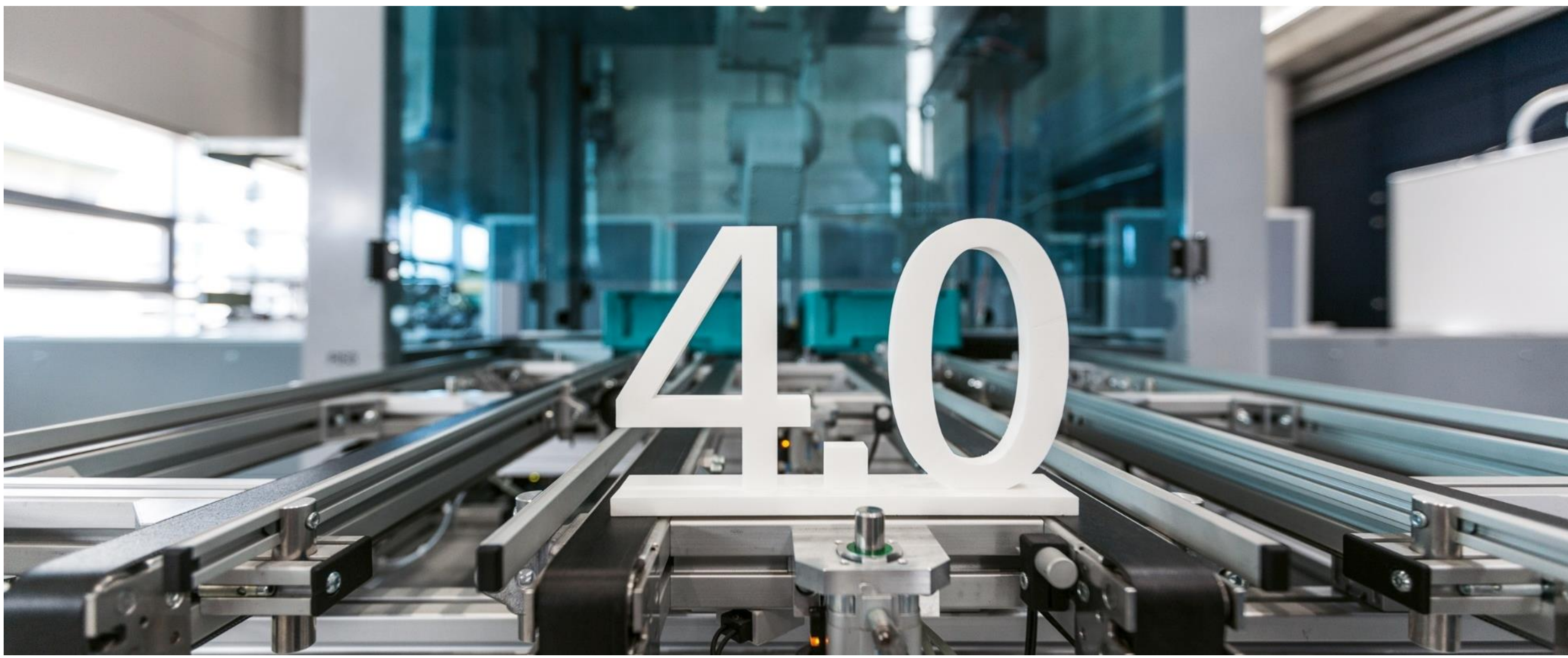
INDUSTRIE 4.0
OPTIMIZATION OF VALUE-ADDING

Prof. Dr.-Ing. Thomas Bauernhansl

September 27th, 2016



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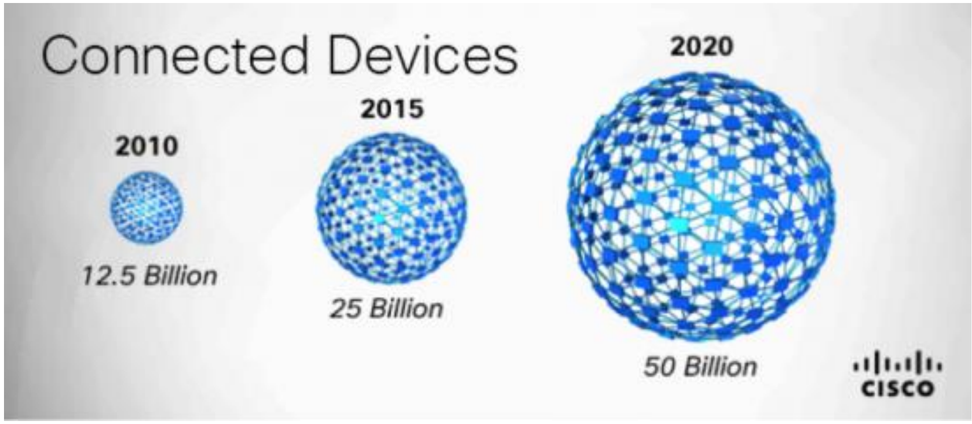
The Digital World of Today and Tomorrow
Internet of Everything

Access-Economy – Holistic global integration as base for new business ecosystems

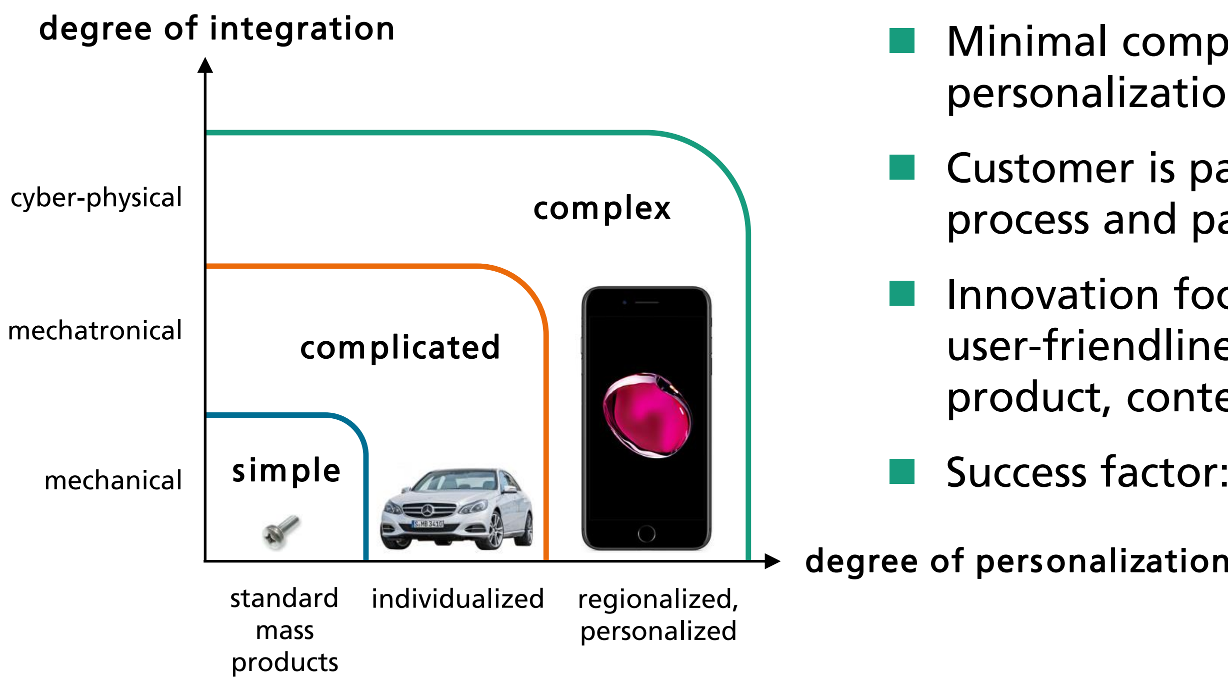
- More than 3 billion people used the internet in 2015.
- 25 billion things were connected in 2015 via internet.
  In 2020 the number is expected to rise up to 50 billion.
- Internet services are uncounted.
  Example: Apple Apple store: > 1 million apps were downloaded more than 75 billion times
- New economic activities arise:
  - Shared economy
  - Prosumer
  - Industrie 4.0
  - …



