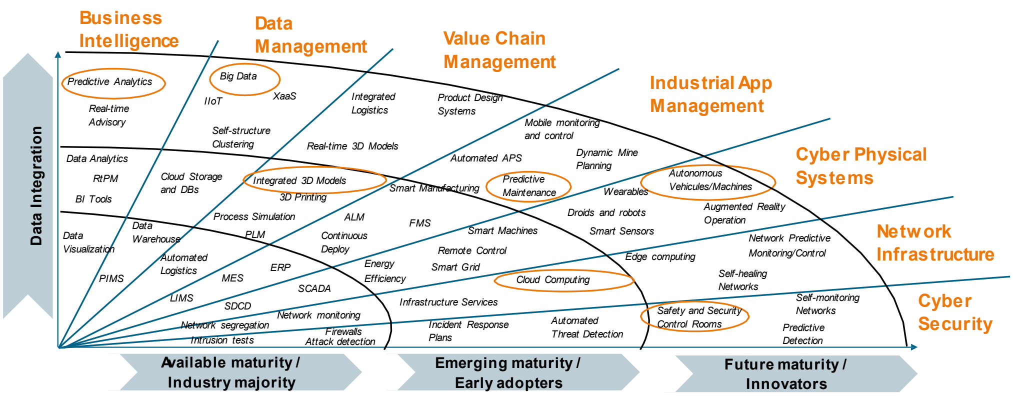
Digitalization Technological Landscape – Focus on what really matters



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Siemens Digitalization Master Plan
Project Overview

Objective

Improve the High voltage Capacitor plant processes efficiency and **turn it into a reference for Industry 4.0 for Siemens Brazil**.

Project Description

This project consists on the elaboration of a **Digitalization Master Plan (DMP) for a Capacitor plant**

Project Goals

The Project goals are to **identify process improvements through digitalization**, generating a clear view for the future projects and all the steps that the factory must take to **increase its efficiency, reduce operational costs** and have **a detailed roadmap of investments towards Industry 4.0 and use it as a reference to be replicated in other manufacturing industries.**

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Project Deliverables

Deliverable	Description
Project Plan / Kick-off	Project Plan and initial presentation to project team
Data Gathering Reports	1 week of process data gathering and detailed reports
Process Detailed Workflow	Process detailed workflow for all production areas
Asset Map	Process asset mapping and analysis
Process Simulation 2D (Plant Simulation)	Process simulation on Tecnomatix Plant Simulation and process and bottleneck analysis
AS IS Validation Workshop	Workshop for validating all process findings and analysis
MES/APS Blueprint	MES/APS functional requirement analysis
Future Architecture (TO BE)	Digitalization proposed future architecture
Digitalization Opportunities	List of all digitalization projects and opportunities, prioritized and detailed by cost and ROI
Opportunities Process Simulation 2D	Process simulation of the most important opportunities (Smart Manufacturing, Welding Automation, Visual Control Room)
Opportunities Process Simulation 2D	Process simulation of the most important opportunities (Smart Manufacturing, Welding Automation, Visual Control Room)
Implementation Roadmap	Digitalization roadmap for all prioritized opportunities
Validation Workshop	Validation workshop for the Digitalization Master Plan

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Data

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Process Modeling and Simulation

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Process Modeling and Simulation

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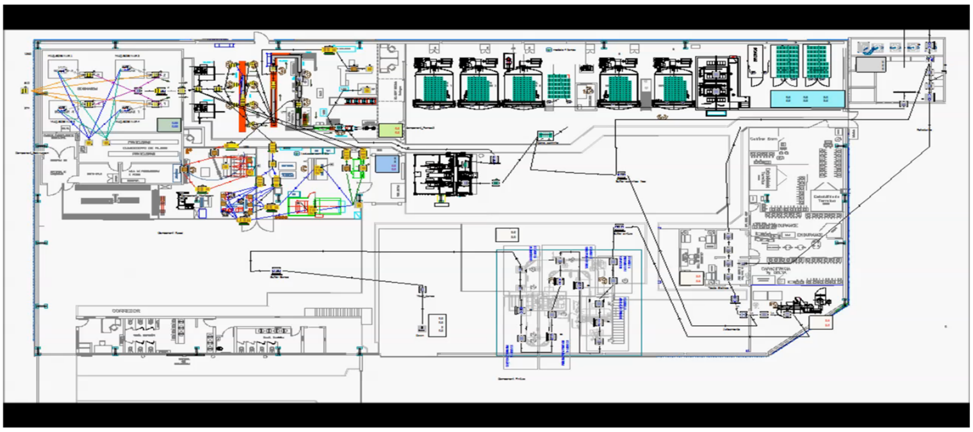
Process Simulation with Technomatix Plant Simulation – AS IS Video



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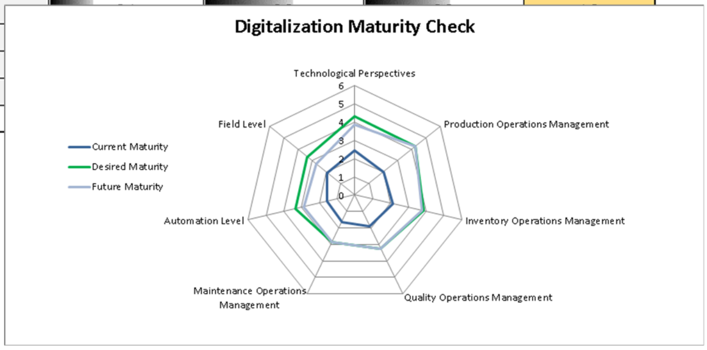
Digitalization Maturity Matrix

Dimension	Current Maturity	Desired Maturity	Future Maturity	Gap
Technological Perspectives	2,4	4,3	3,9	1,8
Production Operations Management	2,0	4,3	4,3	2,3
Inventory Operations Management				
Quality Operations Management				
Maintenance Operations Management				
Automation Level				
Field Level				



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Digitalization Opportunities / Priorization

Project Type	Opportunities
Data Acquisition	19
Production Control	2
Manufacturing Management	21
Data Integration	9
Process Improvement	9
Data Visualization	15
Total	75

Project Type	Prioritized Opp.
Data Acquisition	11
Production Control	2
Manufacturing Management	17
Data Integration	8
Process Improvement	3
Data Visualization	15
Project Type	56

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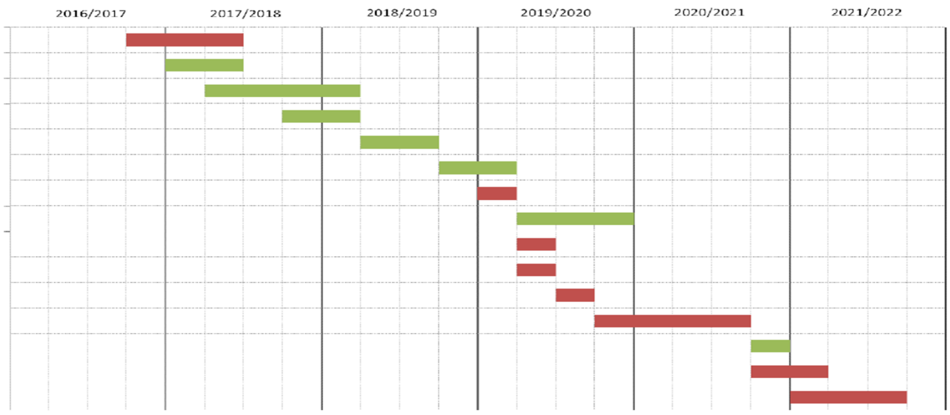
Implementation Rodmap
Proposed Implementation Schedule



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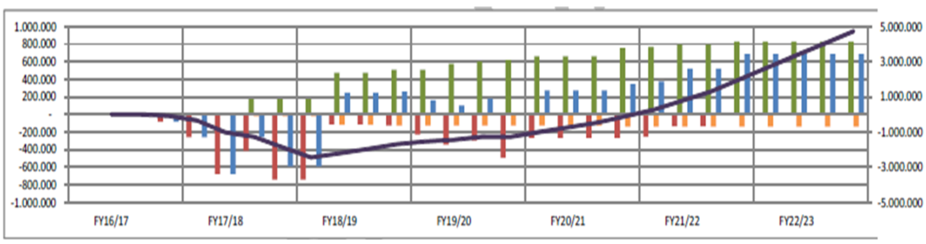
Return on Investment



ROI

- ROI (Capex) 65%
- Expected Return (Year) R$ 3.060.379,96
- Opex (Year) R$1.077.948,49

