Industry 4.0 Made Tangible – Tangible Things Within Industry 4.0

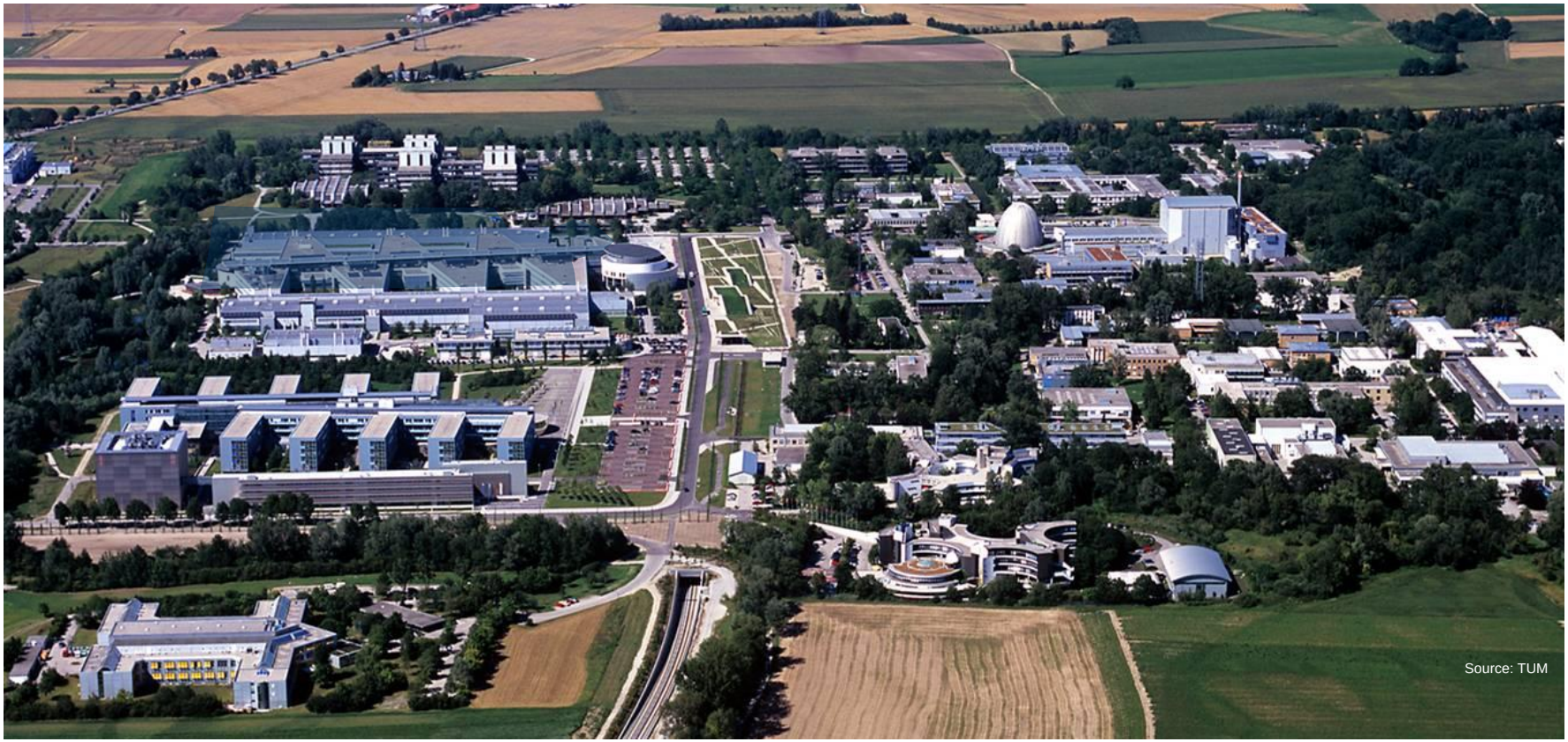
McMaster Manufacturing Forum 2017

Hamilton, Ontario, April 6th 2017

Michael F. Zaeh, Prof. Dr.-Ing, TU Munich, Germany

(Institute for Machine Tools and Industrial Management)

The Garching Campus of TU Munich

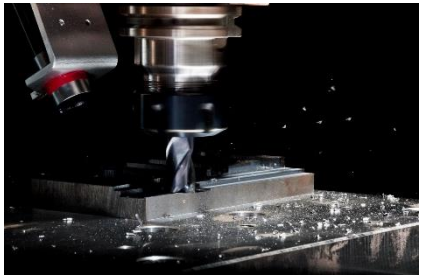


Some numbers: Founded in 1868, 14 departments, 500 professors, 10 000 staff, 40 000 students

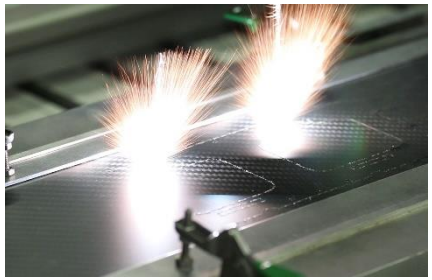
Institute for Machine Tools and Industrial Management

Factory Planning
(Prof. Reinhart)
Technology Management, Human Factors, Bionics

Machines and Robots
(Prof. Reinhart, Prof. Zaeh)
Structural Behaviour, New Applications



Technologies
(Prof. Zaeh)
Cutting, Joining,
Additive Manufacturing



Our laboratory

2 prof., 61 researchers, 17 supporting staff, 6 management team, budget 10 MEuro p.a.

Agenda

Industry 4.0 Made Tangible – Tangible Things Within Industry 4.0

1 A Definition in a Nutshell

2 Innovations in Machine Tools

3 Additive Manufacturing is Part of it

4 Artificial Intelligence – Two Examples

5 What has Already been done?

6 How to Tackle it

7 Summary

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Industry 4.0 – A Definition in a Nutshell

Industry 4.0

- **Industry 4.0** is an initiative **of the Federal German Government** in cooperation with **Industry**, which is striving to secure Germany´s top position by empowering it with respect to digital tools and methods.
- A major goal is the ***Smart Factory***, which is characterized by **changeability**, **resource efficiency**, **ergonomic design** as well as **integration of business partners** in the processes.
- The term was introduced in **2011** during the **Hanover Trade Show**. In October 2012 the **Federal German Government** introduced **recommendations** concerning **Industry 4.0**.

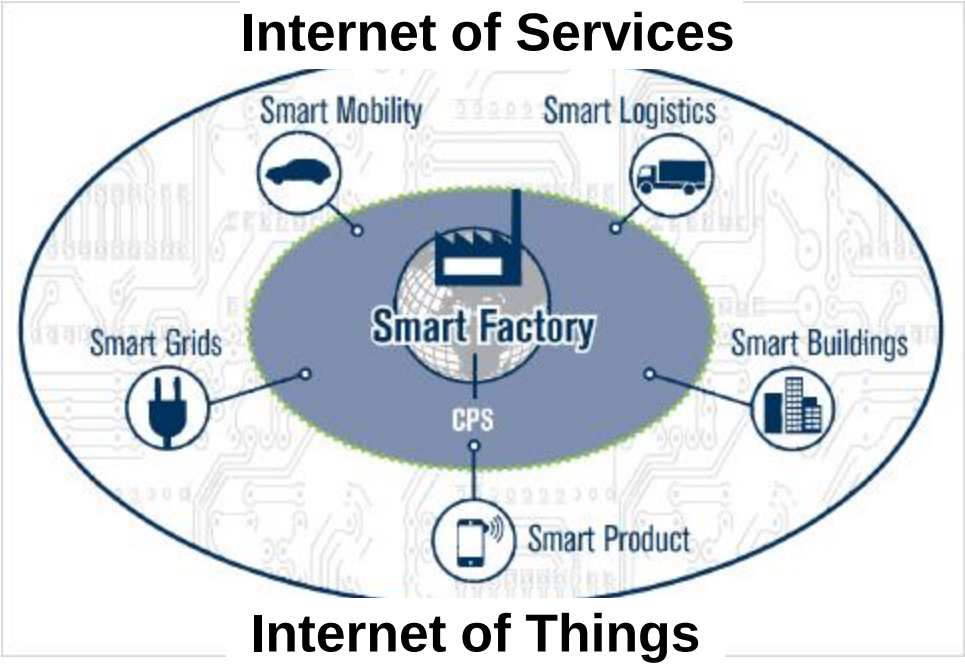
<u>To bring it to the point:</u>

- **Use of networked systems** of all kinds within and between factories as well as towards customers and suppliers **(Cyber-Physical Systems (CPS) and Cyber-Physical Production Systems (CPPS))**
- The **connected mode** *(Internet of Things, Internet of Everything)* allows for the accumulation of data on a large scale and for the extraction of certain patterns **(Big Data)**, also for new business models.

Industry 4.0 – A Definition in a Nutshell

Added value in production because of Industry 4.0

- Increase of flexibility
- Smarter integration of the workforce
- Efficient use of resources
- Reduced time to market
- Improved competitiveness
- Powerful SCM
- Reduced peak loads
- Customer requirements better taken care of



It is nothing but CIM reloaded.

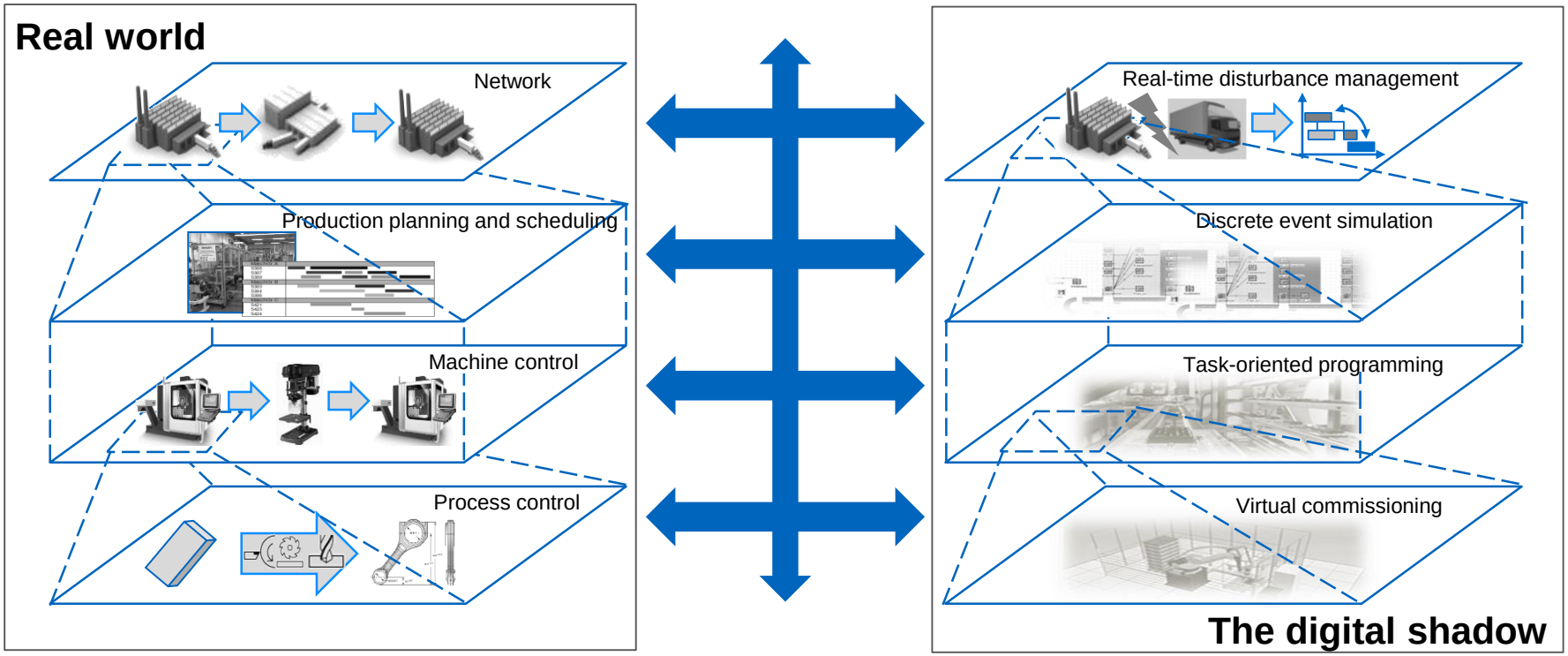
Those who master it have a competitive edge.