source: The Internet of Things, MIT Technology Review, statista, cisco

Change of Product Architecture

The ability to manage complexity effectively becomes a key competitive advantage



- Minimal complexity, maximum personalization and economies of scale
- Customer is part of the personalization process and pays for it
- Innovation focus: ecosystem, user-friendliness, minimum viable product, context sensitiveness
- Success factor: openness

sources: Wildemann, H.: Wachstumsorientiertes Kundenbeziehungsmanagement statt König-Kunde-Prinzip; Seemann, T.: Einfach produktiver werden – complexity im Unternehmen senken; Bildquellen: apple.de

Vertical Integration

Core elements of the Fourth Industrial Revolution

Infrastructure (physical, digital)

Cyber-physical System

Product Life Cycle (valuable = personalized + sustainable)

Interaction

Physical Systems (act, sense, communication) | **Human Beings** (decide, create, communicate)

Reflection

Digital Shadow (Real time model of everything)

Transaction

Software Service (Machine skills, Apps for humans, Platform services)

Interoperation

Cloud based Platforms (private, community, public)

Prescription

Analytics (Big Data/machine learning)

Communication

Internet of Everything (human beings, services, things)

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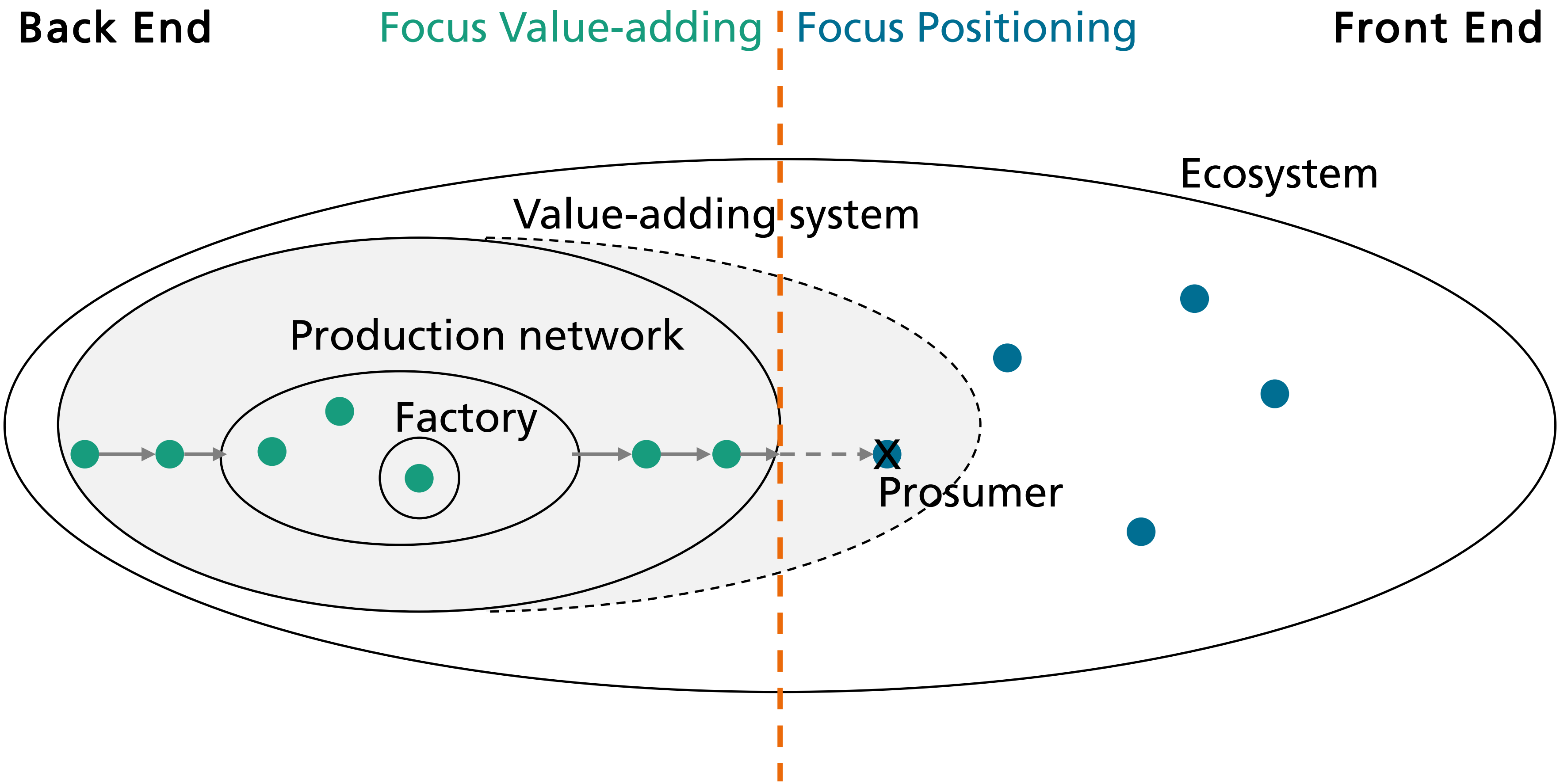
Horizontal Integration

From B2B and B2C to Business to User (B2U)