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Agenda

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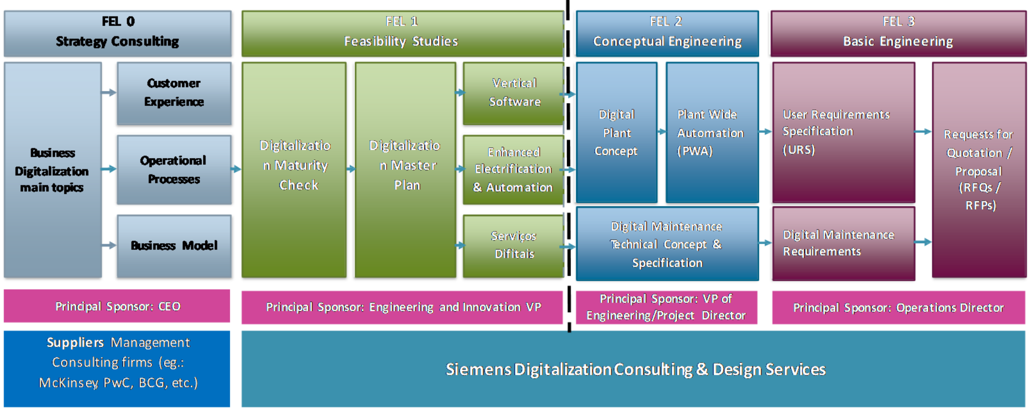
Digitalization Implementation Strategy
FEL0 to FEL3



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Furture Digitalization Opportunities and Continuous Improvement Plan

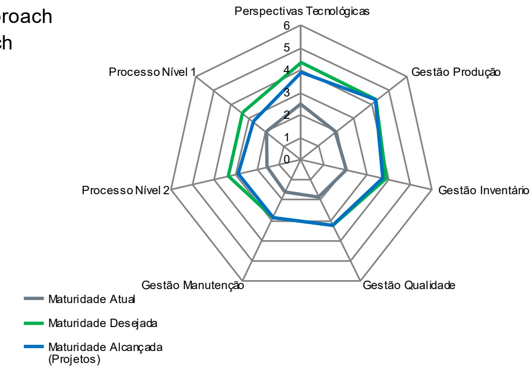
Future Digitalization Opportunities

- New IoT opportunities
- New maturity models for specific industry approach
- Integration to Acatech Maturity Index approach

Continuous Improvement Plan

- Yearly revision of Digitalization Master Plan
- Lessons Learned from implemented projects

Digitalization Maturity



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Agenda

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Obrigado Thank you Gracias
Danke Thank you
Merci
Grazie Grazie
Gracias Gracias
Merci
Thank you Obrigado
Danke Thank you
Obrigado Merci
Danke
Obrigado Gracias Danke
Obrigado

SPI chemtech
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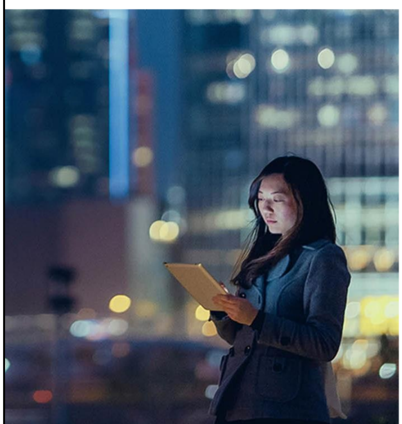
Ingenuity for life

Contacts



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SPI chemtech
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Eng. Pierluigi Astorino

Mestre em Engenharia mecânica pela Politécnico di Milano, Pierluigi tem se destacado na Fiat Chrysler Automobiles como diretor da Engenharia de Manufatura LATAM. O início da carreira na FCA foi nas plantas da Itália, até que foi convidado para integrar o time global de desenvolvimento do Polo Automotivo Jeep, em 2013. Nos últimos meses tem dedicado especial atenção a temas relacionados a Industria 4.0 – atividade que tem liderado a frente da Engenharia de Manufatura. As ações desenvolvidas já são destaque e benchmarking para toda a FCA.

pierluigi.astorino@fcagroup.com

FCA Fiat Chrysler Automobiles

Indústria 4.0 na FCA Latam: melhoria da qualidade, produtividade e desenvolvimento de pessoas por meio da Manufatura Inteligente

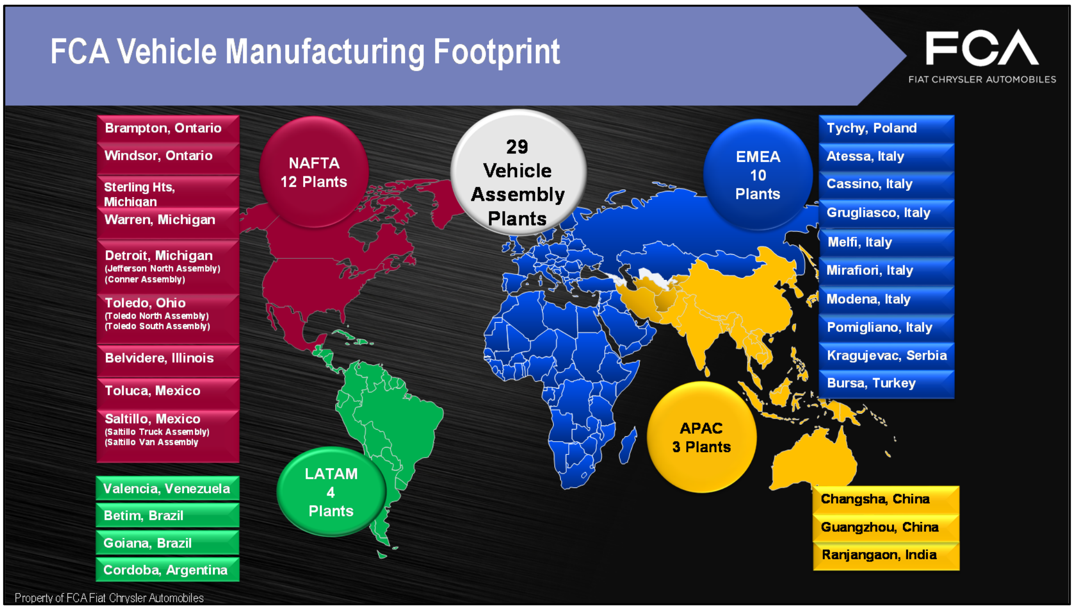
Abstract

Keywords


22° International Summit on high technology
Smart Production – Challenges of the 4th Industrial Revolution
FCA
FIAT CHRYSLER AUTOMOBILES


Industry 4.0 in FCA Latam:
Smart digital manufacturing to enhance quality, productivity and people development
Pierluigi Astorino - Manufacturing Eng. LATAM
FCA
FIAT CHRYSLER AUTOMOBILES

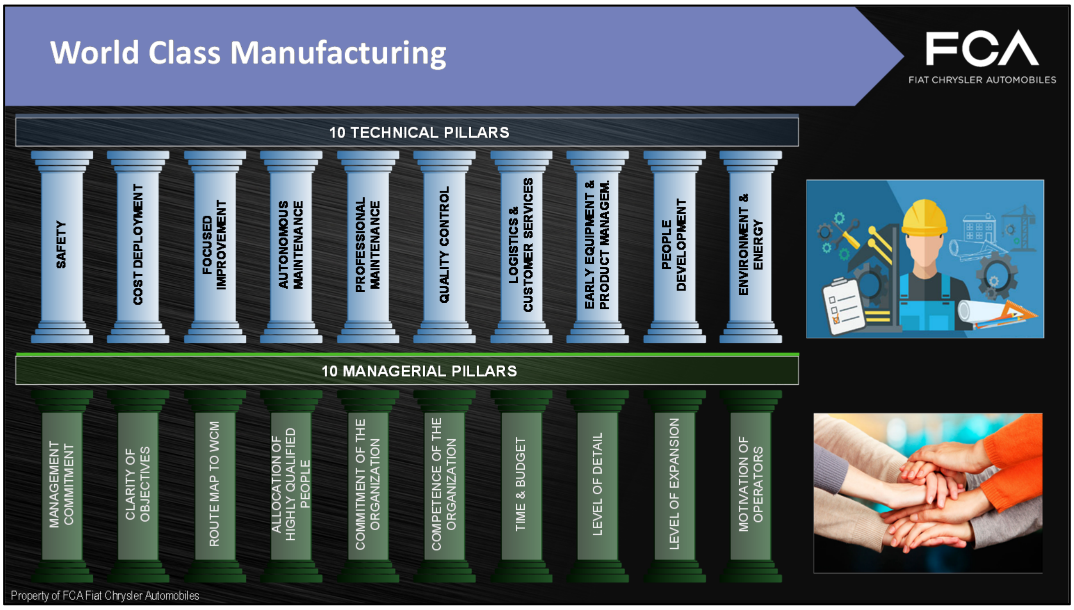

FCA in the world
FCA
FIAT CHRYSLER AUTOMOBILES
FIAT INDUSTRIAL
CNH INDUSTRIAL
FIAT GROUP
2011
2013
2014
2016
FCA
FIAT CHRYSLER AUTOMOBILES
2017
15 brands
162 Plants
+140 Markets
87 Centers of R&D
231,000 Employees
CHRYSLER
CHRYSLER
FCA
FIAT CHRYSLER AUTOMOBILES
Ferrari
Jeep
Teksid
Property of FCA Fiat Chrysler Automobiles