Sources: Working group on Industry 4.0., acatech,Weyrich

Industry 4.0 – A Definition in a Nutshell

On the way to Industry 4.0

The digital twin/shadow from the supply chain all the way to the processes



Cyber-Physical Systems allow the synchronization and merging of the real and the virtual world.

Industry 4.0 – A Definition in a Nutshell

McKinsey´s Opinion and View

We define **Industry 4.0** as the next phase in the digitization of the manufacturing sector, driven by four disruptions:

- the astonishing rise in **data volumes**, computational power, and connectivity, especially new low-power wide-area networks;
- the emergence of **analytics and business-intelligence** capabilities;
- new forms of **human-machine interaction** such as touch interfaces and augmented-reality systems;
- and improvements in transferring **digital instructions** to the physical world, such as advanced robotics and 3-D printing.

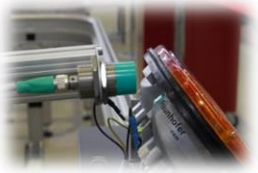
The four trends are not the reason for the 4.0.

Cornelius Baur and Dominik Wee (McKinsey, June 2015)

Source: McKinsey

Industry 4.0 – A Definition in a Nutshell

On the way to Industry 4.0

1	Steam power driven production systems (loom) in the late 18th and early 19th century	
2	Mass production (starting approx. 1870) and mechanized production (Taylorism, Fordism)	
3	Use of electronics and IT for increased automatization of production since approx. 1969	
4	Intelligent objects (CPS, CPPS) and Internet of Things in development	

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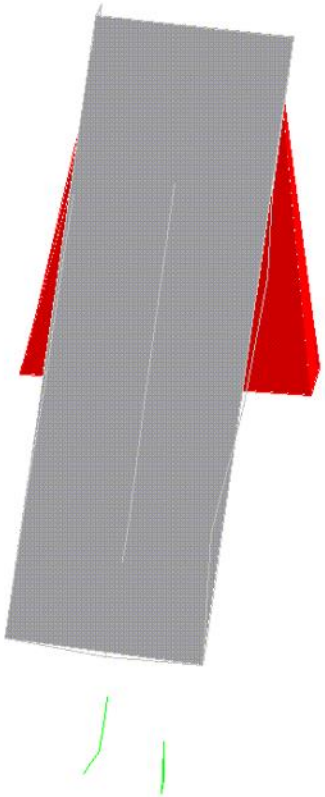
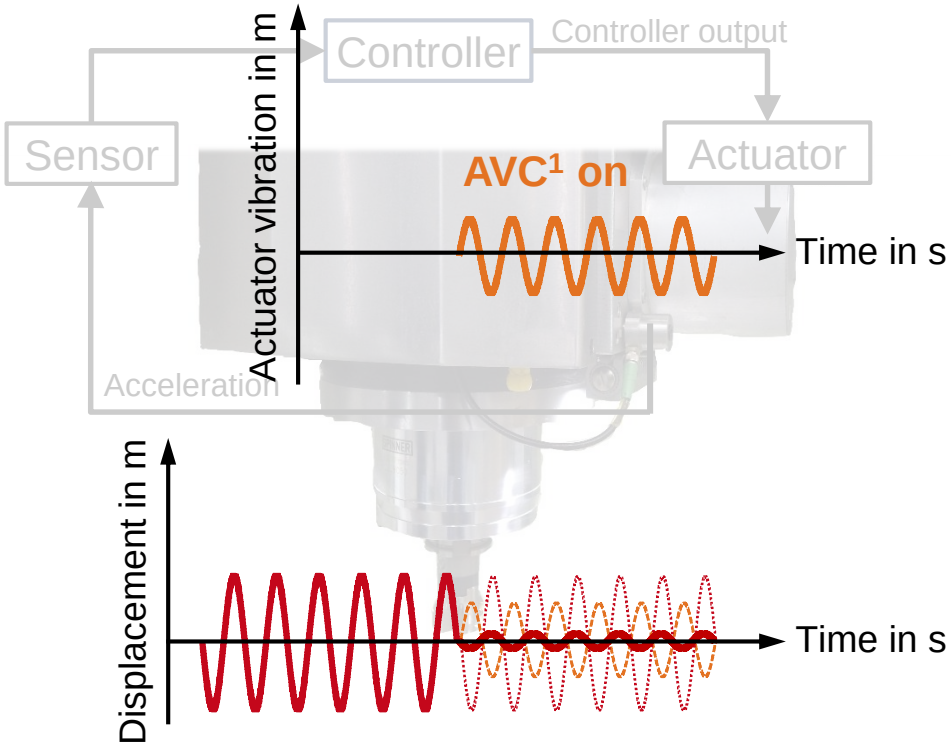
Industry 4.0 – Innovations in Machine Tools

Active Vibration Control



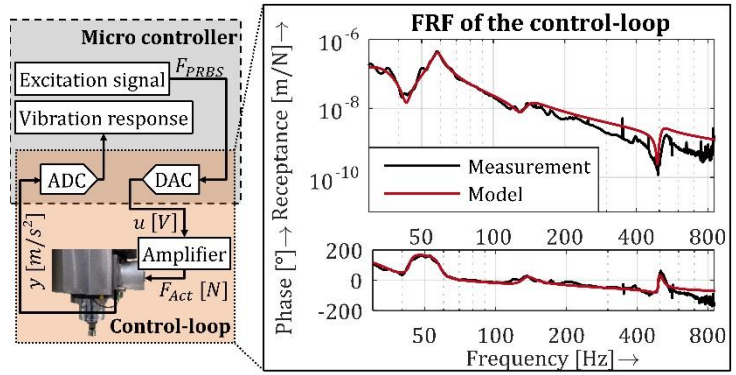


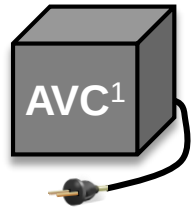
[1]AVC: Active Vibration Control

Industry 4.0 – Innovations in Machine Tools

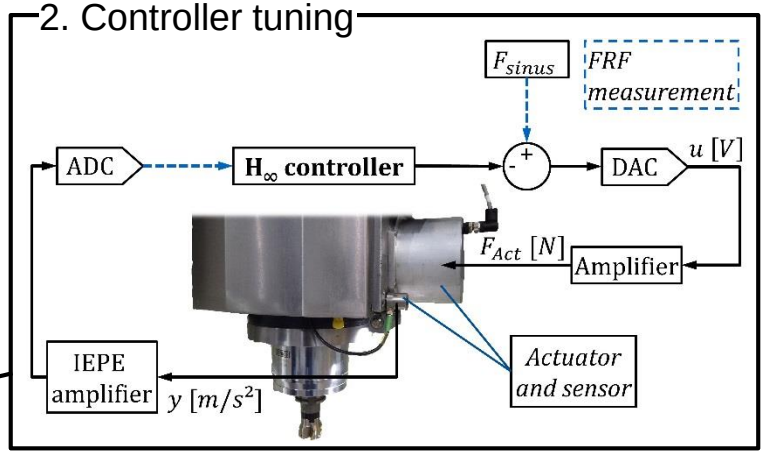
Automatic Tuning of Active Vibration Control Systems

1. Automatic system identifikation

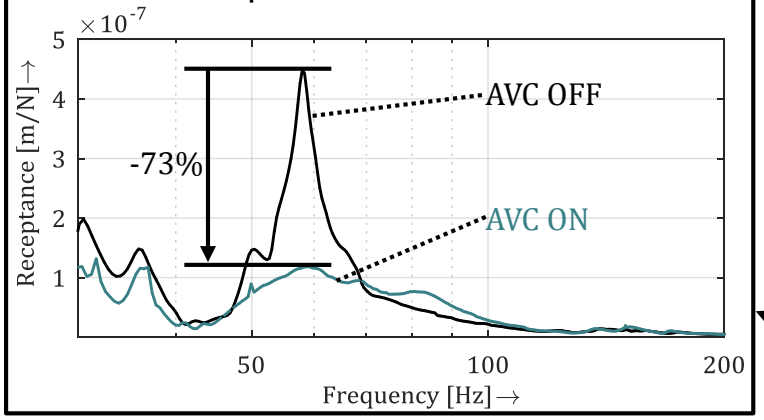




2. Controller tuning



3. Controller performance test



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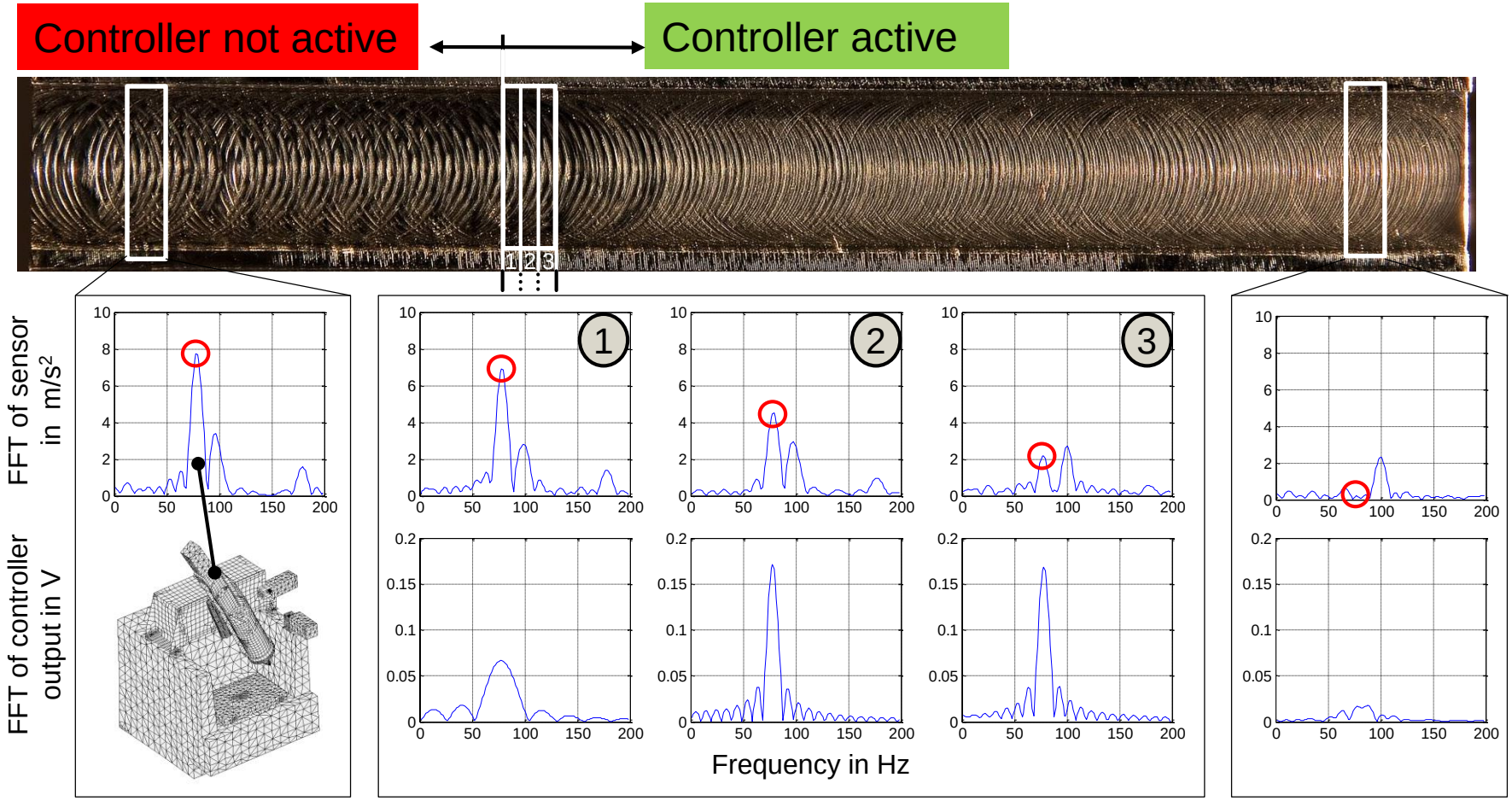
[1]AVC: Active Vibration Control