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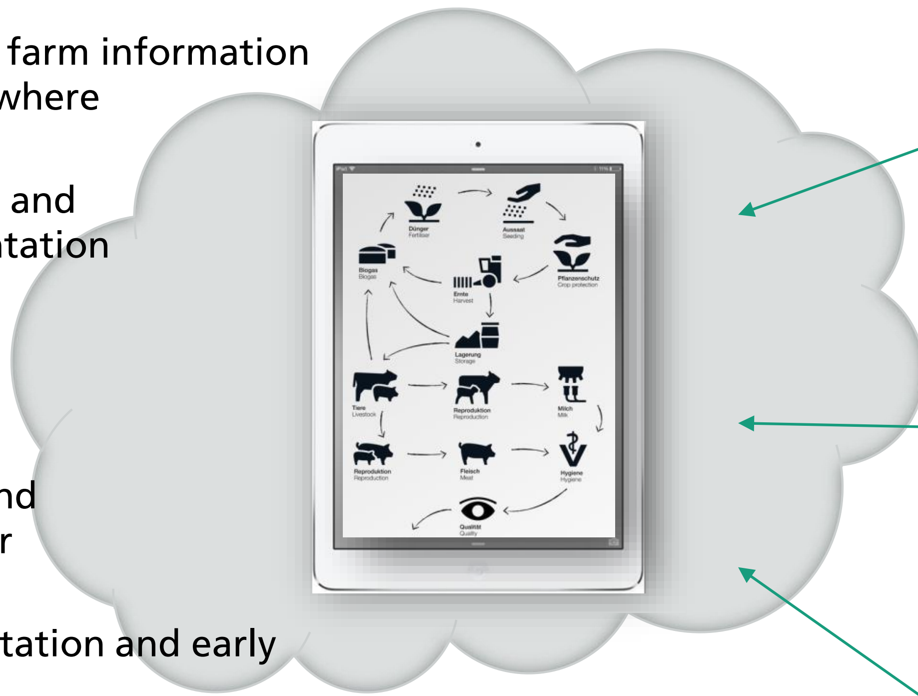
Business Ecosystems

»Farmnet 365« – an agricultural machinery initiative

365FarmNet

- **Online Tracking**
  Real time access to farm information any time from anywhere
- **Traceability**
  Digital, automated and complete documentation
- **Transparency**
  Integration of all farm processes
- **Efficiency**
  Decision support and knowledge transfer
- **Quality**
  Tracking, documentation and early warnings
- **Analytics**
  Prediction, Big Data processing



Machines

...

Equipment

...

Content

...

source: farmnet

The Base: Processing Power and Connectivity

Moore and Metcalfe are right and define the scope and value of an enterprise

Connectivity

Metcalfe:

»The benefit of a communication system increases with the square of the number of participants.«

Performance

Moore:

»Computer performance doubles every 18 months.«

Ecosystems for Smart Business Models

Transparency

- cyber-physical systems
- Internet of Things and Services
- real time & at run time
- everything as a service

Knowledge

sources of pictures: wikipedia.de, ibm.com, abcnews.com

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10 Design Rules for Optimization of Value-Adding

10 Guidelines for the Value-Adding System of the Future

How Industrie 4.0 will change automotive production

- **Guideline 1: Merge production- and logistic system into one value-adding system**
  Production and logistics systems act as integrated entity for reaching the enterprise goals.
- **Guideline 2: Dissolve line and tact depending on product variety and work flow complexity**
  Granularity of structures and processes is adapted to the complexity of the product programs and frame conditions.
- **Guideline 3: Set-up processes and structures mobile and scalable**
  Value-adding structures can be re-designed dynamically and economically when needed.
- **Guideline 4: Design intelligent systems**
  Self-regulated subsystems contribute with their self-healing abilities to an entire robust system.
- **Guideline 5: Make support processes value-adding**
  All support process (i.e. logistics) are either transformed into adding-value support processes or eliminated.
- **Guideline 6: Replace material flow with information flow**
  Information is used effectively to reduce waste and stock and to support a downstream customization.
- **Guideline 7: Shift process complexity to where it can be handled most efficiently**
  The value-adding systems' boundaries are flexible, integrating customers and supplier as value-add partners in the value-adding system.
- **Guideline 8: Represent system elements and processes continuously in a digital shadow**
  Accurate prediction and evaluation of upcoming events is made possible.
- **Guideline 9: Optimize production based on data science**
  In complex systems correlation is more important than causality.
- **Guideline 10: Focus the human role on design and optimization**
  Humans use their skills to enhance the value-adding and thus optimize the total system.

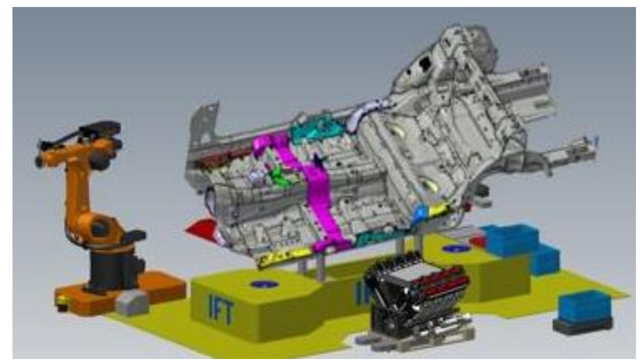
Guideline 1: Merge Production and Logistic System into one Value-adding System

Production and logistics systems act as integrated entity for reaching the enterprise goals.

Fixed production today

- decoupled optimization of production and logistics
- competing target systems
- optimization of production results in higher complexity and higher costs in the logistics
- Separated production and logistics functions to ensure transparency

Changeable production tomorrow



- global optimum instead of individual optimization
- Transparency by self-descriptive systems
- No separation of productive and logistics areas
- Changeable productive and logistics structures

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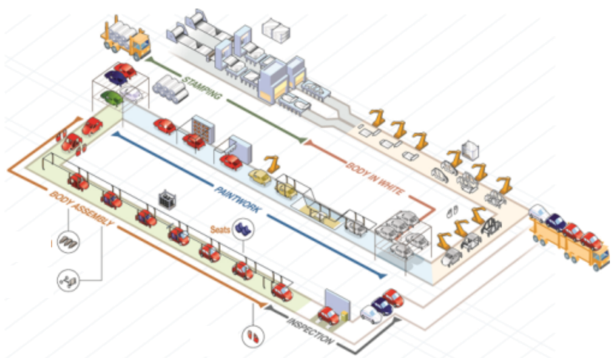
Guideline 2: Dissolve Line and Cycle-time depending on Product Variety and Work Flow Complexity

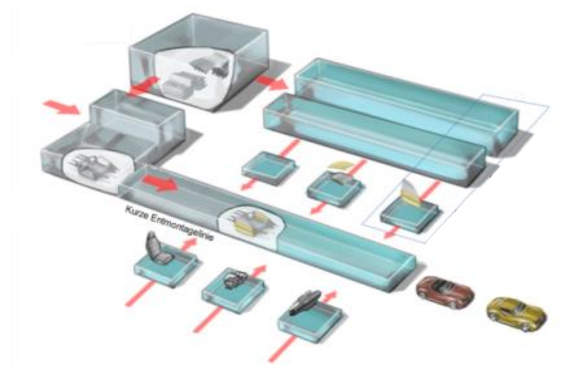
Granularity of structures and processes is adapted to the complexity of the product programs and frame conditions.