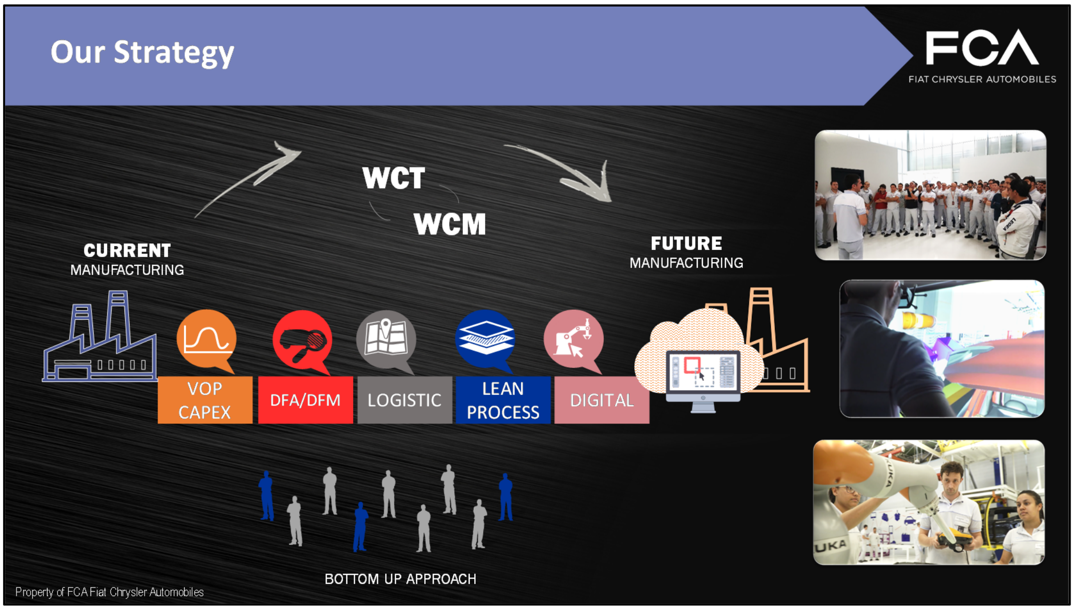

FCA Vehicle Manufacturing Footprint
FCA
FIAT CHRYSLER AUTOMOBILES
Brampton, Ontario
Windsor, Ontario
Sterling Hts, Michigan
Warren, Michigan
Detroit, Michigan
(Jefferson North Assembly)
(Conner Assembly)
Toledo, Ohio
(Toledo North Assembly)
(Toledo South Assembly)
Belvidere, Illinois
Toluca, Mexico
Saltillo, Mexico
(Saltillo Truck Assembly)
(Saltillo Van Assembly)
Valencia, Venezuela
Betim, Brazil
Goiana, Brazil
Cordoba, Argentina
NAFTA
12 Plants
29
Vehicle
Assembly
Plants
LATAM
4
Plants
EMEA
10
Plants
APAC
3 Plants
Tychy, Poland
Atessa, Italy
Cassino, Italy
Grugliasco, Italy
Melfi, Italy
Mirafiori, Italy
Modena, Italy
Pomigliano, Italy
Kragujevac, Serbia
Bursa, Turkey
Changsha, China
Guangzhou, China
Ranjangaon, India
Property of FCA Fiat Chrysler Automobiles

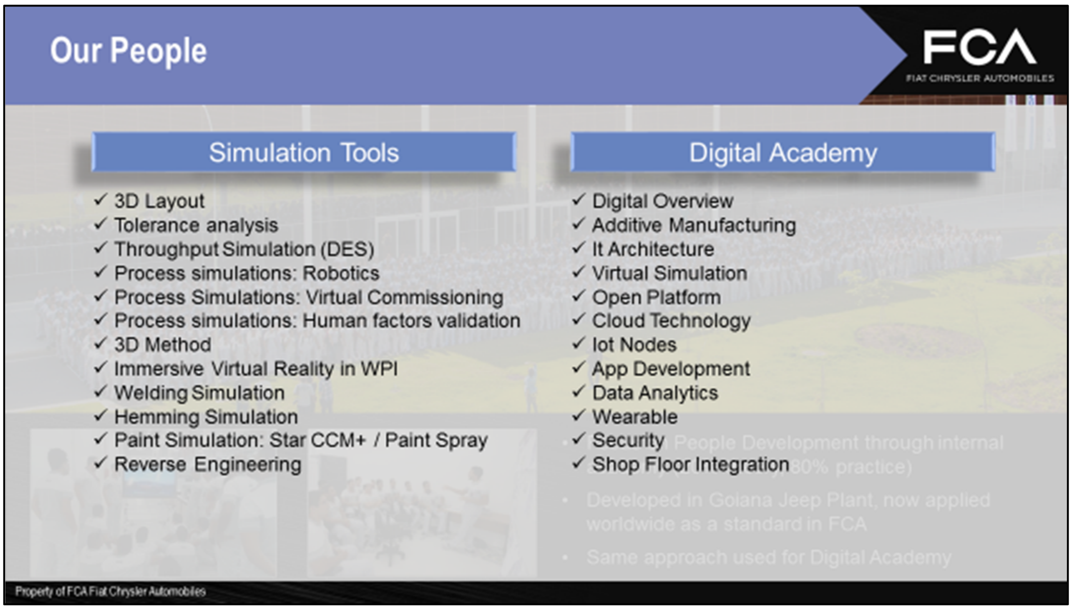

FCA in Latin America
FCA
FIAT CHRYSLER AUTOMOBILES
Jeep
Teksid
Jeep Automotive Pole
GOIANA - PE
Fiat Automotive Pole
BETIM - MG
FCA Engine Factory
CAMPO LARGO - PR
Fiat Automotive Pole
CORDOBA - ARGENTINA
50.000
EMPLOYEES
6
R&D CENTER
473.000
UNITS SOLD
24
PLANTS
Property of FCA Fiat Chrysler Automobiles


World Class Manufacturing
WCM
WORLD CLASS MANUFACTURING

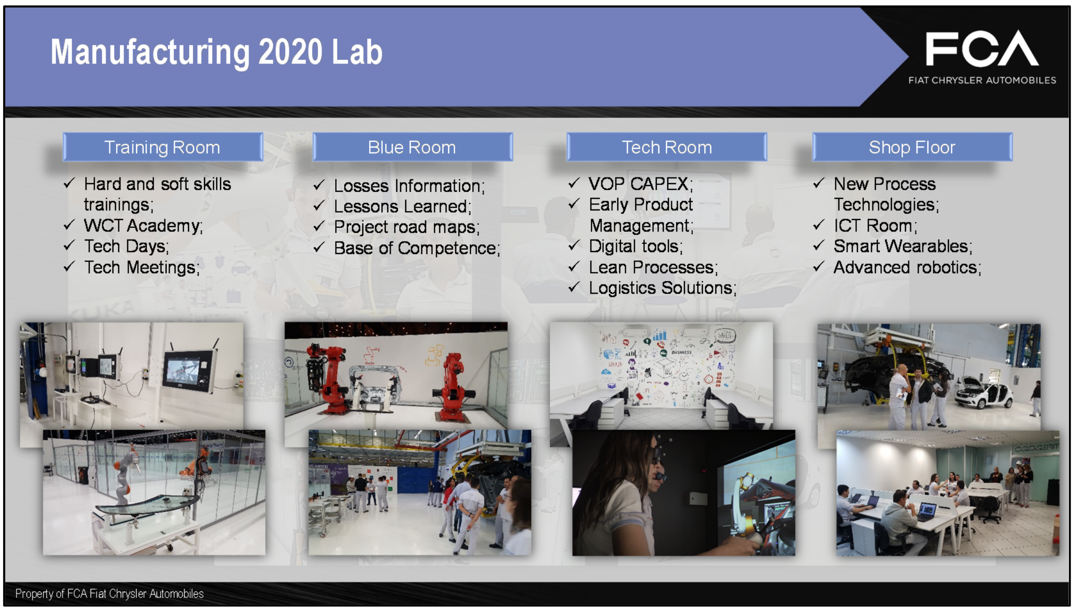

World Class Manufacturing – Global Reality
FCA
FIAT CHRYSLER AUTOMOBILES
Embraco
ArcelorMittal
Unilever
elica
FCA
CNH INDUSTRIAL
ARISTON THERMO GROUP
Royal Mail
More than 2000 factories in the world, out of FCA perimeter.
Property of FCA Fiat Chrysler Automobiles


World Class Manufacturing
FCA
FIAT CHRYSLER AUTOMOBILES
10 TECHNICAL PILLARS
SAFETY
COST DEPLOYMENT
FOCUSED IMPROVEMENT
AUTONOMOUS MAINTENANCE
PROFESSIONAL MAINTENANCE
QUALITY CONTROL
LOGISTICS & CUSTOMER SERVICES
EARLY EQUIPMENT & PRODUCT MANAGEM.
PEOPLE DEVELOPMENT
ENVIRONMENT & ENERGY
10 MANAGERIAL PILLARS
MANAGEMENT COMMITMENT
CLARITY OF OBJECTIVES
ROUTE MAP TO WCM
ALLOCATION OF HIGHLY QUALIFIED PEOPLE
COMMITMENT OF THE ORGANIZATION
COMPETENCE OF THE ORGANIZATION
TIME & BUDGET
LEVEL OF DETAIL
LEVEL OF EXPANSION
MOTIVATION OF OPERATORS
Property of FCA Fiat Chrysler Automobiles