Industry 4.0 – Innovations in Machine Tools

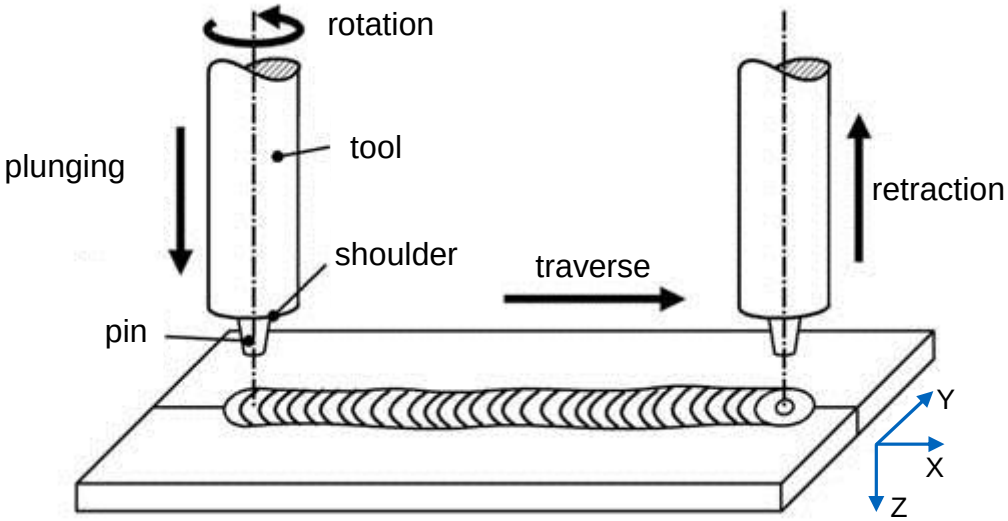
Active Vibration Damping using Piezoelectric Actuators



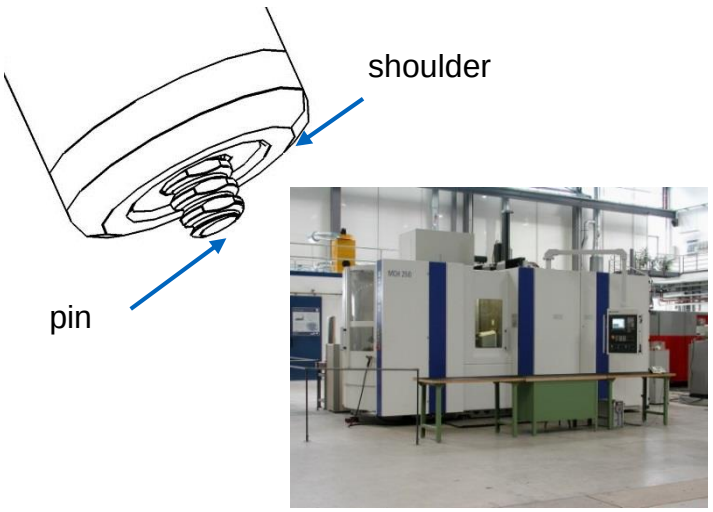
Industry 4.0 – Innovations in Machine Tools

Friction-Stir-Welding (FSW) - Basic principle

Process:



Tool:



Parameters:

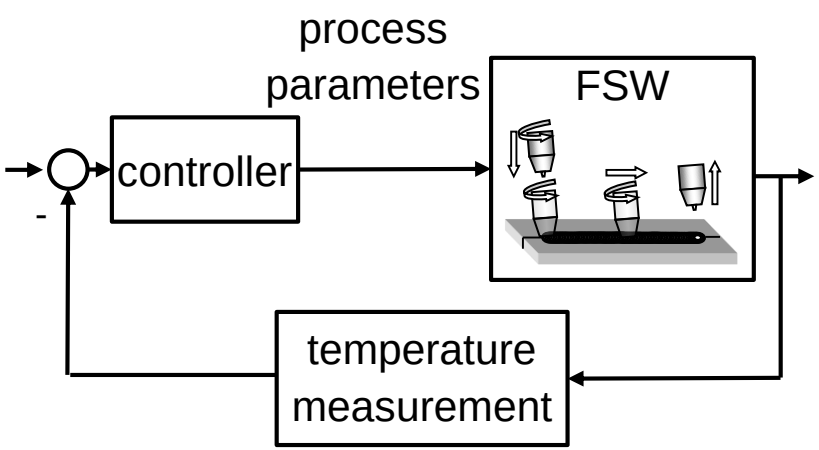
- Rotational speed
- Velocity in traverse direction
- Tool geometry
- Material properties

Characteristics of the process:

- High weld seam quality
- No shielding gas necessary
- Dissimilar joints are possible
- High process forces (5 to 20 kN even in Al)

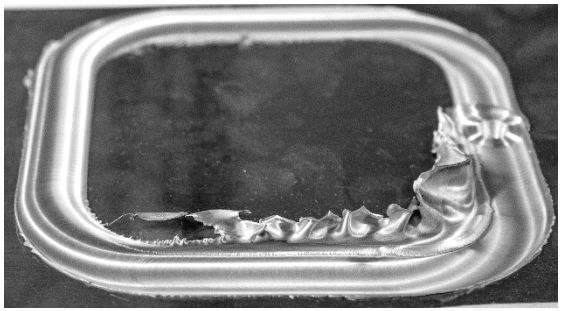
Industry 4.0 – Innovations in Machine Tools

Friction Stir Welding (FSW) in Temperature Controlled Mode



Benefits

- The heat accumulation is avoided leading to a reduced formation of flash.
- A high tensile strength of the welds results, because the optimum welding temperature can be maintained.
- The controller adjusts the process parameters automatically, which facilitates to set up the welding process for the operator.



Friction stir weld made without temperature control → flash

conventional – position or force control

Friction stir weld made with temperature control → constant weld quality

temperature control

Industry 4.0 – Innovations in Machine Tools

The Robot Becomes a Machine Tool

KUKA KR 240 R2500 prime

- max. reach: 2500 mm
- costs: about 80 000 €
- repeatability: 0.06 mm

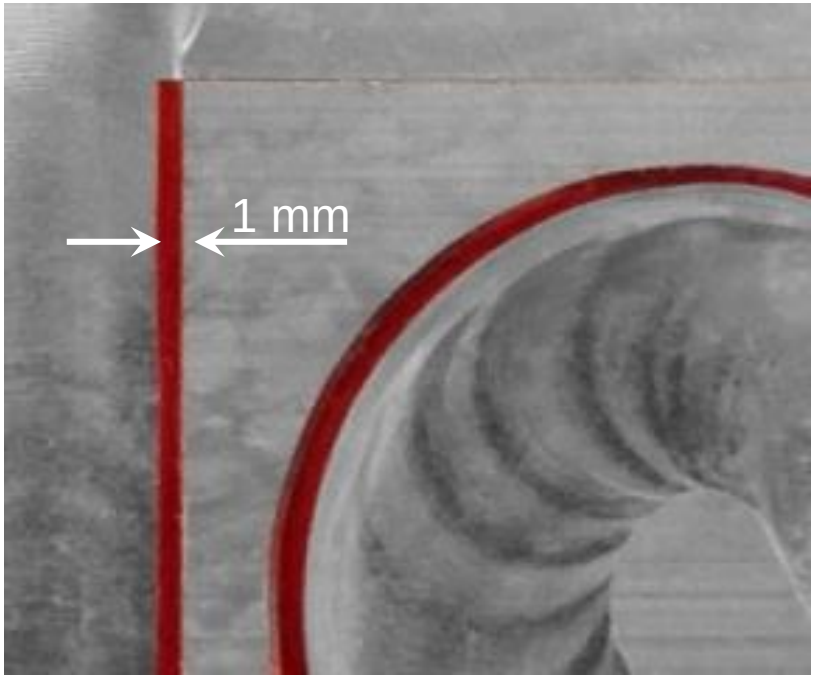
Advantages of the robot

- huge working area
- excellent space utilization
- low investment costs
- good agility & flexibility

Disadvantages of the robot

- low accuracy
- poor static and dynamic stiffness

static deviation (aluminum)