Fixed production today



- fixed chain of singular plant technology
- strict organizational split of section, lines and line sections
- fixed line balance
- fixed just in time sequence
- high efforts in control
- low possibility to adapt during product life cycle
- changes interrupt the whole production

Changeable production tomorrow



- universal process modules
- interconnection of modules adapted to the situation
- system-inherent routing flexibility
- self-similar systems-of-systems architectures
- dynamic reconfiguration subsystems
- no separation of body, paintwork, interior assembly
- no dissection of the overall organization

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All Objects in a Factory will be Mobile to a Large Extend

Example: swarm intelligence for logistics

source: Fraunhofer IML, Prof. Dr. Michael ten Hompel

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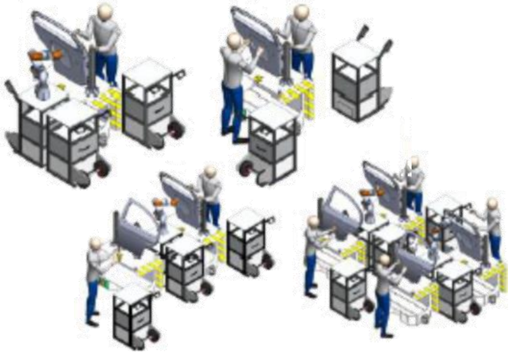
Guideline 3: Set-up Processes and Structures Mobile and Scalable

Value-adding structures can be re-designed dynamically and economically when needed.

Fixed production today

- fixed allocation of products to resources and to production tasks
- fixed layout
- safety fences between humans and machines
- fixed and investment-intensive automation
- resources dedicated to one specific operation

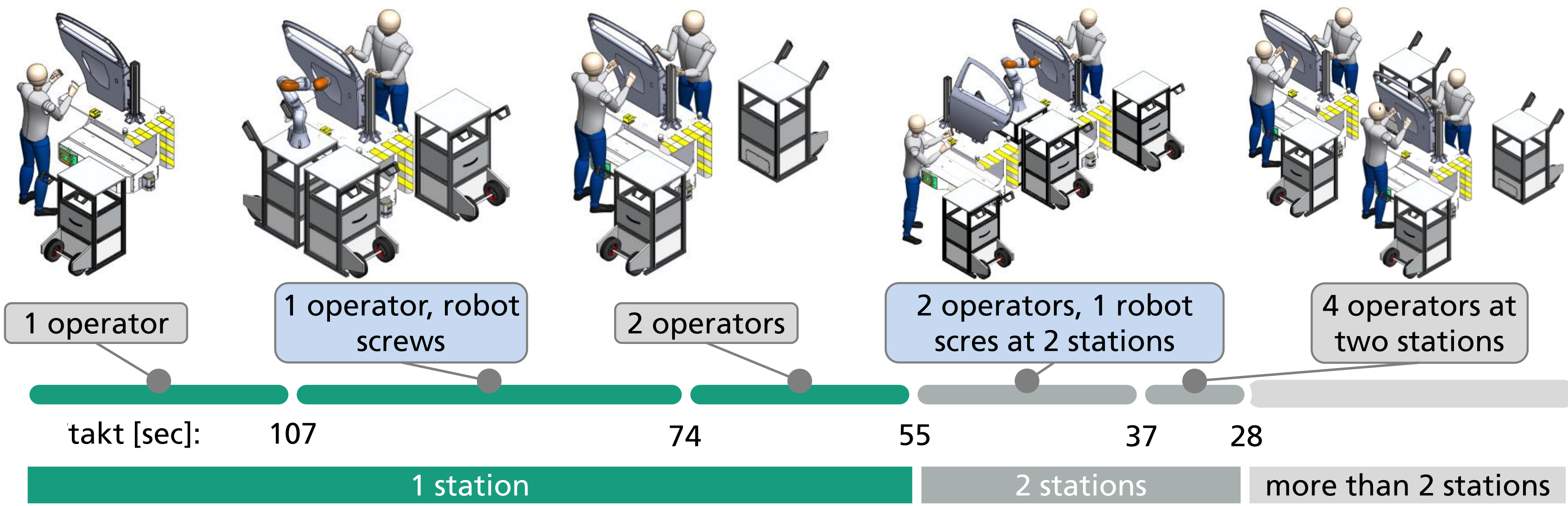
Changeable production tomorrow



- individual coordination of sequence and operation
- scalable automation
- human-robot-cooperation
- scaling and flow-orientation layout-adaption to daily production schedule
- system adaption according to availability of resources

Output-oriented Configuration of Process Modules

Example: Assembly of a door module with HRC in ARENA2036



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Guideline 4: Design Intelligent Systems

Self-regulated subsystems contribute with their self-healing abilities to an entire robust system.

Fixed production today

- centralized planning, controlling and optimization
- incorrect master data
- selective operating data recording
- manual commissioning, programming and optimization
- uncertain planning data
- planning based on experience

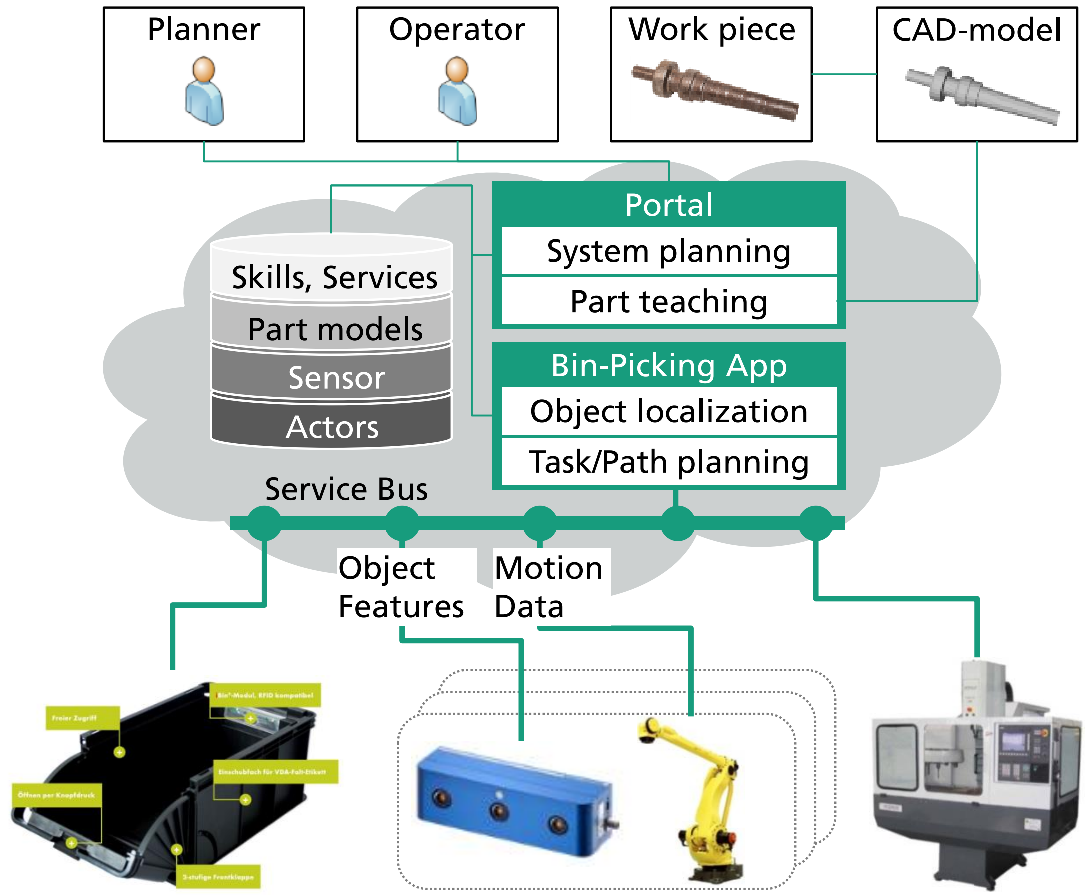
Changeable production tomorrow

- intelligence shifted to decentralized entities
- plug-and-produce of system-elements into systems of higher complexity
- self-description of CPS: always up-to-date information base
- cloud-based self-control
- changeable functional range of system elements
- virtual commissioning
- automated, self-optimizing operation planning