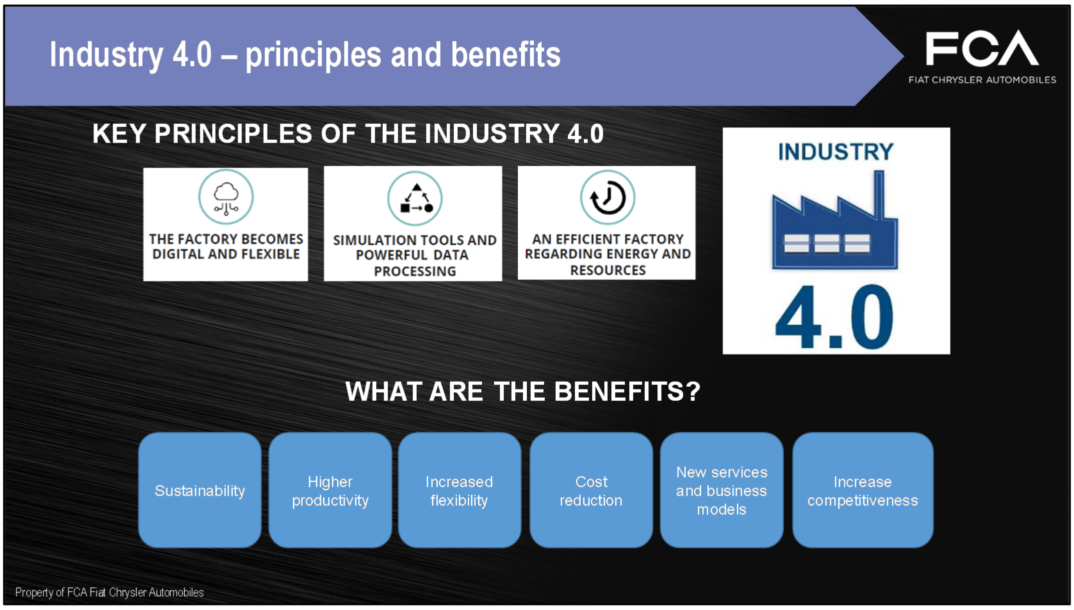

Our Strategy
FCA
FIAT CHRYSLER AUTOMOBILES
WCT
WCM
CURRENT
MANUFACTURING
FUTURE
MANUFACTURING
VOP CAPEX
DFA/DFM
LOGISTIC
LEAN PROCESS
DIGITAL
BOTTOM UP APPROACH
Property of FCA Fiat Chrysler Automobiles


Our People
FCA
FIAT CHRYSLER AUTOMOBILES
Simulation Tools
✓ 3D Layout
✓ Tolerance analysis
✓ Throughput Simulation (DES)
✓ Process simulations: Robotics
✓ Process Simulations: Virtual Commissioning
✓ Process simulations: Human factors validation
✓ 3D Method
✓ Immersive Virtual Reality in WPI
✓ Welding Simulation
✓ Hemming Simulation
✓ Paint Simulation: Star CCM+ / Paint Spray
✓ Reverse Engineering
Digital Academy
✓ Digital Overview
✓ Additive Manufacturing
✓ It Architecture
✓ Virtual Simulation
✓ Open Platform
✓ Cloud Technology
✓ Iot Nodes
✓ App Development
✓ Data Analytics
✓ Wearable
✓ Security
✓ Shop Floor Integration
Developed in Goiana Jeep Plant, now applied worldwide as a standard in FCA
Same approach used for Digital Academy
Property of FCA Fiat Chrysler Automobiles

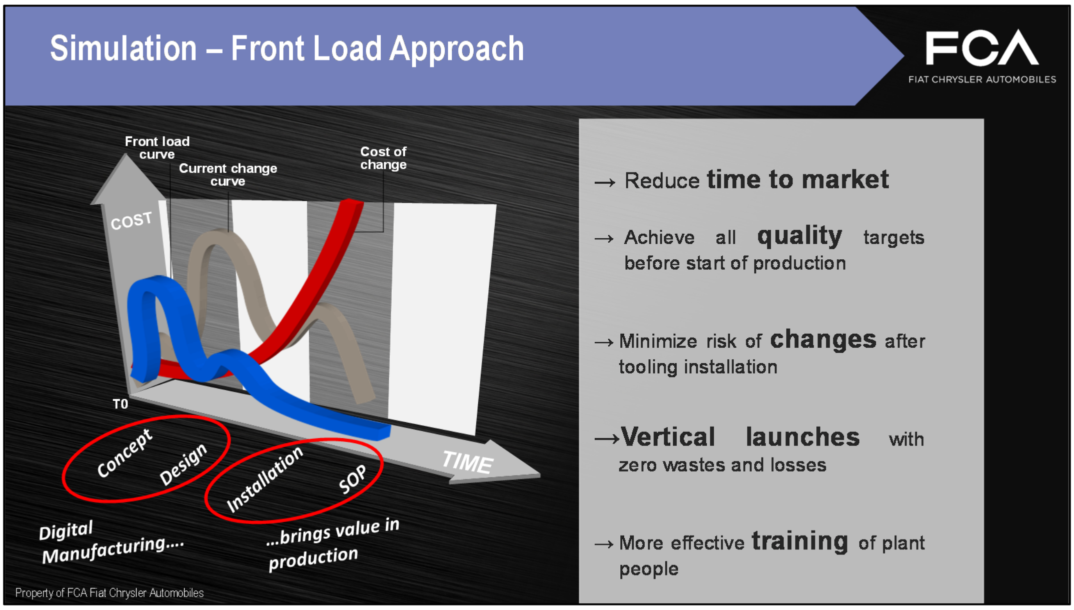

Gamification
FCA
FIAT CHRYSLER AUTOMOBILES
Development of innovative training games to be played on mobile devices to enhance:
• Training experience
• Understanding of company processes
• Knowledge of main tools and methods
Property of FCA Fiat Chrysler Automobiles

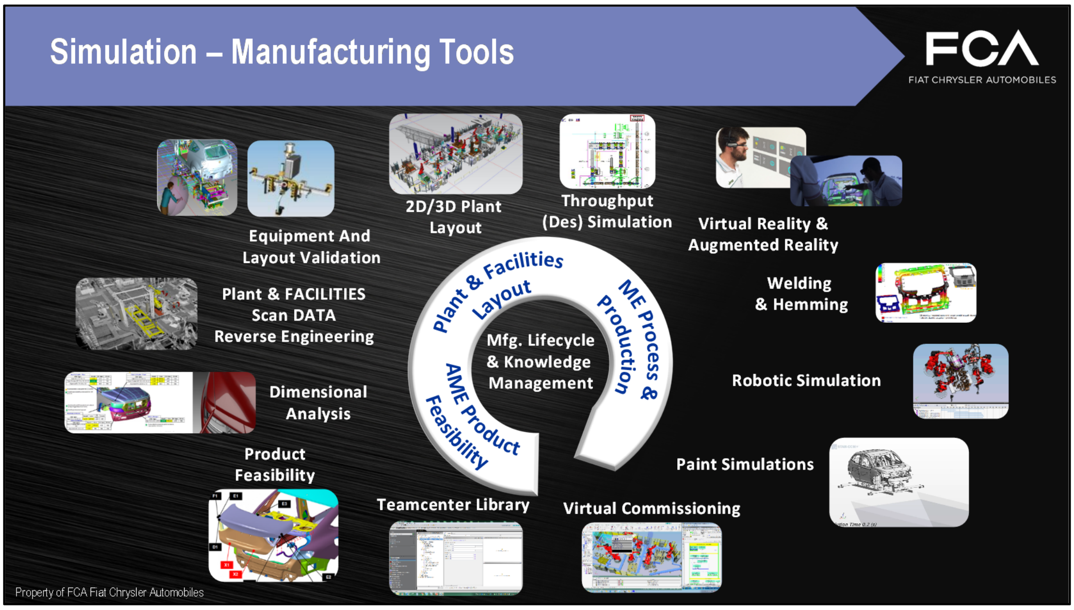

Manufacturing 2020 Lab
FCA
FIAT CHRYSLER AUTOMOBILES
Training Room
✓ Hard and soft skills trainings;
✓ WCT Academy;
✓ Tech Days;
✓ Tech Meetings;
Blue Room
✓ Losses Information;
✓ Lessons Learned;
✓ Project road maps;
✓ Base of Competence;
Tech Room
✓ VOP CAPEX;
✓ Early Product Management;
✓ Digital tools;
✓ Lean Processes;
✓ Logistics Solutions;
Shop Floor
✓ New Process Technologies;
✓ ICT Room;
✓ Smart Wearables;
✓ Advanced robotics;
Property of FCA Fiat Chrysler Automobiles