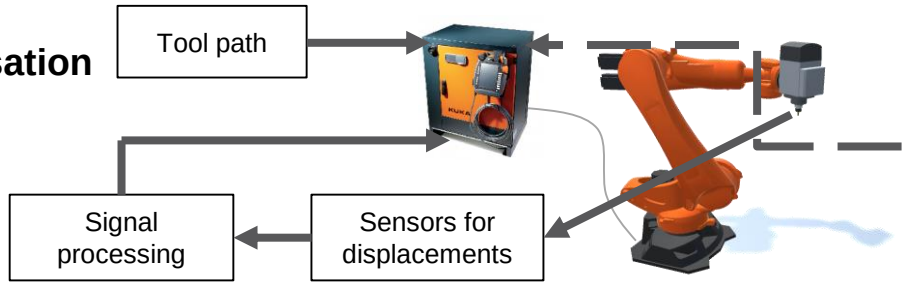
Source: KUKA

Industry 4.0 – Innovations in Machine Tools

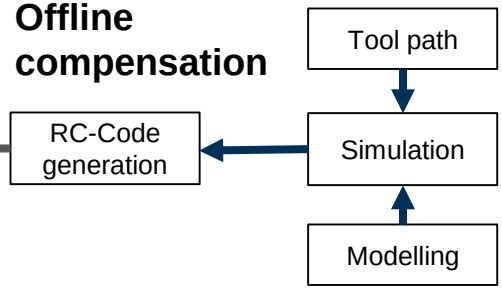
The Robot becomes a Machine Tool

Methods to improve the static stiffness

Online compensation

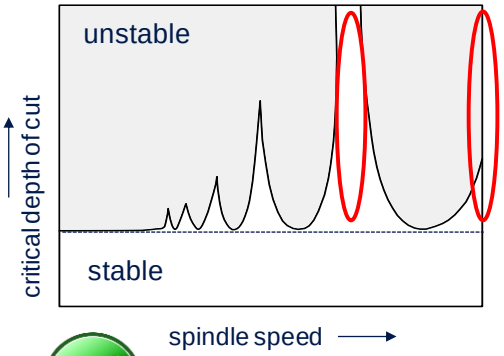


Offline compensation



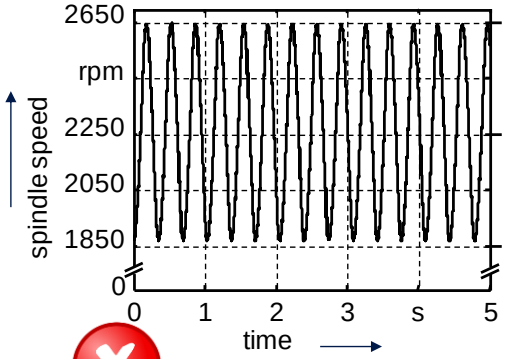
Methods to reduce the chatter-affinity

Utilization of the RPM/speed dependency



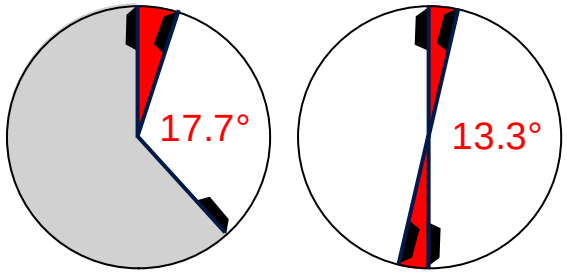
suitable

Periodic spindle speed variation



not suitable

Use of unevenly spaced cutters

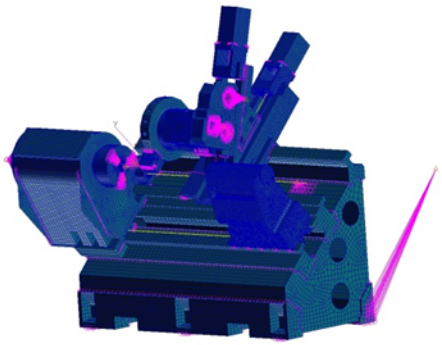


partially suitable

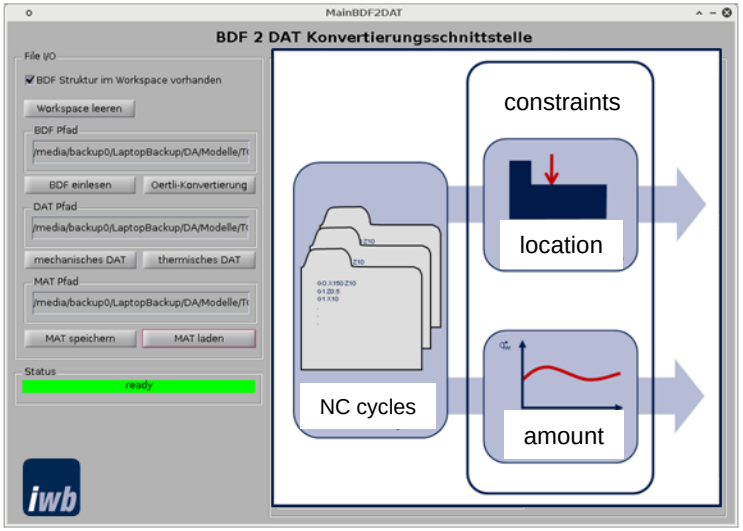
Industry 4.0 – Innovations in Machine Tools

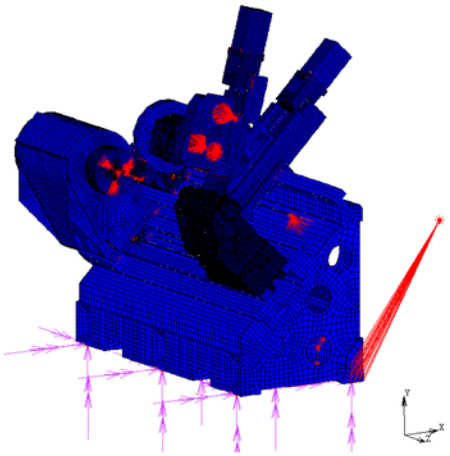
Simulation of the Thermal Behaviour / How to get to the Model Quickly

- Software tool for semi-automatic creation of a thermal model …
- transforms mechanical models into thermal models including …
- definition of the constraints (conduction, convection, radiation).



Mechanical model





Thermal model

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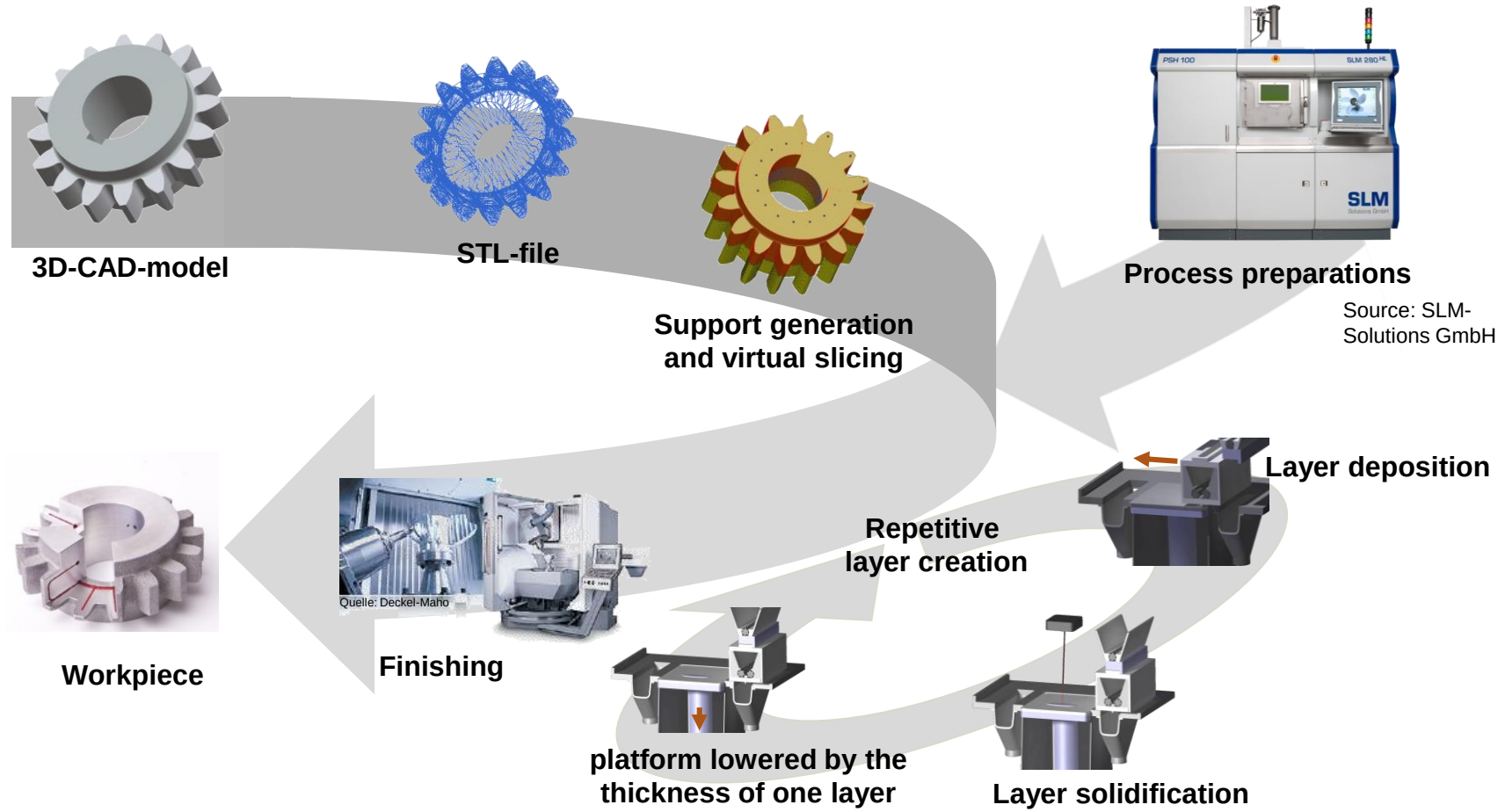
Industry 4.0 – Additive Manufacturing is Part of it

The powder bed based Additive Manufacturing …



… is characterized by a completely integrated process chain.

Industry 4.0 – Additive Manufacturing is Part of it

Additive Manufacturing of Gears

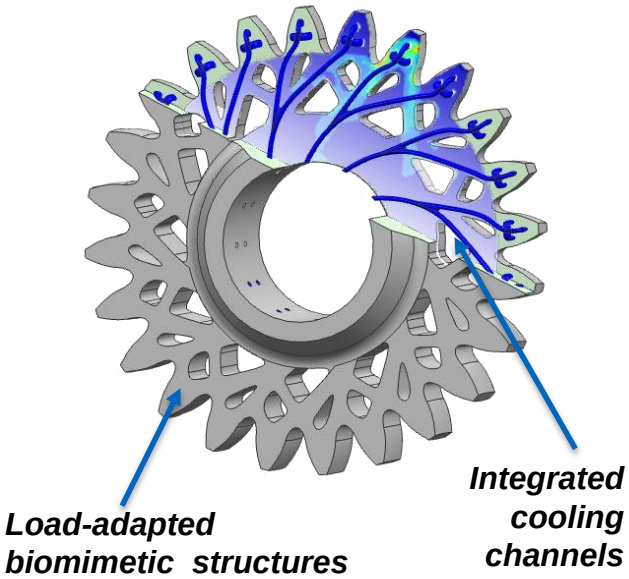
Fraunhofer IGCV

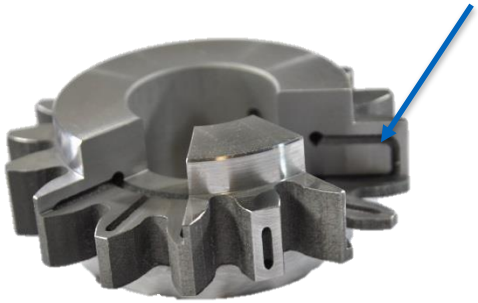
Motivation:

- Lightweight design und functional integration is also increasing in gear manufacturing using case hardening steels
  ➔ Laser beam melting of case hardening steels

Approach:

- Reference alloy: ASTM 5115 (16MnCr5)
- EOS M270 machine,
  beam source: 200 W Ytterbium fibre laser
- Process sequence: stress relief annealing, case hardening, hard finishing





Results and outlook:

- Average mass reduced by 25 %
- conformal cooling for high temperature transmission
- Shorter lead times and process sequences

Sources: Stahl, Kamps, Fraunhofer IGCV

Industry 4.0 – Additive Manufacturing is Part of it

Additive Manufacturing of a Reamer (reaming tool holder)

Fraunhofer IGCV

Motivation:

- External reamers require high precision (e.g. for valve spool finishing)
- Lightweight design is good for dynamic behaviour

➔ Laser Beam Melting (LBM) of titanium and steel alloys

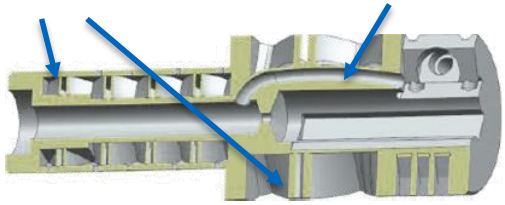
Approach:

- TiAl6V4 as standard alloy for lightweight applications
- 1.2709 (X3NiCoMoTi18-9-5) as standard steel alloy
- SLM 250HL machine, 400 W YLR-fibre laser

Conventional Design ***Lightweight AM-Design*** ***Lightweight AM-Design (finished)***

Results:

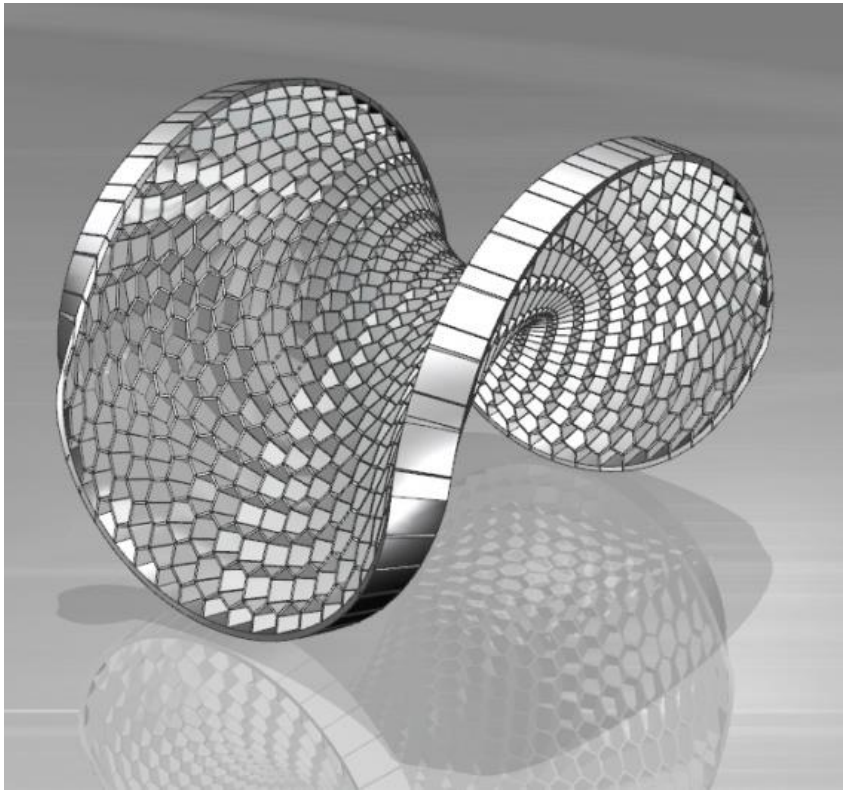
- Process was adopted by industrial partner Mapal (with further development)
- Approximately 54 % mass reduction resulting in lower vibration amplitudes during the machining process

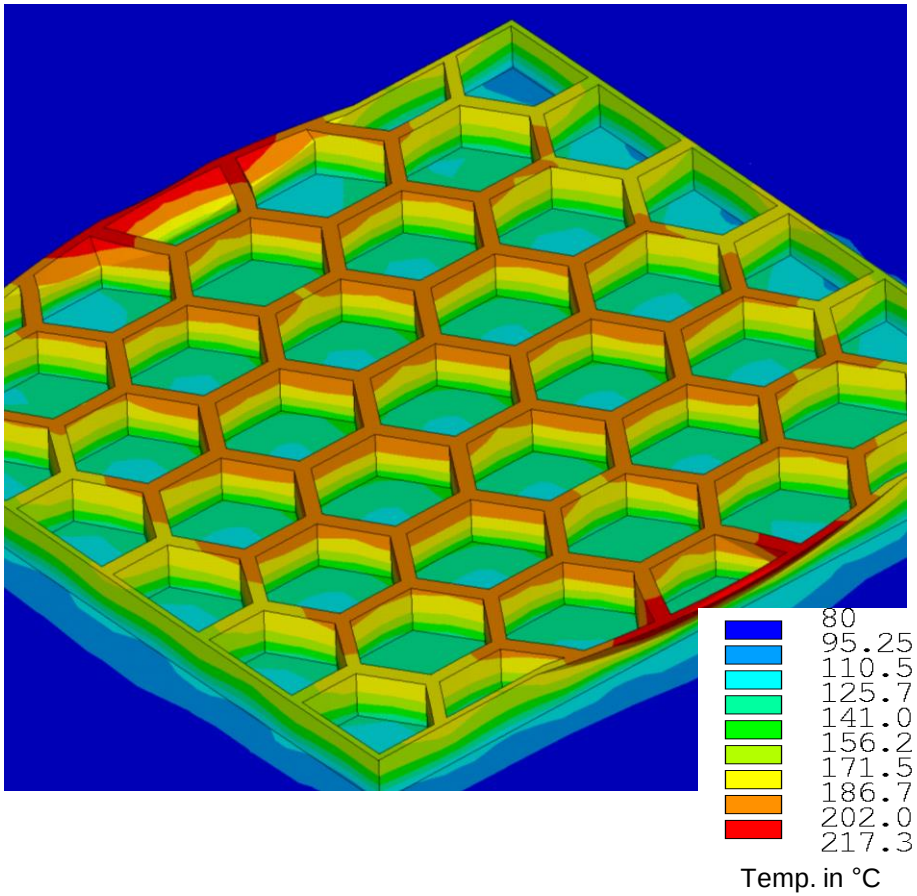


Source: Fraunhofer IWU/IGCV

Industry 4.0 – Additive Manufacturing is Part of it

Geometrical Features are for free, because …





… the manufacturing costs of a part are not determined by the features, but predominantly by the part volume.

Sources: Fraunhofer IGCV, iwb

Industry 4.0 – Additive Manufacturing is Part of it

Hybrid Approach Integrating Additive and Cutting Technologies

Laser Cladding

Laser Cladding

Milling

DMG Mori Lasertec 65 3D (also on www.youtube.com)

Laser Cladding

Milling

Source: DMG Mori

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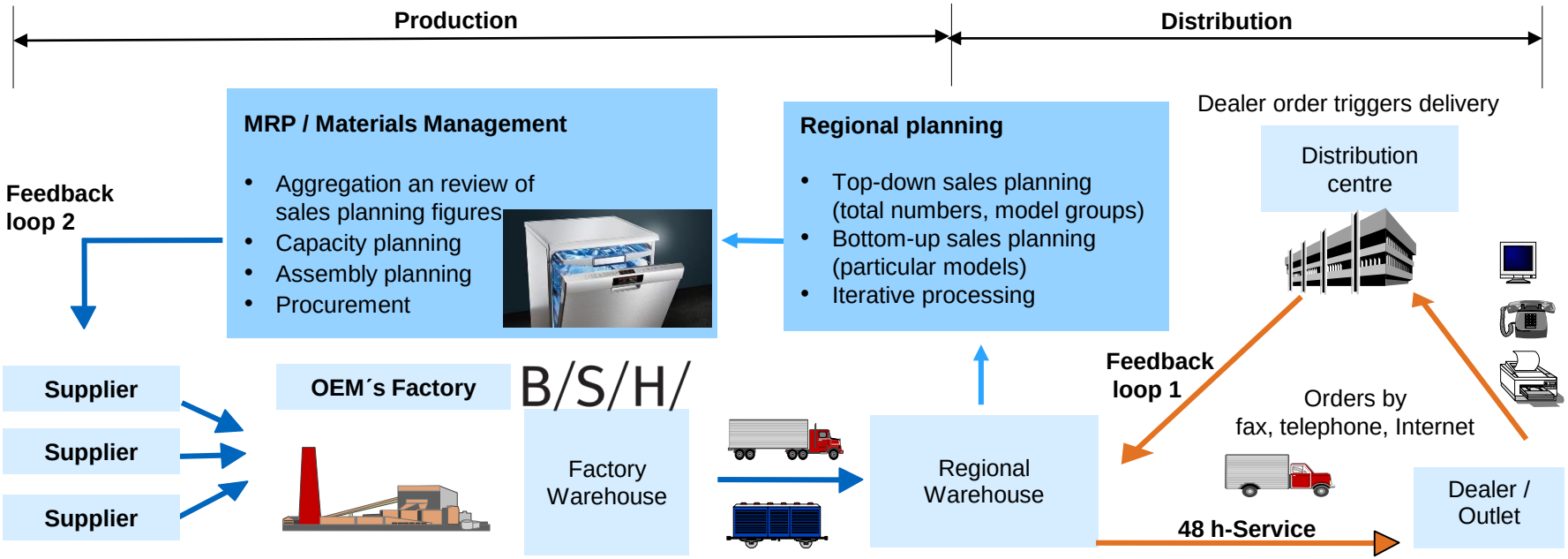
Industry 4.0 – Artificial Intelligence – Two Examples

An *Evolutionary Algorithm* in Job Order Planning

Decription of the Initial Situation: Assembly of Household Appliances (Dish Washers etc.)



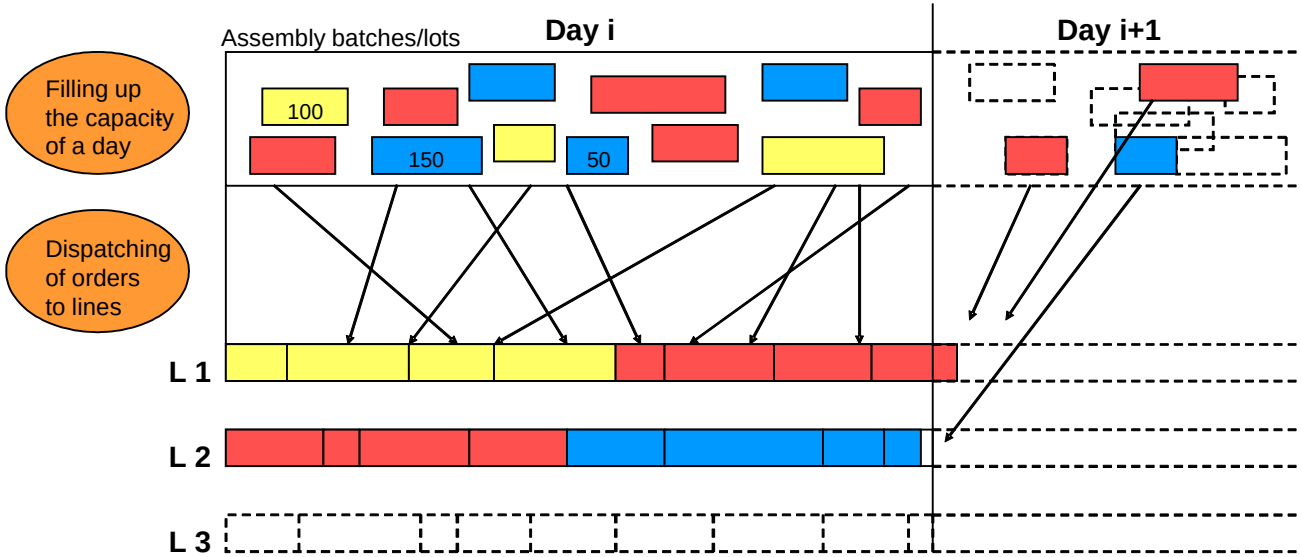
- Manual planning of the job order sequences based on input (forecast) from sales and distribution
- 8 assembly lines with different capacities and capabilites; high set-up costs when changing from one batch/lot to another
- Manual optimization not possible due to high number of solutions, constraints and interdependencies

Industry 4.0 – Artificial Intelligence – Two Examples

An *Evolutionary Algorithm* in Job Order Planning

Decription of the Initial Situation: Assembly of Household Appliances (Dish Washers etc.)