Cyber-physical Production Systems
Example: Bin-picking as a cloud services

Advantage

- externalization of skills, services, maintenance
- lean robot workcell (»Lean Client«)
- centralized collection of data
  - optimization by statistical learning
- best practice solutions accessible
- displayed at HMI 2015



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Guideline 5: Make Support Processes Value-adding

All support process (i.e. logistics) are either transformed into value-adding support processes or eliminated.

Fixed production today

- fix installation of massive material flow systems
- complex supply chain network
- long-lasting planning horizon (forecast)
- high safety stock level
- material staging area is the bottleneck
- low time-share of value-add activities in total throughput time

Changeable production tomorrow

- innovative parallelization of assembly and logistics
- flexibility enabled by flexible material staging
- no material areas in production
- commissioning on tour
- assembly on AGV
- »best-fit« to avoid adjusting processes

Robots will be Mobile, Flexible and Safe

Example: SEW Eurodrive – freely navigating DTS (carries the robot for bin picking)

source: IPA

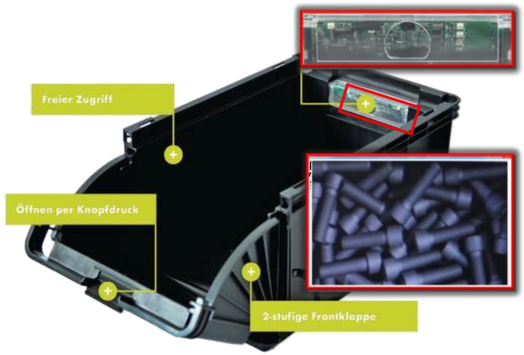
Guideline 6: Replace Material Flow with Information Flow

Information is used effectively to reduce waste and stock and to support a downstream customization.

Fixed production today

- information is inflexibly linked to material flow
- lagged information flows
- information Overflow
- high level of buffer inventories to cope with insufficiencies

Changeable production tomorrow



- real-time information access
- information flow adapted to actual needs
- intelligent integration of information
- simulation based on real time data
- product differentiation through software variants

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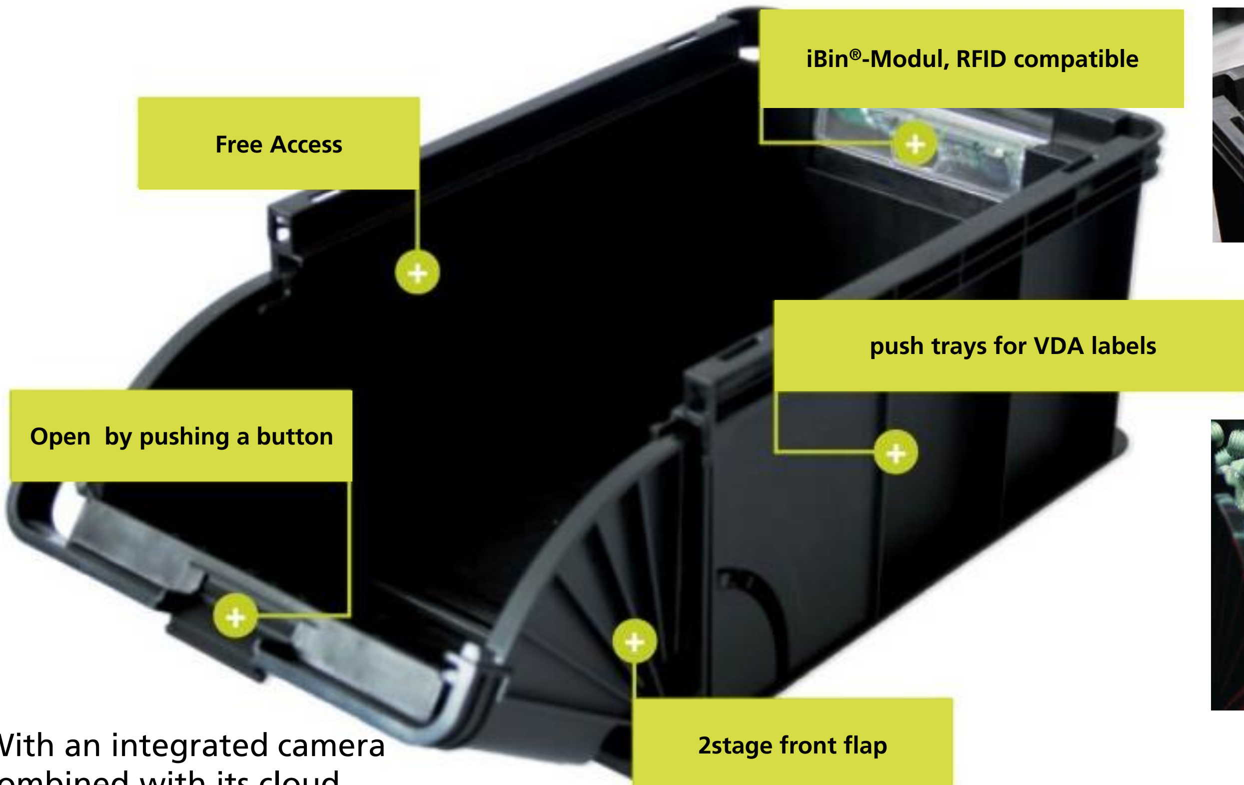
All Objects in a Factory will be Smart

iBin – Intelligent bins order their filling autonomously



With an integrated camera combined with its cloud, iBin counts the parts enclosed in it.

source: Fraunhofer IML, Prof. Dr. Michael ten Hompel

Guideline 7: Shift Process Complexity to Where it can be Handled Most Efficiently

The value-adding systems' boundaries are flexible, integrating customers and supplier as value-add partners in the value-adding system.