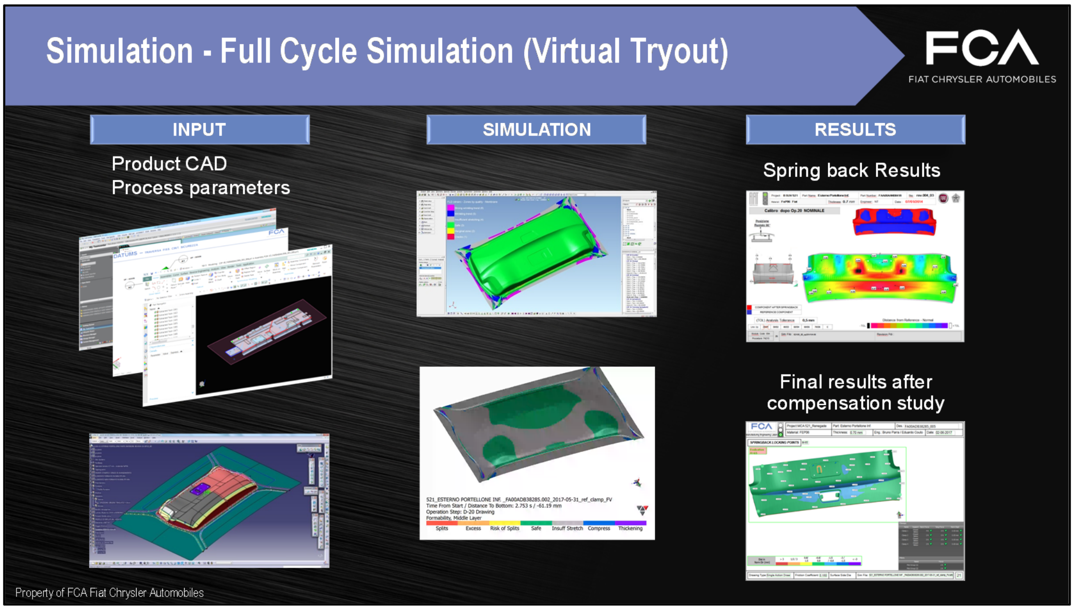

Industry 4.0 in FCA Latam
Autonomous Robots
Simulation
System Integration
Internet of Things
Cybersecurity
Cloud Computing
Additive Manufacturing
Augmented Reality
Big Data
Industry 4.0

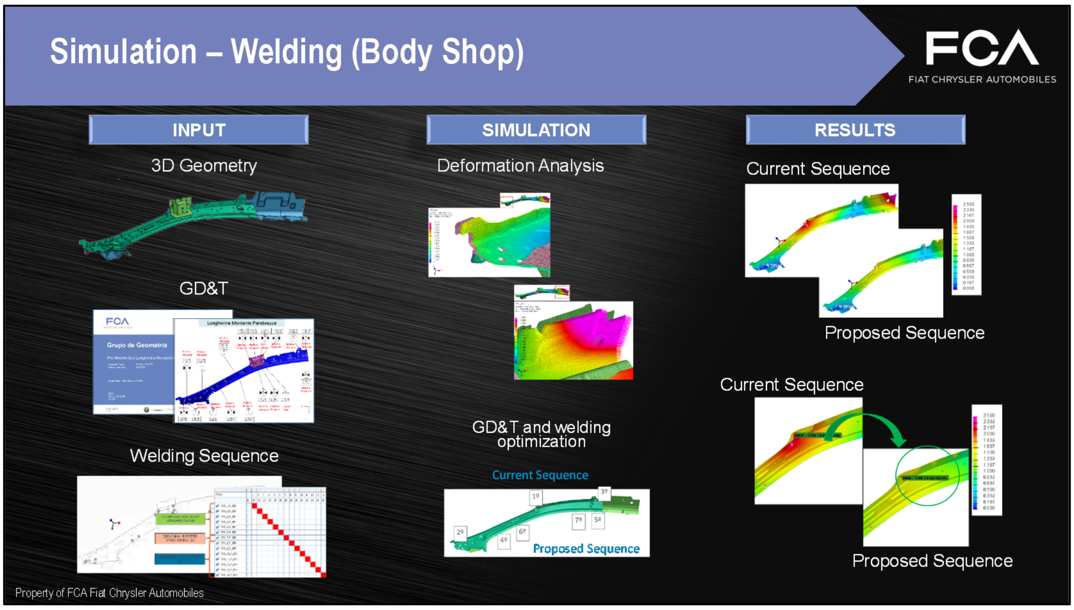

Industry 4.0 – principles and benefits
FCA
FIAT CHRYSLER AUTOMOBILES
KEY PRINCIPLES OF THE INDUSTRY 4.0
THE FACTORY BECOMES DIGITAL AND FLEXIBLE
SIMULATION TOOLS AND POWERFUL DATA PROCESSING
AN EFFICIENT FACTORY REGARDING ENERGY AND RESOURCES
INDUSTRY 4.0
WHAT ARE THE BENEFITS?
Sustainability
Higher productivity
Increased flexibility
Cost reduction
New services and business models
Increase competitiveness
Property of FCA Fiat Chrysler Automobiles

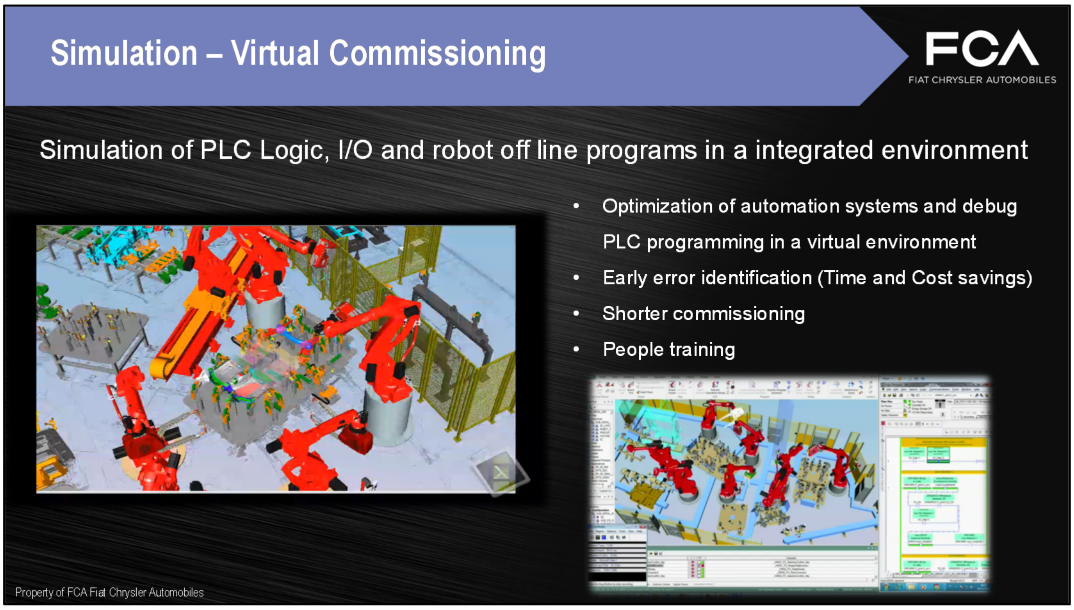

Main Technologies
FCA
FIAT CHRYSLER AUTOMOBILES
Simulati on
Autonomo us Robot
Augment ed Reality
Cloud Computi ng
Cyber Securit y
System Integrated
Big Data
Additive Manufacturi ng
INDUSTRY 4.0
Property of FCA Fiat Chrysler Automobiles

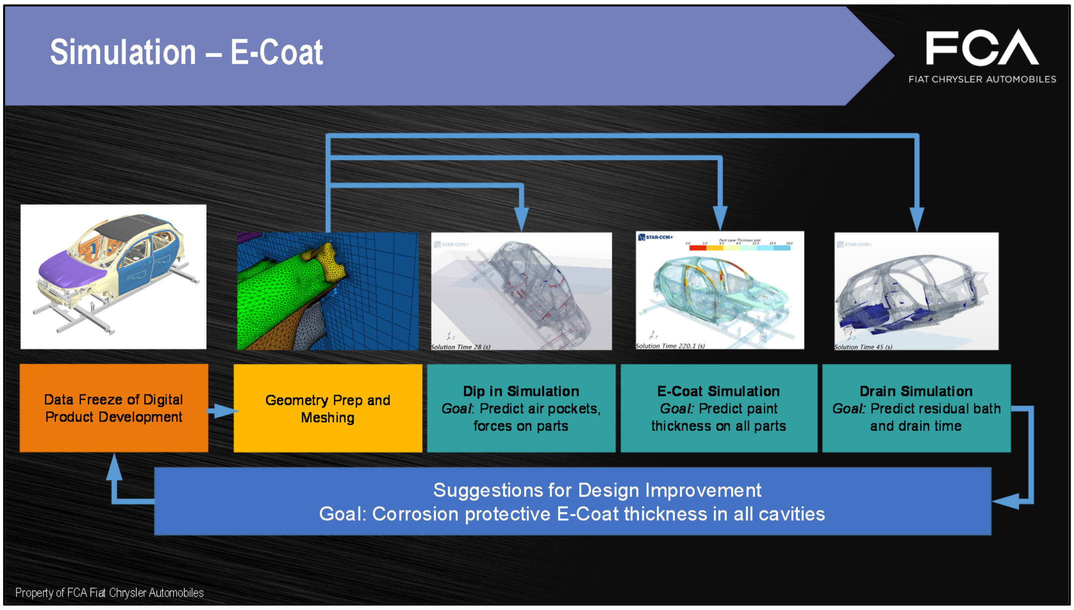

Simulation – Front Load Approach
FCA
FIAT CHRYSLER AUTOMOBILES
Front load curve
Current change curve
Cost of change
COST
T0
TIME
Concept
Design
Installation
SOP
Digital Manufacturing….
…brings value in production
→ Reduce time to market
→ Achieve all quality targets before start of production
→ Minimize risk of changes after tooling installation
→ Vertical launches with zero wastes and losses
→ More effective training of plant people
Property of FCA Fiat Chrysler Automobiles