Manual job order planning for the next day on the basis of set-up codes
(indicating similarities among the models and thus in set-up and line requirements)



Line scheduling
Similar models are being aggregated to internal orders and dispatched to lines

Sequence optimization
Set-up-codes help to group and to minimize the set-up times, efforts and costs

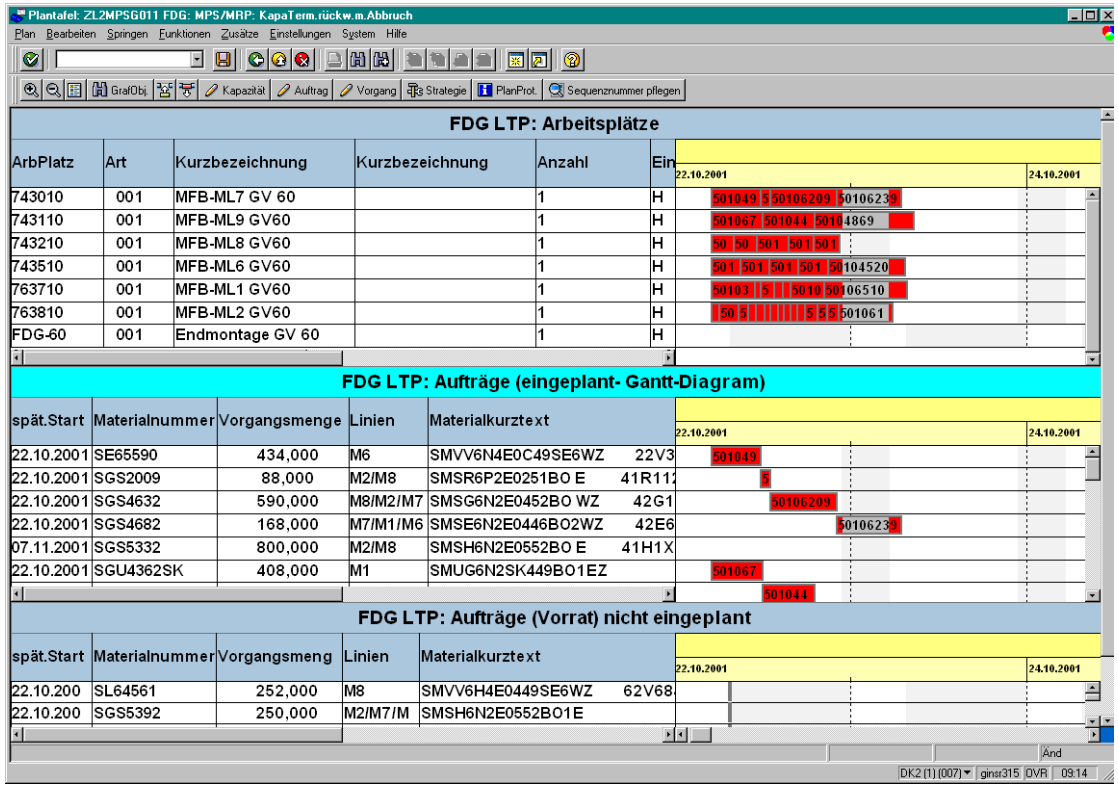
Set-up code

Digit-#
1 Model-#
2 Heat exchanger
3 Control
4 Programs
5 Noise reduction
6 Salt sensor
7 …
8…

Industry 4.0 – Artificial Intelligence – Two Examples

An *Evolutionary Algorithm* in Job Order Planning

Decription of the initial situation: assembly of household appliances (Dish Washers etc.)



Dispatching to assembly lines via mouse click

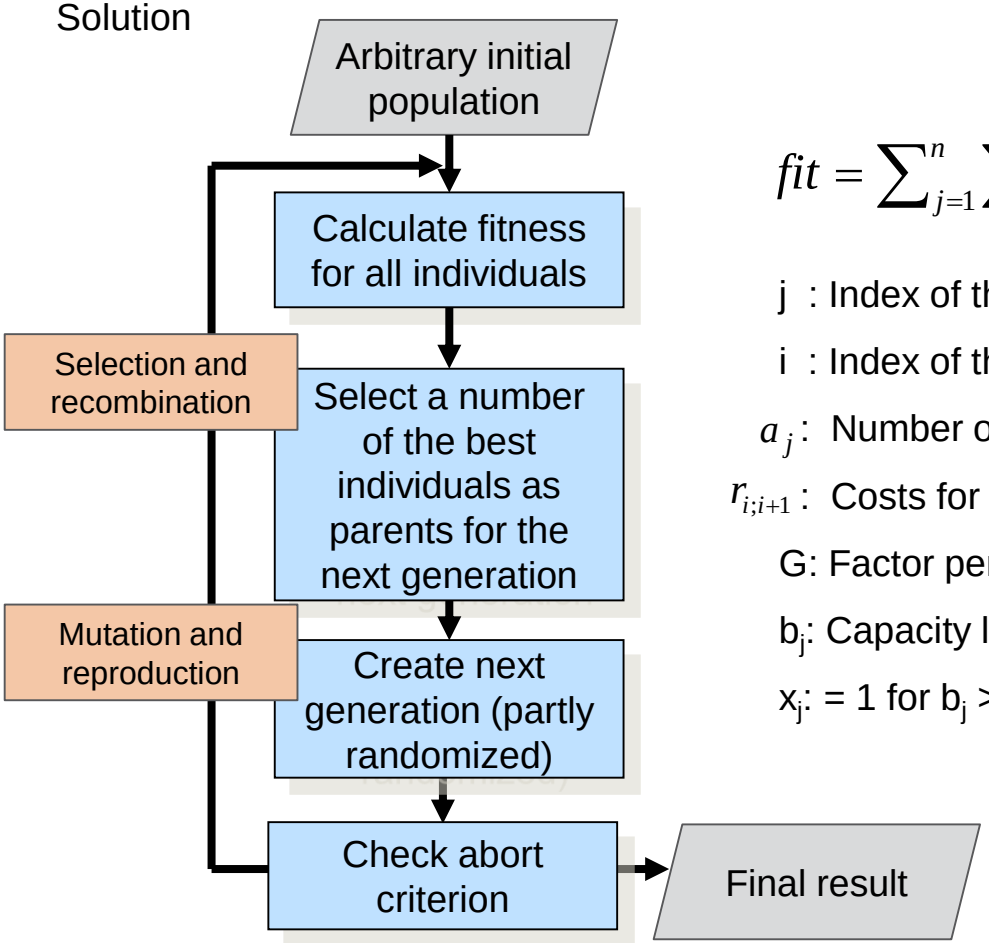
Line options indicated by a colour code

- Manual planning on the basis of SAP planning charts
- Sequencing done iteratively based on set-up code and experience of the person in charge (2 hours per day)

Industry 4.0 – Artificial Intelligence – Two examples

An *Evolutionary Algorithm* in Job Order Planning

Solution



$$fit = \sum_{j=1}^{n} \sum_{i=1}^{a_j - 1} r_{i;i+1} + G \sum_{j=1}^{n} (b_j - k_j) * x_j$$

j : Index of the assembly line (j = 1,2,…,n)

i : Index of the order on the assembly line j (i = 1,2,…,aj)

a_j : Number of orders on line j

$r_{i;i+1}$: Costs for changing from order i to order i+1

G: Factor penalizing capacity overload (or other unwanted effects)

b_j: Capacity load of line j; k_j: available capacity of line j

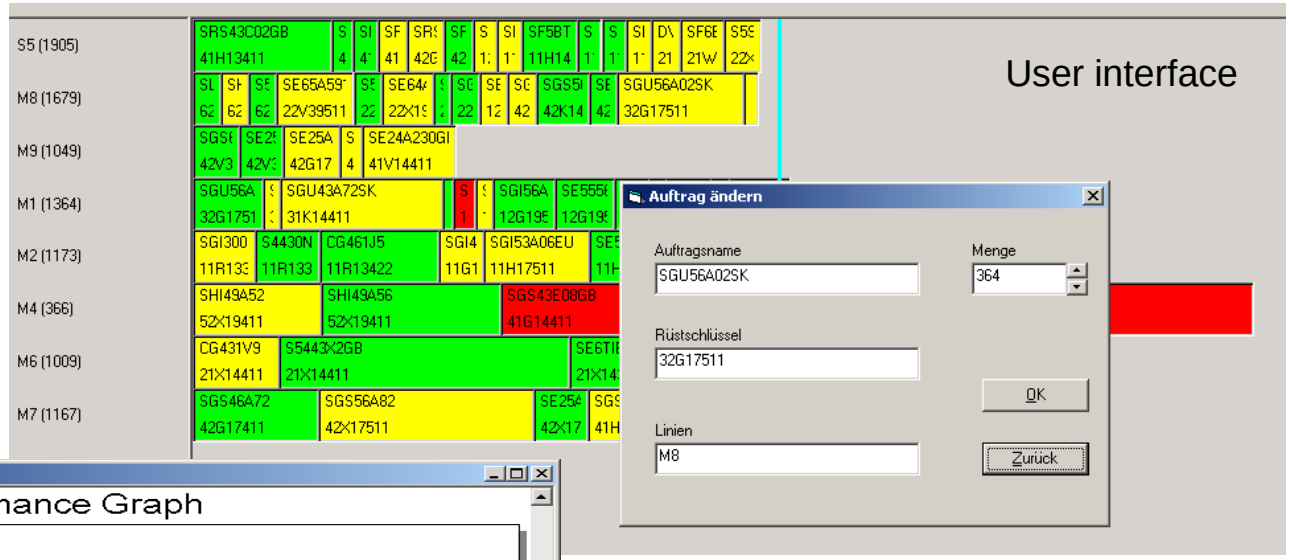
x_j: = 1 for $b_j > k_j$, otherwise 0

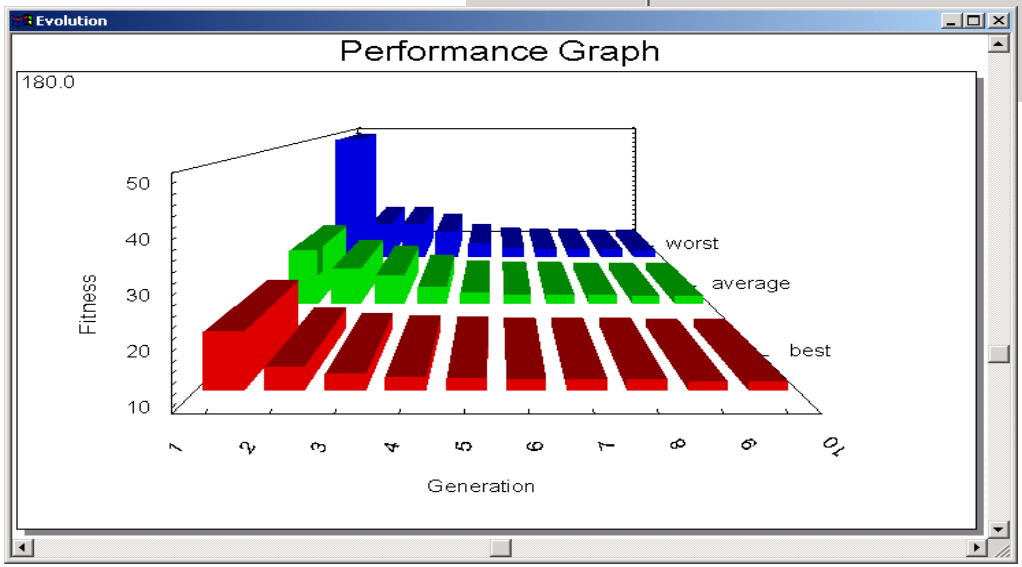
Industry 4.0 – Artificial Intelligence – Two Examples