Fixed production today

- pre-defined products with plenty variants
- complexity of business processes and production must mainly be handled by OEM
- market risks and coordination efforts at introduction of new product designs
- system integration limited to core partners, due to cost and efforts
- many interfaces, partly standardized
- big networks of many small JIS-plants

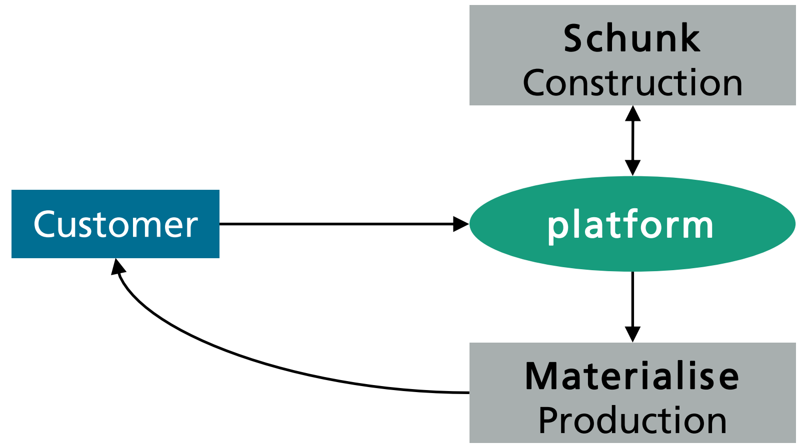
Changeable production tomorrow

- active complexity management
- ad hoc configuration of value chains (MaaS)
- complexity of individualization managed by the customer as »Pro-Sumer«
- Open Source, Open Innovation and Co-Creation
- integration of additive manufacturing
- Everything as a service
- Just in Realtime (JIR) delivery

Business Model Innovation
Example Schunk eGRIP

Since 2015 suitable grippers can be ordered at Schunk, based on the CAD-Files of the parts that are transported.

- Reduction of order time and guarantee of high benefit for customers through integration of customers in the development process
- Communication via online-platform
- The partner company Materialise takes over the 3D print



source: Schunk GmbH; Materialise]

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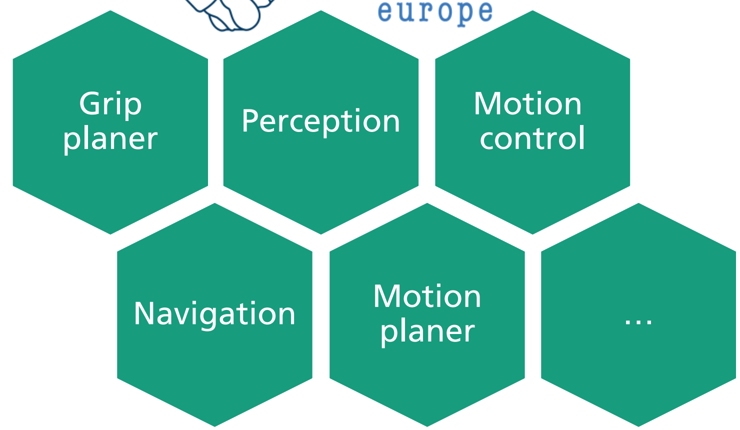
Open Source Communities as Enabler
Example: ROS for Industrial Robotics

Why Open Source?

- more than two million free open source software packages (FOSS) available
- robotics research available as bundled software components brings technology push
- increase of critical mass, quality, transferability etc.
- supports business models, especially for SME
- »rapid prototyping« of technologies
- cost advantage 33 % compared to new development[1]

Example: ROS industrial consortium europe

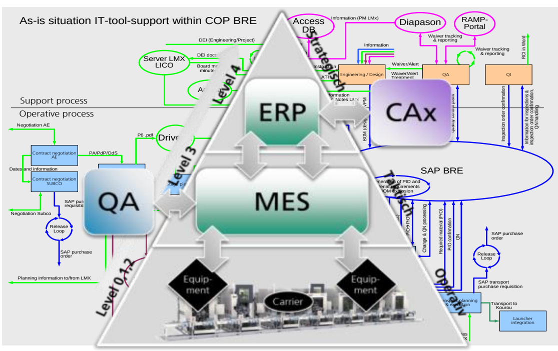


source: [1]N. Blümlein: Function-based System Engineering for Service Robot Prototypes (Diss Uni Stuttgart, 2013); [2]2014 Black Duck Software, Inc

Guideline 8: Represent System Elements and Processes Continuously in a Digital Shadow

Accurate prediction and evaluation of upcoming events is made possible.

Fixed production today



- unidirectional information flow from planning to »physical« operation level
- production planning and control as sequential processes
- inconsistent and incorrect data
- simulation with historic data
- high effort of planning in different planning phases

Changeable production tomorrow

- real-time system model for value adding
- automated maintaining of master and dynamic data
- localization, supervision and forecast based on live data
- production planning based on real situation
- transparency on current state makes prediction of future easier

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All Entities of a Factory have a Digital Shadow

Example: material-flow-simulation inside a 3D-point cloud of ARENA2036

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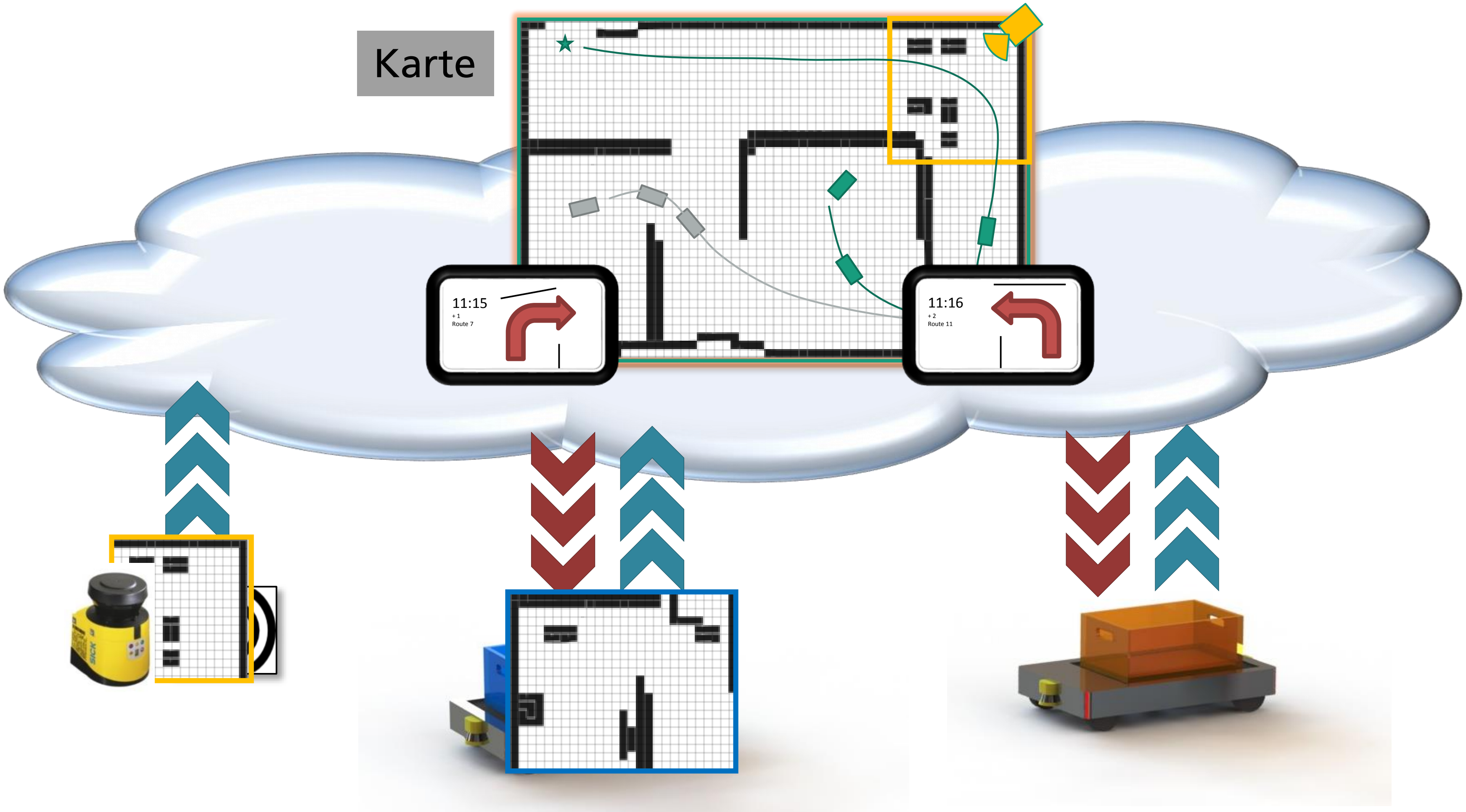
All Entities of a Factory have a Digital Shadow