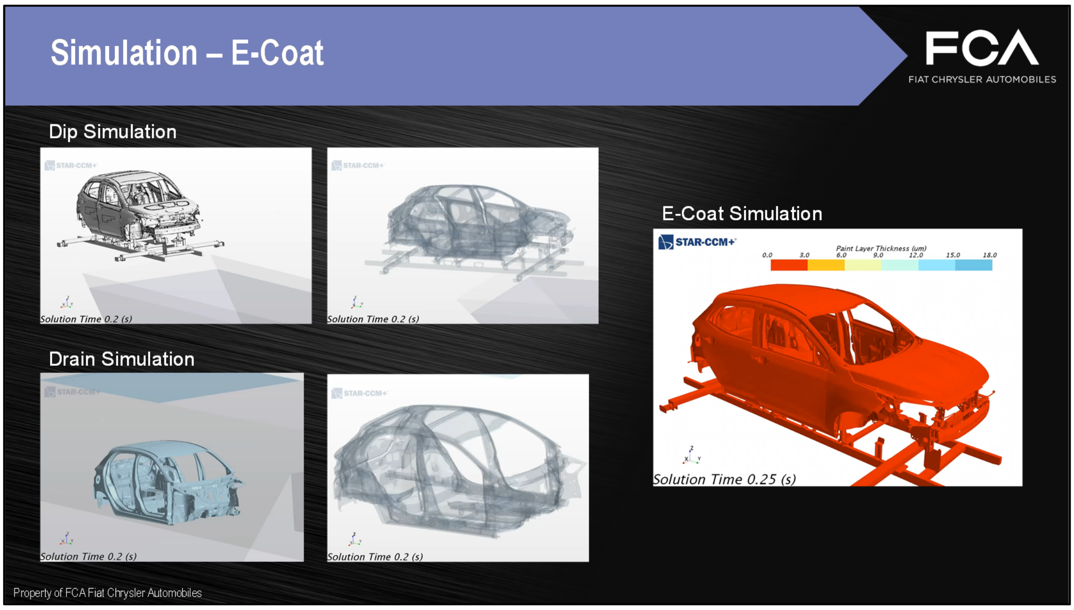

Simulation – Manufacturing Tools
FCA
FIAT CHRYSLER AUTOMOBILES
2D/3D Plant Layout
Throughput (Des) Simulation
Equipment And Layout Validation
Virtual Reality & Augmented Reality
Plant & FACILITIES Scan DATA Reverse Engineering
Welding & Hemming
Plant & Facilities Layout
ME Process & Production
Mfg. Lifecycle & Knowledge Management
AME Product Feasibility
Robotic Simulation
Dimensional Analysis
Product Feasibility
Paint Simulations
Teamcenter Library
Virtual Commissioning
Property of FCA Fiat Chrysler Automobiles

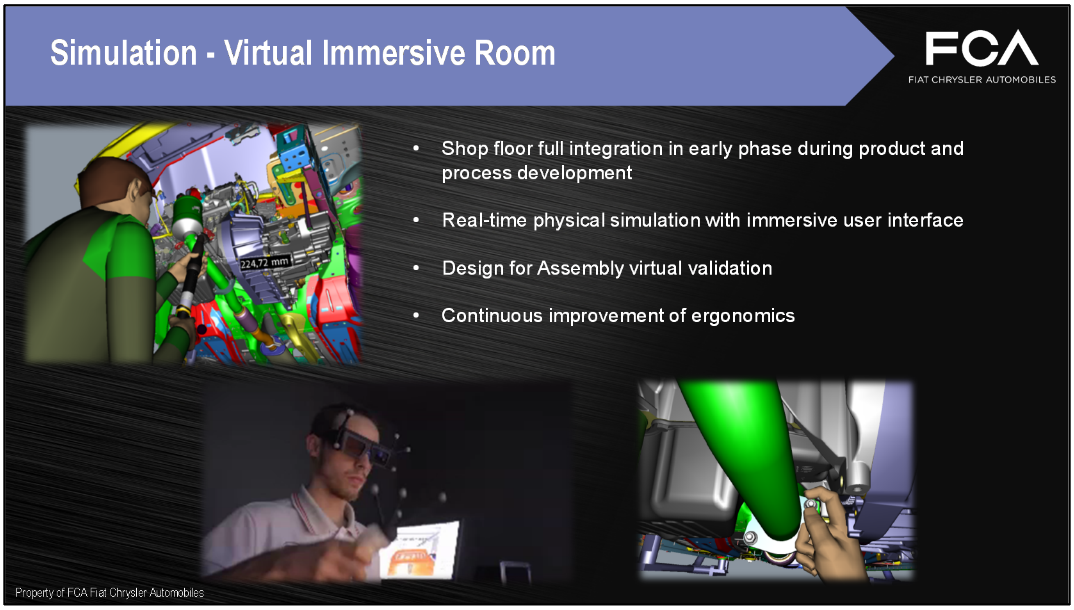

Simulation - Full Cycle Simulation (Virtual Tryout)
FCA
FIAT CHRYSLER AUTOMOBILES
INPUT
SIMULATION
RESULTS
Product CAD
Process parameters
Spring back Results
Final results after compensation study
Property of FCA Fiat Chrysler Automobiles

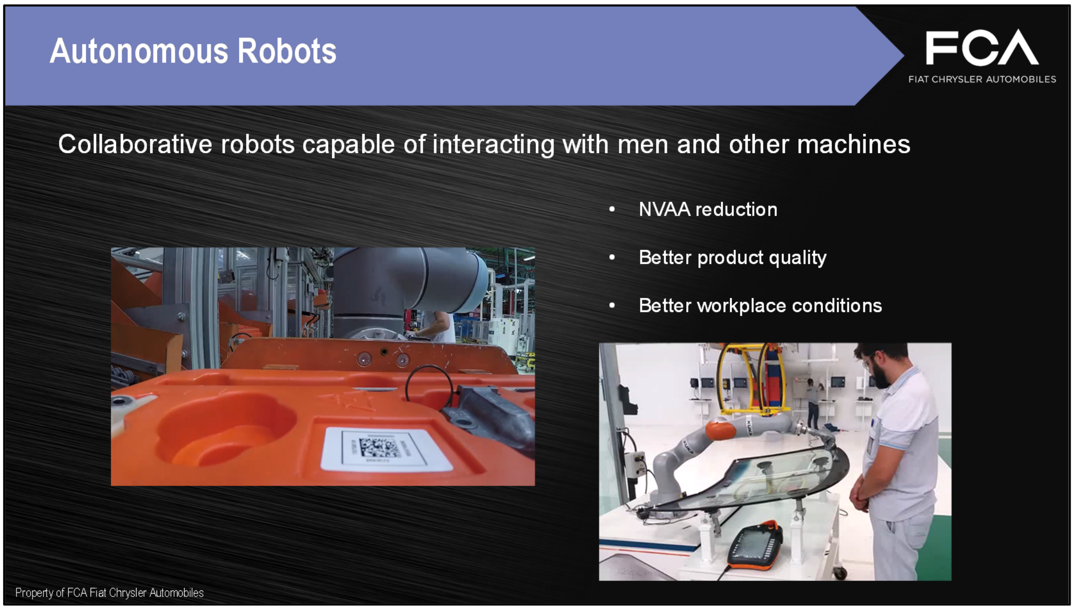

Simulation – Welding (Body Shop)
FCA
FIAT CHRYSLER AUTOMOBILES
INPUT
3D Geometry
GD&T
Welding Sequence
SIMULATION
Deformation Analysis
GD&T and welding optimization
Current Sequence
Proposed Sequence
RESULTS
Current Sequence
Proposed Sequence
Current Sequence
Proposed Sequence
Property of FCA Fiat Chrysler Automobiles