An *Evolutionary Algorithm* in Job Order Planning

Results

… achieved in an industrial project involving two PhD candidates and one student



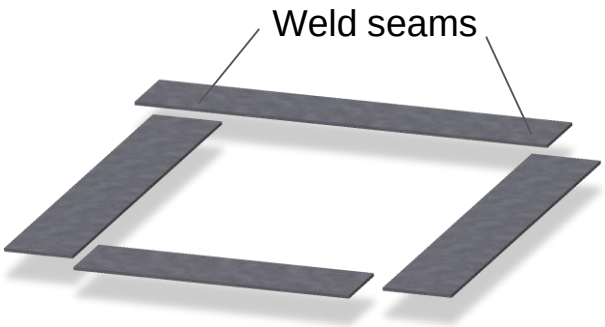


- In use since 2005
- Planning time reduced from 2 hours to 10 minutes per day
- Increased quality of the planning result (= better fitness)
- Reduced costs for material and line use
- Increased productivity

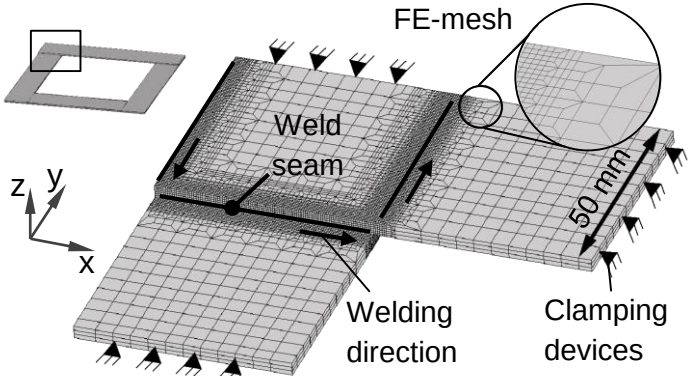
Industry 4.0 – Artificial Intelligence – Two Examples

Artificial Neural Networks and *Evolutionary Algorithms* to Minimize Welding Distortions

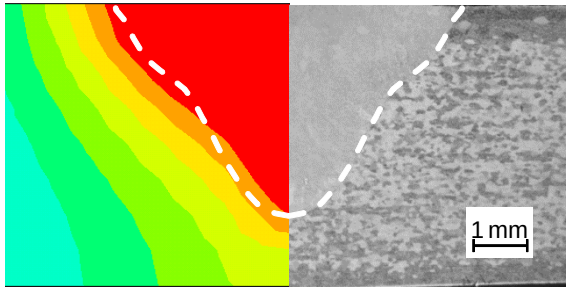
- Laser Welding induces deformations of the workpiece, which are hard to predict and to control.
- Finite-Element-Simulation is possible, but very time-consuming.
- The accuracy of the workpiece depends on a multitude of parameters.



Welding job with many possible sequences

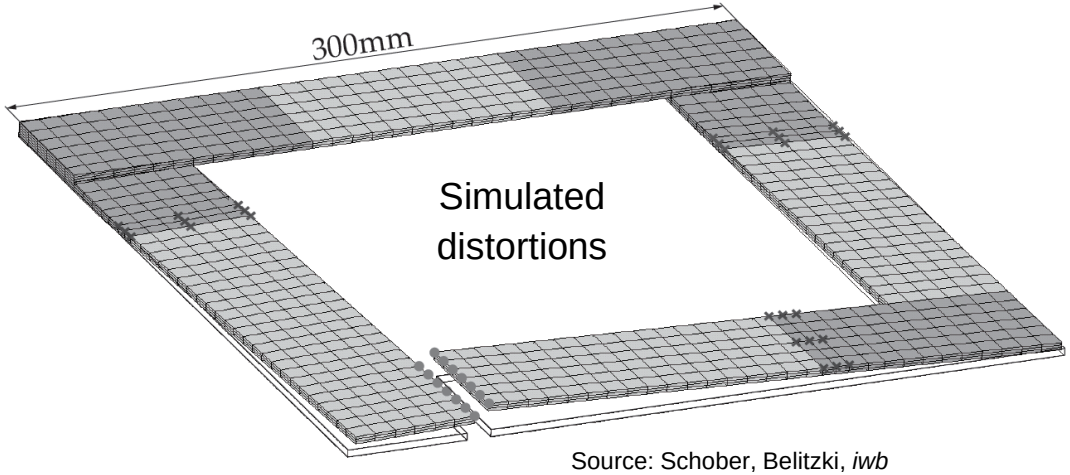


FE-model: mesh, constraints and clamping situation



$P_{Nd:YAG}$ = 3,0 kW; P_{HLDL} = 3,0 kW; v = 1,0 m/min, Al

Calibration of the heat source model



Source: Schober, Belitzki, *iwb*

Industry 4.0 – Artificial Intelligence – Two Examples

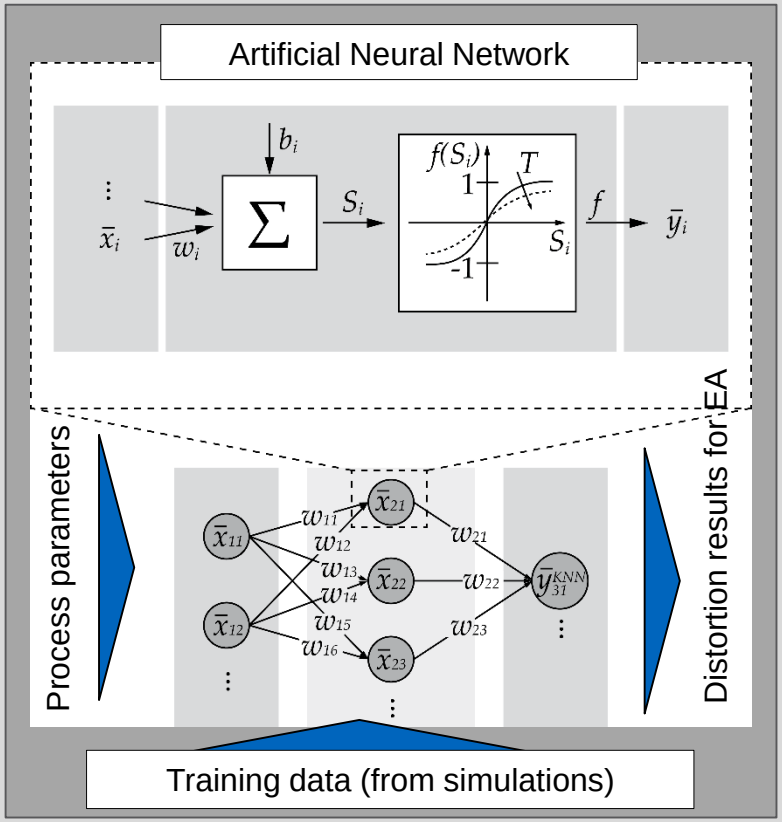
Artificial Neural Networks and *Evolutionary Algorithms (EA)* to Minimize Welding Distortions

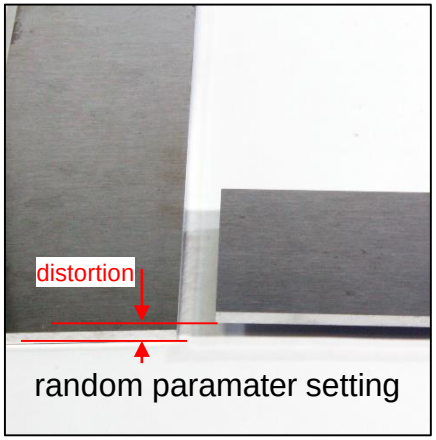
- *Evolutionary Algorithm:* beneficial for calibration of the Heat Source Models
- *Artificial Neural Network:* capable of handling the multiplicity of parameter settings
- *Evolutionary Algorithm:* determines the minimum distortion at the final joint closing the frame

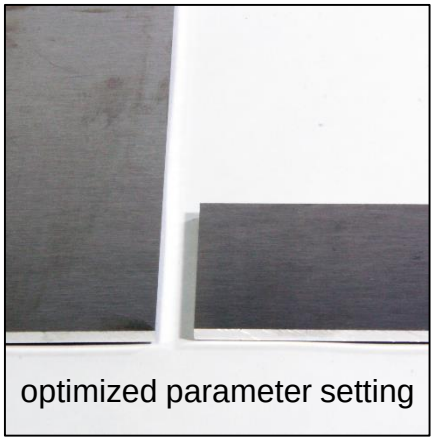
Evolutionary Algorthm

Selection
Recombination
Mutation
Reproduction
of process parameters

minimizes a fitness function representing the distortions







Agenda

Industry 4.0 Made Tangible – Tangible Things Within Industry 4.0

1 A Definition in a Nutshell

2 Innovations in Machine Tools

3 Additive Manufacturing is Part of it

4 Artificial Intelligence – Two Examples

5 What has Already been done?

6 How to Tackle it

7 Summary

Industry 4.0 – What has been done already?

Bosch Rexroth Group (AG) … is implementing pilot projects

Rexroth
Bosch Group

- Bosch Rexroth (a manufacturer of drive and control technology) is implementing Industry 4.0 on the shop floor step by step … small but quick steps
- Gain experience in pilot projects (there are more than 100 such projects in the Bosch-group)
- Semi-automatic production line with more than 200 different hydraulic valves
- Via an RFID-tag the workpiece authenticates itself at the machines
- Bosch contributes to standards in different national and international committees

Sources: Bosch Rexroth, Jenke, **technik**report 7-8 /15, p. 22

Industry 4.0 – What has been done already?

General Electric Company Corporation Definitely Sees High Significance …

- Industry 4.0 and the Internet of Things are of high significance for General Electric
- Data based services for the customer aiming at a more efficient use of General Electric products (jet engines, trains, power plants, wind energy plants)
- Predict-and-Prevent-Model instead of a repair oriented approach
- Just like Bosch, GE also contributes to standards in different national and international committees.

Sources: Thomas Schulz, General Electric, in **technik**report 7-8 /15, S. 18 ff.

Industry 4.0 – What has been done already?