Example Cloud Navigation



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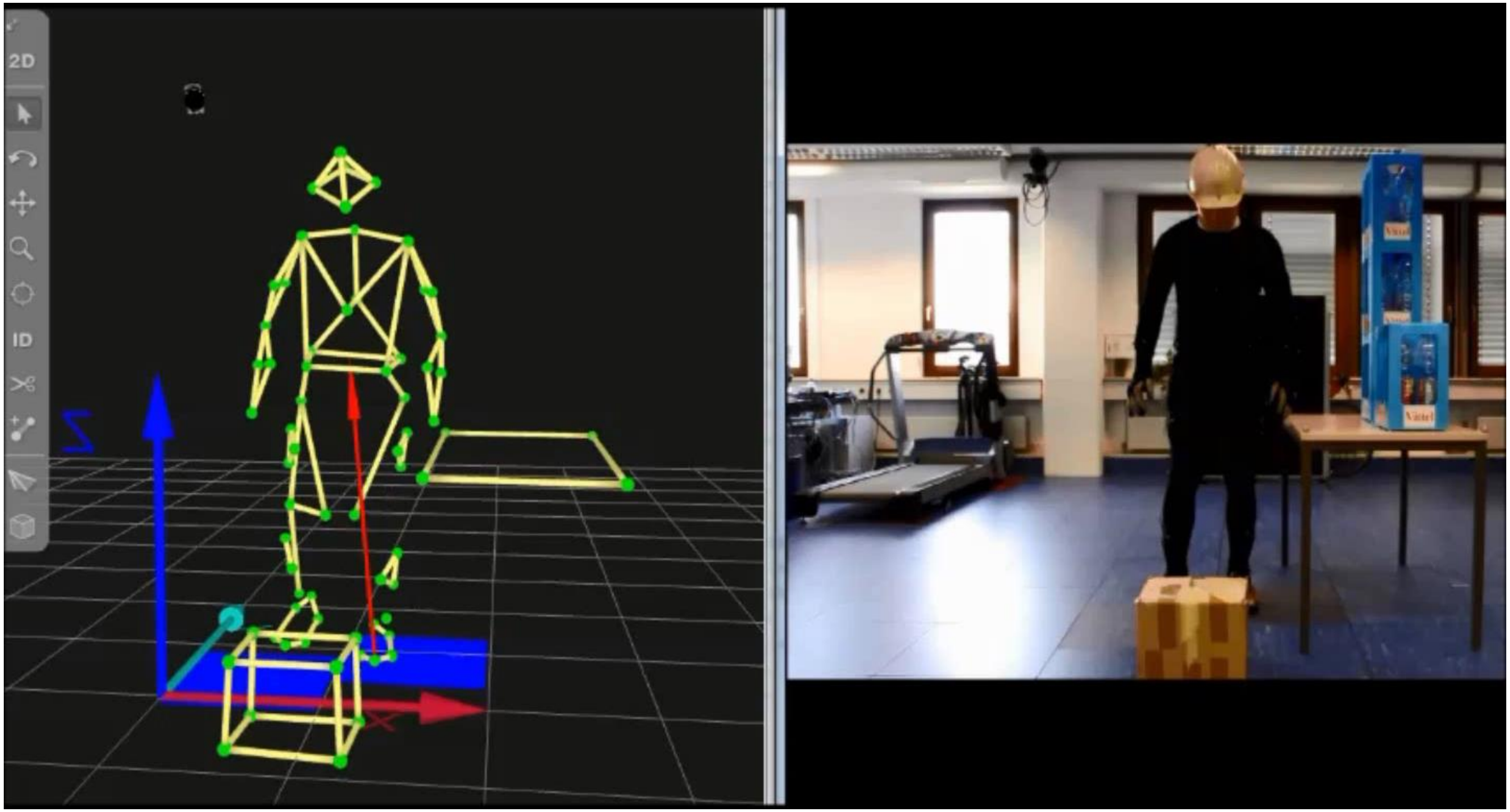
All Entities of a Factory have a Digital Shadow

Example: Motion Capturing for feed-back of real processes into planning models



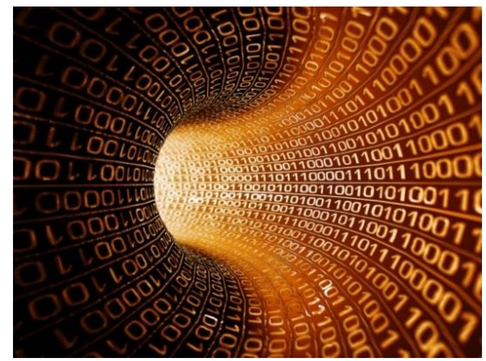
Guideline 9: Optimize Production, Based on Data Science

In complex systems correlation is more important than causality.

Fixed production today

- lean optimization (Six Sigma) of complicated systems
- search for root cause (Causality)
- problem solving by experts
- main question: WHY?

Changeable production tomorrow



- utilization of structured and un-structured data
- analytics with Big Data algorithms
- automated pattern recognition
- search for recipes (Correlation)
- main question: WHAT?

Automated Detection of Dependencies

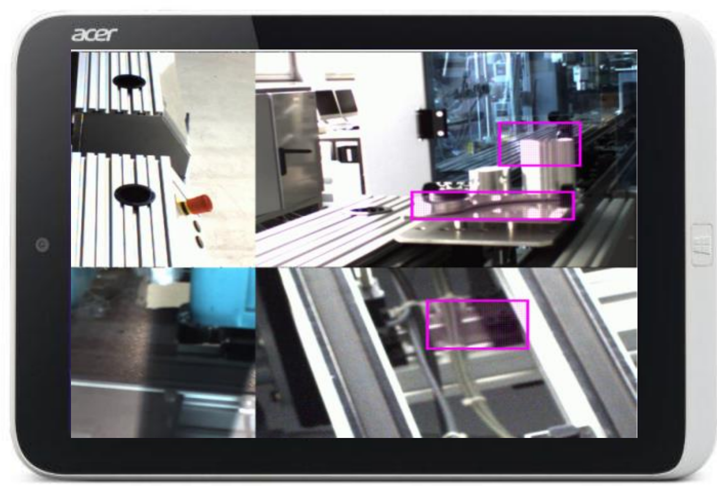
Between processes and deriving optimization potential

Through

- “minimally invasive“ process monitoring via camera without elaborate system integration
- feature-based configuration and recognition of conditions in the videos via adaptive evaluation algorithms

Benefits

- near real-time process analysis with direct assignment of the cause for loss
- detection and quantitative evaluation of potential for process optimization
- permanent transparency through forwarding errors and machine condition to operators and planers



Guideline 10: Focus the Human Role on Design and Optimization

Humans use their skills to enhance the value-adding and thus optimize the total system.