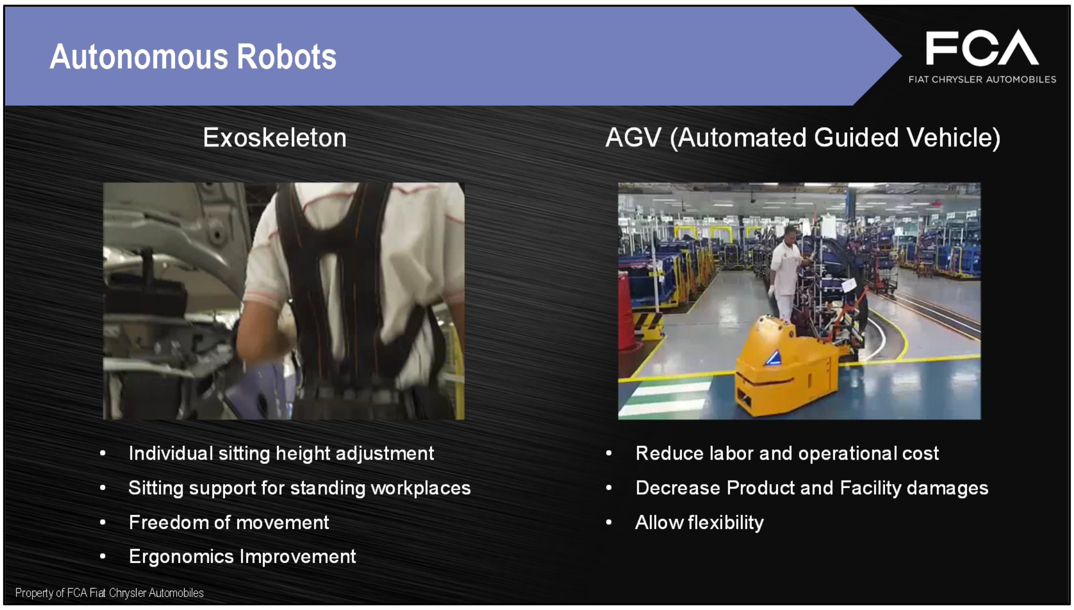

Simulation – Virtual Commissioning
FCA
FIAT CHRYSLER AUTOMOBILES
Simulation of PLC Logic, I/O and robot off line programs in a integrated environment
• Optimization of automation systems and debug PLC programming in a virtual environment
• Early error identification (Time and Cost savings)
• Shorter commissioning
• People training
Property of FCA Fiat Chrysler Automobiles


Simulation – E-Coat
FCA
FIAT CHRYSLER AUTOMOBILES
Data Freeze of Digital Product Development
Geometry Prep and Meshing
Dip in Simulation
Goal: Predict air pockets, forces on parts
E-Coat Simulation
Goal: Predict paint thickness on all parts
Drain Simulation
Goal: Predict residual bath and drain time
Suggestions for Design Improvement
Goal: Corrosion protective E-Coat thickness in all cavities
Property of FCA Fiat Chrysler Automobiles

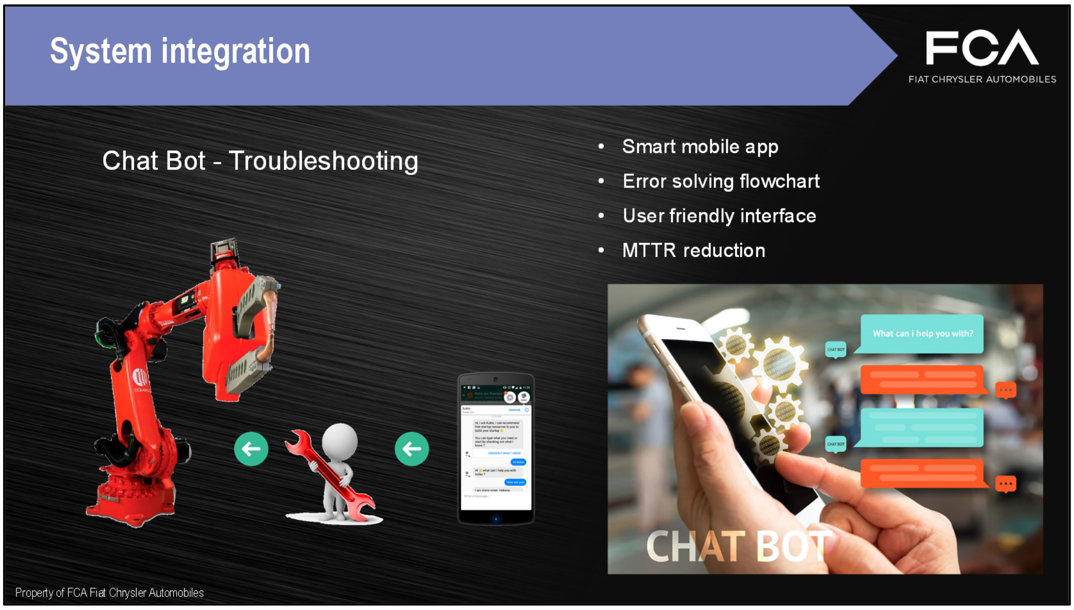

Simulation – E-Coat
FCA
FIAT CHRYSLER AUTOMOBILES
Dip Simulation
Solution Time 0.2 (s)
Solution Time 0.2 (s)
Drain Simulation
Solution Time 0.2 (s)
Solution Time 0.2 (s)
E-Coat Simulation
STAR-CCM+
Solution Time 0.25 (s)
Property of FCA Fiat Chrysler Automobiles


Simulation - Virtual Immersive Room
FCA
FIAT CHRYSLER AUTOMOBILES
• Shop floor full integration in early phase during product and process development
• Real-time physical simulation with immersive user interface
• Design for Assembly virtual validation
• Continuous improvement of ergonomics
Property of FCA Fiat Chrysler Automobiles

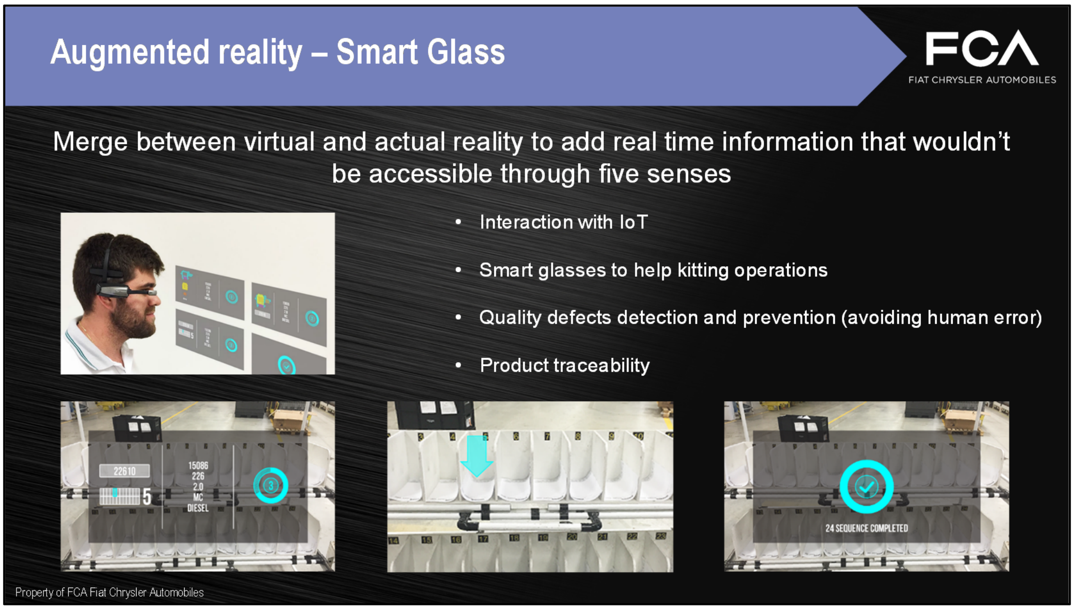

Autonomous Robots
FCA
FIAT CHRYSLER AUTOMOBILES
Collaborative robots capable of interacting with men and other machines
• NVAA reduction
• Better product quality
• Better workplace conditions
Property of FCA Fiat Chrysler Automobiles

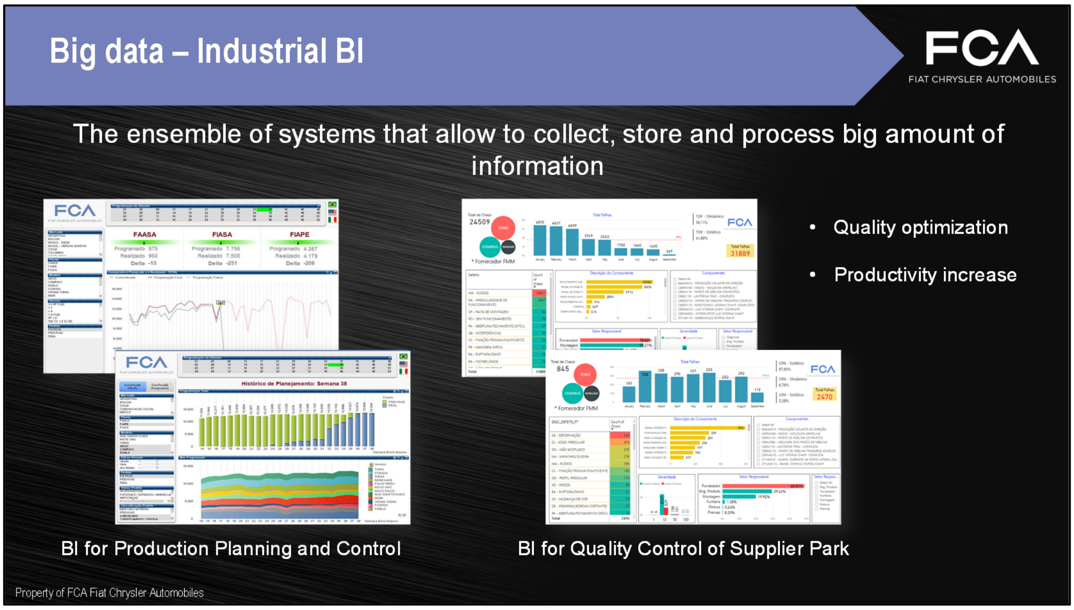

Autonomous Robots
FCA
FIAT CHRYSLER AUTOMOBILES
Exoskeleton
AGV (Automated Guided Vehicle)
• Individual sitting height adjustment
• Sitting support for standing workplaces
• Freedom of movement
• Ergonomics Improvement
• Reduce labor and operational cost
• Decrease Product and Facility damages
• Allow flexibility
Property of FCA Fiat Chrysler Automobiles