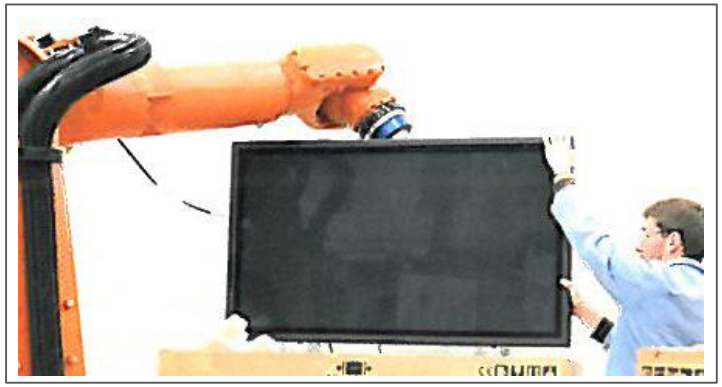
EU funded Project CustomPacker – Packing in a Hybrid Workplace Environment

Initial situation

- Products: Big and heavy electronic consumer goods
- Previously manual packing
- High variability of the products to be handled (size, shape, weight, box content, …)
- Monotonous and exhausting work

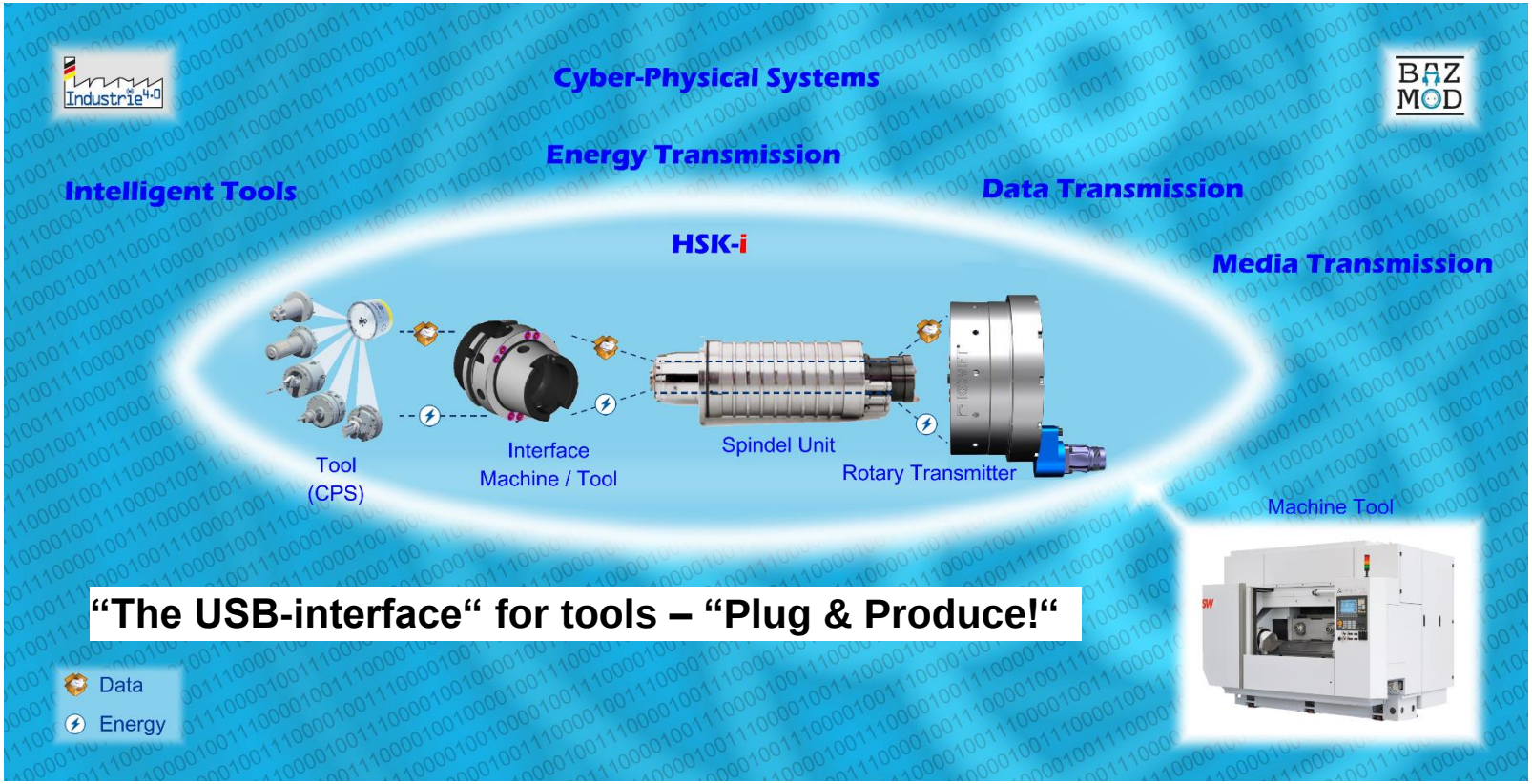
Goal

- Reduce packing times and costs
- Flexible handling of all different variants of the product
- Safe and ecomonic cooperation of humans and robots in an industrial environment



Industry 4.0 – What has been done already?

Standardized Interface Between Tool and Machine for Data and Energy Transfer



Source: BazMod - Bauteilgerechte Maschinenkonfiguration durch Einsatz von CPS (Workpiece conformal machine configuration via CPS)

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Industry 4.0 – How to Tackle it

Big Data – Additional Value Possible?

- **Is data already acquired and stored** because of legal regulations and/or because of customer requirements, for example because of …
  - traceability issues,
  - legal regulations or
  - tool monitoring systems in use?

  If so, it is worth while thinking about that.

- Questions to be asked:

  Which conclusions can be drawn from the data?
  Which analyses are desirable and will create additional value?
  Which data is missing for this purpose and how can that be gathered?

➔ **Look for quick wins** in the field of data / big data ----> Just do it!

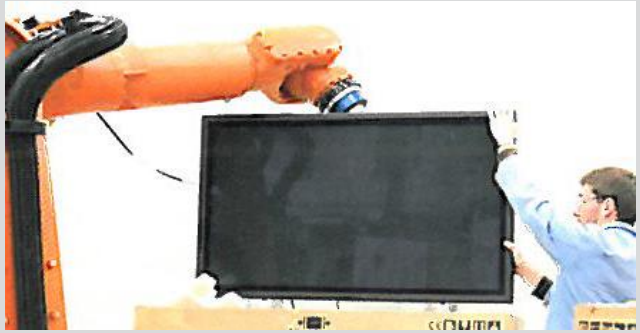
➔ Recommendation: **Workshop / Brainstorming**, if possible in cooperation with academia

Industry 4.0 – How to Tackle it

Shop Floor – Potentials?

- **Is data** from tool monitoring systems available?
  (to draw conclusions on the reduction of inventory / more efficient procurement / other savings?)

- Can one benefit from modern **tools or processes**?
  (tools equipped with data interfaces; Additive Manufacturing)



- **Joint application of machine tools and robots**?
  (exchange of workpieces, deburring, chip removal, …)

- **Support of the workforce by robots?**
  Is it possible to enhance the effectiveness of the workforce using robots or other devices?
  (hybrid workplaces, supply of parts by the robot/ fine manipulation by the human, …)

➔ Make use of **innovative approaches** on the shop floor!

➔ Collaborative Robotics and meaningful work

Source: iwb, TUM, CustomPacker

Industry 4.0 – How to Tackle it

Potentials in Sales, Supply Chain, Customer Service

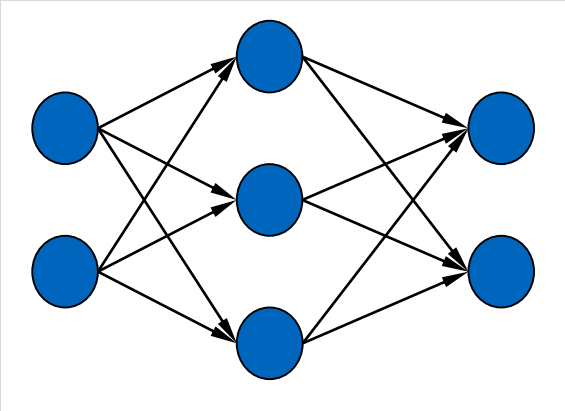
- Monitoring of the **supply chain** via network?
- **KanBan via network**
  (suppliers have access to inventory; releasing of purchase orders solely based on inventory, …)
- **Data entry by the customer**
  (example: Gleason Remote-Order-Entry)
- Opportunities for **new business models**?
  (in particular in the B2C-relationship)
- **Every PC is Industry-4.0-compatible**
  (a PC is a CPS or CPPS just by itself)

➔ Make use of approaches in indirect areas of the enterprise!

Industry 4.0 – How to Tackle it

Other Unused Potentials

- Use the **ERP-System** as much as possible for the **paperless** processing of sales orders and purchase orders!
- **Avoid** the **repeated generation** of geometric data!
- Use **mobile connected devices** for the workforce!
- Explore possibilities of **AI / EA / ANN** applications!



They are promising wherever
- repetitive tasks are executed
- decision making is required based on knowledge or models of a process
- an exhaustive calculation is too time consuming or simply not possible

➔ Workshops/Brainstorming is the right thing to do first.

➔ Academia is a good partner to go with.

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Industry 4.0 - The Summary

- **Industry 4.0** stands for the vision of a fully interconnected production system.

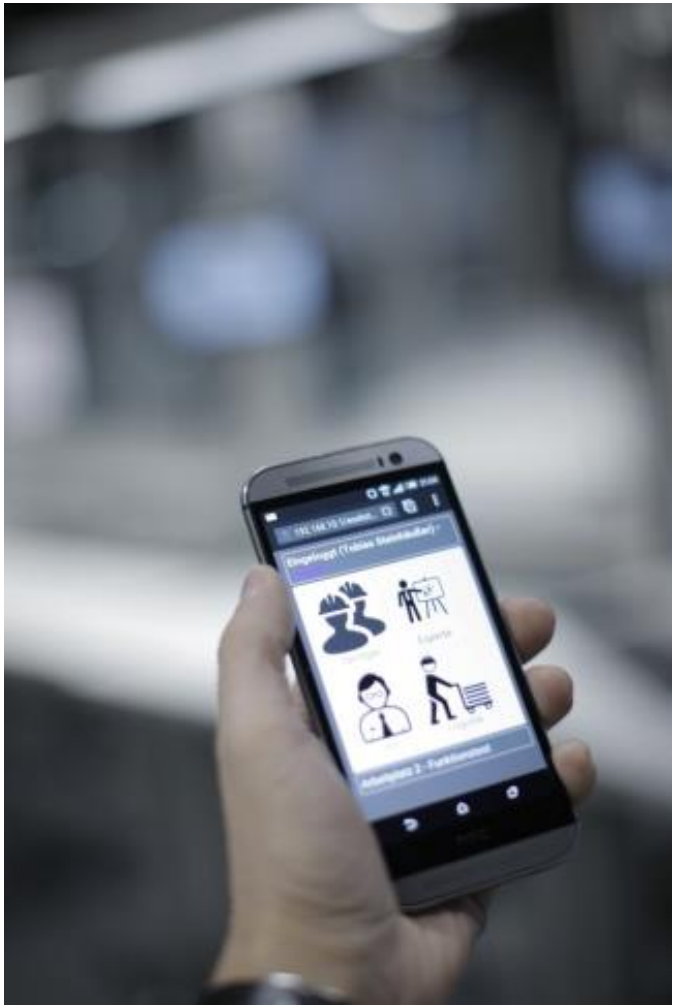
- **Objectives are** (among others):
  - Increased flexibility (lot size 1)
  - Increased productivity
  - Reduced time to market

- **Industry 4.0 is not a job killer, it is a job creator**, because it does improve the competitiveness of enterprises, which use it wisely.

- **Industry 4.0 is not a revolution**. Everyone still has the chance to come aboard.

- Everything has to be developed and earned. **There is very little that can be purchased off the shelf.**

- **Germany** has strong funding system on many levels: province, federal government and European Union with all levels integrated with the needs of industry.



The machine tool of the future

… will look pretty much the same as today, …

Sources: EMCO, iwb/Heller , KUKA, Mikromat

The machine tool of the future

… will look pretty much the same as today, …

… it will just have much better inner values.

Sources: EMCO, iwb/Heller , KUKA, Mikromat

Industry 4.0 Made Tangible – Tangible Things Within Industry 4.0

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