Fixed production today

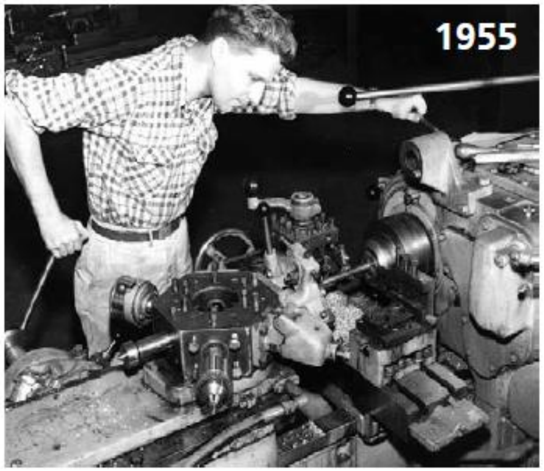
- separation of engineering and operations
- working tact is forced by automated production system
- poor design and optimization autonomy of operators
- routine operations dominating human work

Changeable production tomorrow

- Reverse Taylor: merge engineering and operation
- automation of repetitive and standard work
- human intervenes when deviations occur
- design tasks and coordination are dominating human work

Change in Relationship between Human and Work Environment

Commander



Captain

Conductor

- Tasks of production workers and knowledge workers are merging (Revers Taylor)
- Routine tasks and simple technical and general work are taken over by machines
- New forms of cooperation and communication
- Increase of scope for decision making and dispositive tasks
- New qualification demands: digital competence in all areas

source: Fraunhofer IAO

Business potential of Integrated Industry (Industrie 4.0)

Specialists expect an increase in overall performance between 30 to 50 % in value creation

Estimation of potential benefits

Costs	Effects	Potential
Stock costs	■ Reduction of safety stocks ■ Avoiding Bullwhip and Burbidge effects	**-30 to -40 %**
Manufacturing costs	■ Improving of OEE ■ Process control loops ■ Improvement of vertical and horizontal staff flexibility ■ Use of Smart Wearables	**-10 to -30 %**
Logistic costs	■ Higher level of automation (milk run, picking etc.) ■ Smart Wearables	**-10 to -30 %**
Complexity costs	■ Wider span of supervision ■ Reduced trouble shooting ■ Prosumer model ■ Everything as a Service (XaaS)	**-60 to -70 %**
Quality costs	■ Near-realtime quality control loops	**-10 to -20 %**
Maintenance costs	■ Optimization of stock levels ■ State-oriented maintenance (process data, measurement data) ■ Dynamic priorization	**-20 to -30 %**

Pilot project at Bosch: Restructuring of complete distribution process based on an in-plant logistics center in an Industrie 4.0 project.

supplier

Automotive manufacturer

-10 % milkruns

+10 % produc-tivity

-30 % stock reduction

source: IPA/Bauernhansl, Bosch

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„When the wind of change is blowing,
some people build walls, while others
build windmills.“
(Chinese proverb)

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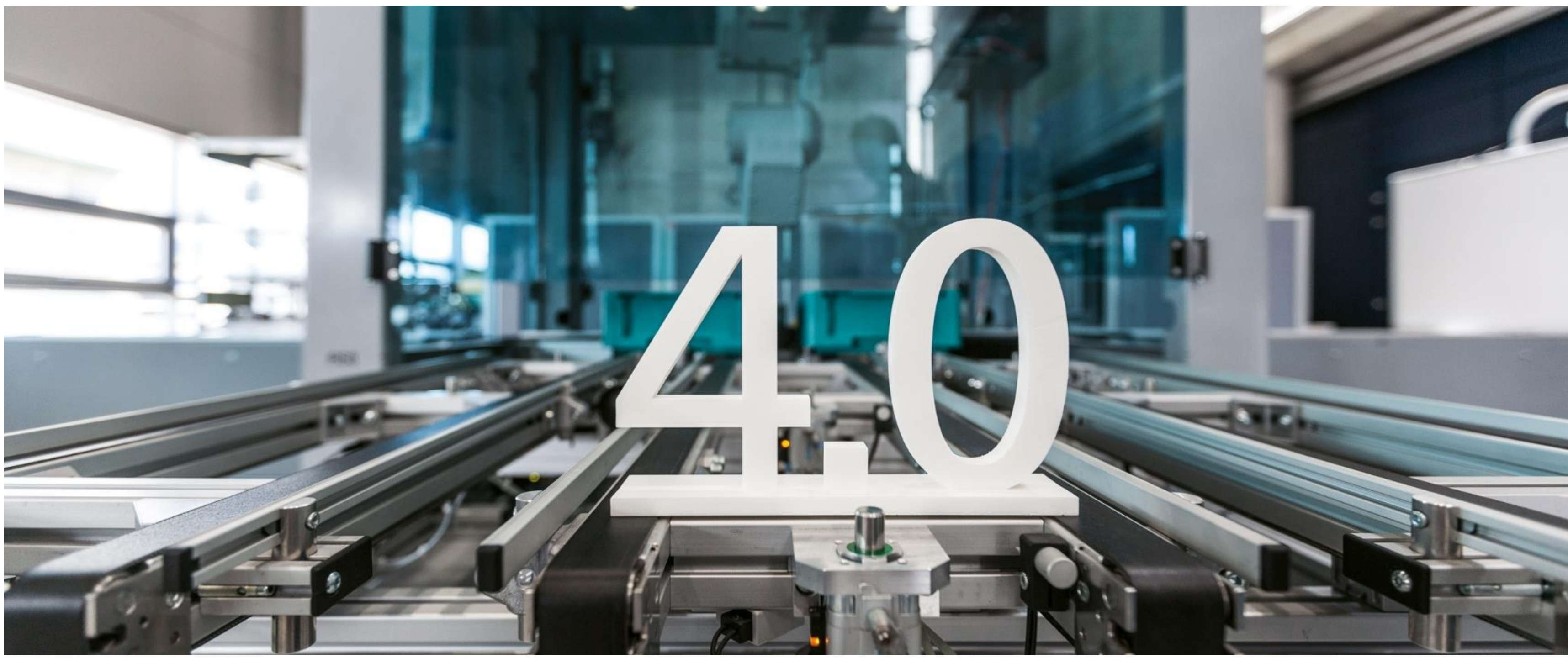

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