Internet of Things – Smart Wearables
FCA
FIAT CHRYSLER AUTOMOBILES
Digitalization of data within the value chain
• Data interchange between machines
• Flexibility with smart wearables
• Productivity increase
• Production Real Time monitoring
Property of FCA Fiat Chrysler Automobiles


System integration
FCA
FIAT CHRYSLER AUTOMOBILES
Chat Bot - Troubleshooting
• Smart mobile app
• Error solving flowchart
• User friendly interface
• MTTR reduction
What can i help you with?
CHAT BOT
Property of FCA Fiat Chrysler Automobiles


Additive manufacturing
FCA
FIAT CHRYSLER AUTOMOBILES
3D printers to produce manufacturing tools
• Fast building with high level of detail
• Cost, time and material use reduction
• Parts personalization
Product Prototypes
Spare Parts
Fixtures
Siena
Property of FCA Fiat Chrysler Automobiles

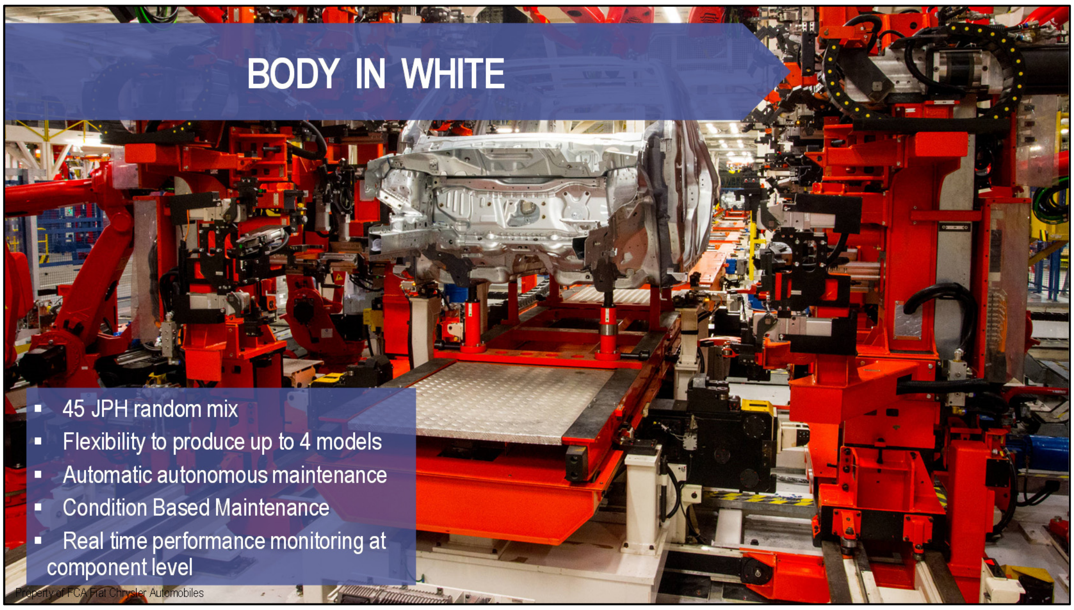

Augmented reality – Smart Glass
FCA
FIAT CHRYSLER AUTOMOBILES
Merge between virtual and actual reality to add real time information that wouldn't be accessible through five senses
• Interaction with IoT
• Smart glasses to help kitting operations
• Quality defects detection and prevention (avoiding human error)
• Product traceability
24 SEQUENCE COMPLETED
Property of FCA Fiat Chrysler Automobiles


Big data – Industrial BI
FCA
FIAT CHRYSLER AUTOMOBILES
The ensemble of systems that allow to collect, store and process big amount of information
• Quality optimization
• Productivity increase
BI for Production Planning and Control
BI for Quality Control of Supplier Park
Property of FCA Fiat Chrysler Automobiles


A factory that has transformed a CHALLENGE...
in OPPORTUNITY
EMPLOYEES
3,218
PEOPLE
TOTAL AREA
4,406,828
SQM
CAPACITY
(3 Shifts)
260,000
VEHICLE/YEAR
CONSTRUCTED AREA
669,851
SQM
WCM

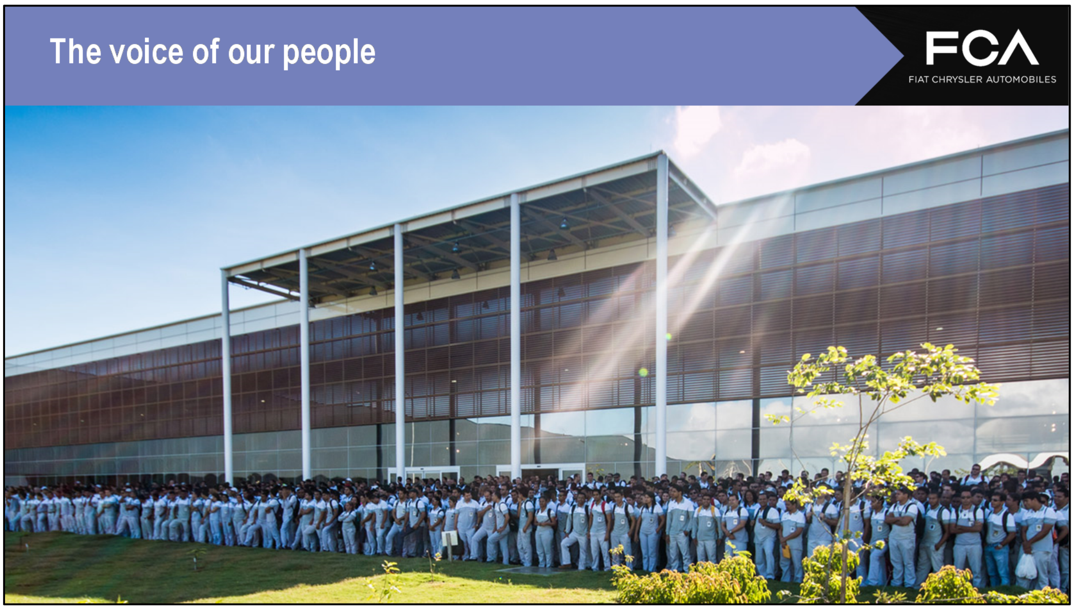

First model of the Jeep Automotive Polo
5 stars in safety in Latin NCAP
About 123 thousand units marketed in Brazil since the launch (until August / 2017)
Second model produced in the Automotive Polo, in less than a year of commercial operation.
More than 73 thousand units sold until August 2017
Pickup of the year - Autoesporte 2017
Red Dot Design Award
IF Design Award
The most awarded car in Brazil
Third model produced at Automotive Polo, in 18 months of operation (September 2016)
Sales success and segment leader
About 35 thousand Compass sold until August 2017
Property of FCA Fiat Chrysler Automobiles


PRESS SHOP
High Production: 18 strokes/min
Set up time < 3 min
Full cycle simulation for new products
BI for production monitoring
Property of FCA Fiat Chrysler Automobiles


BODY IN WHITE
45 JPH random mix
Flexibility to produce up to 4 models
Automatic autonomous maintenance
Condition Based Maintenance
Real time performance monitoring at component level
Property of FCA Fiat Chrysler Automobiles


PAINT SHOP
Primerless compact process
Energy and water consumption reduction
Computerized Maintenance Management System
Automatic thickness control
Property of FCA Fiat Chrysler Automobiles


GENERAL ASSEMBLY
Each workplace optimized for ergonomics
Optimum Logistic layout connected to Supplier Park
Integrated Systems (NPL)
All process and product data available in each workplace
Property of FCA Fiat Chrysler Automobiles


The voice of our people
FCA
FIAT CHRYSLER AUTOMOBILES


Thank you!
pierluigi.astorino@fcagroup.com
FCA
FIAT CHRYSLER AUTOMOBILES

ozonio

Patrocínio

Realização

Universidade Metodista de Piracicaba

Apoio

Parceiros

TECHNISCHE UNIVERSITÄT DARMSTADT

Centro Alemão de Ciência e Inovação – São Paulo

Alemanha País de Ideias

ISSN 2175-9960