2nd Networking Meeting: German-Finnish Technology and University Cooperation
Germany and Finnland – Strong Partnership in Industrial Internet Revolution – The Way Forward?
Symposium at Salon Dahlmann, Berlin, November 11, 2016

Industrie 4.0: Mass Customization in Multiadaptive Smart Factories

Prof. Wolfgang Wahlster
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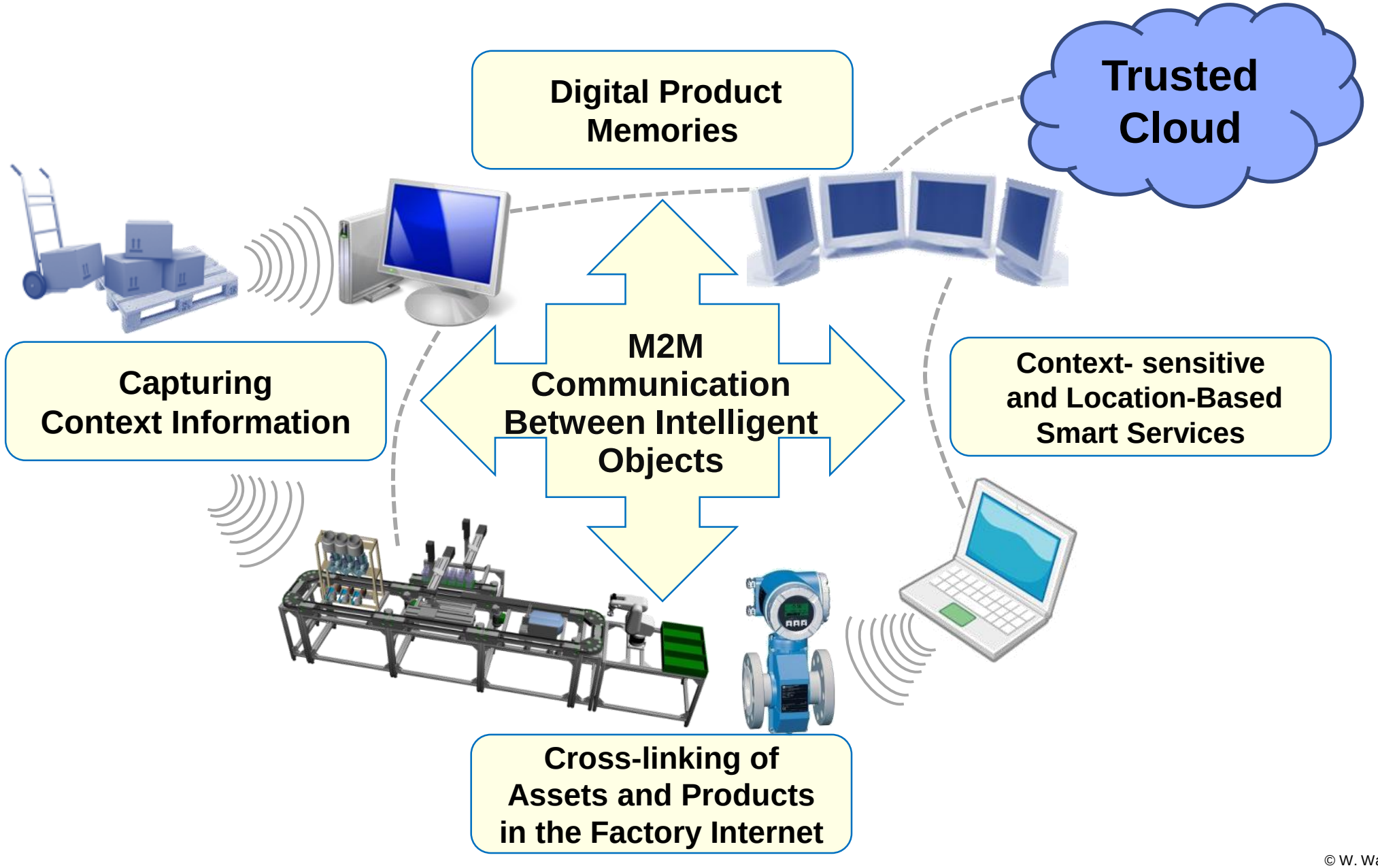
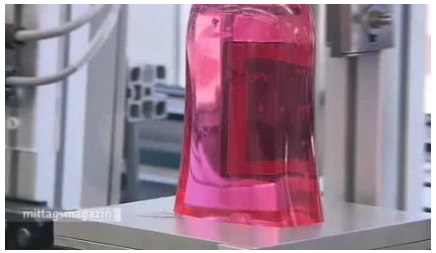
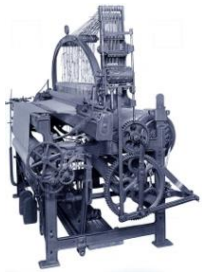
Industrie 4.0: The Internet of Things in the Smart Factory

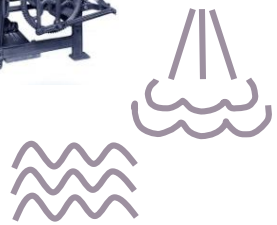


From Industrie 1.0 to Industrie 4.0: Towards the 4th Industrial Revolution

In 2010, the term Industrie 4.0 was coined by this team







First **Mechanical Loom** 1784

1. Industrial Revolution through introduction of mechanical production facilities powered by water and steam

2. Industrial Revolution through introduction of mass production based on the division of labour powered by electrical energy

010001101
001010100
100101010
010010101

3. Industrial Revolution through Introduction of electronics and IT for a further automatization of production

4. Industrial Revolution based on Cyber-Physical Production Systems

Industrie 4.0

Industrie 3.0

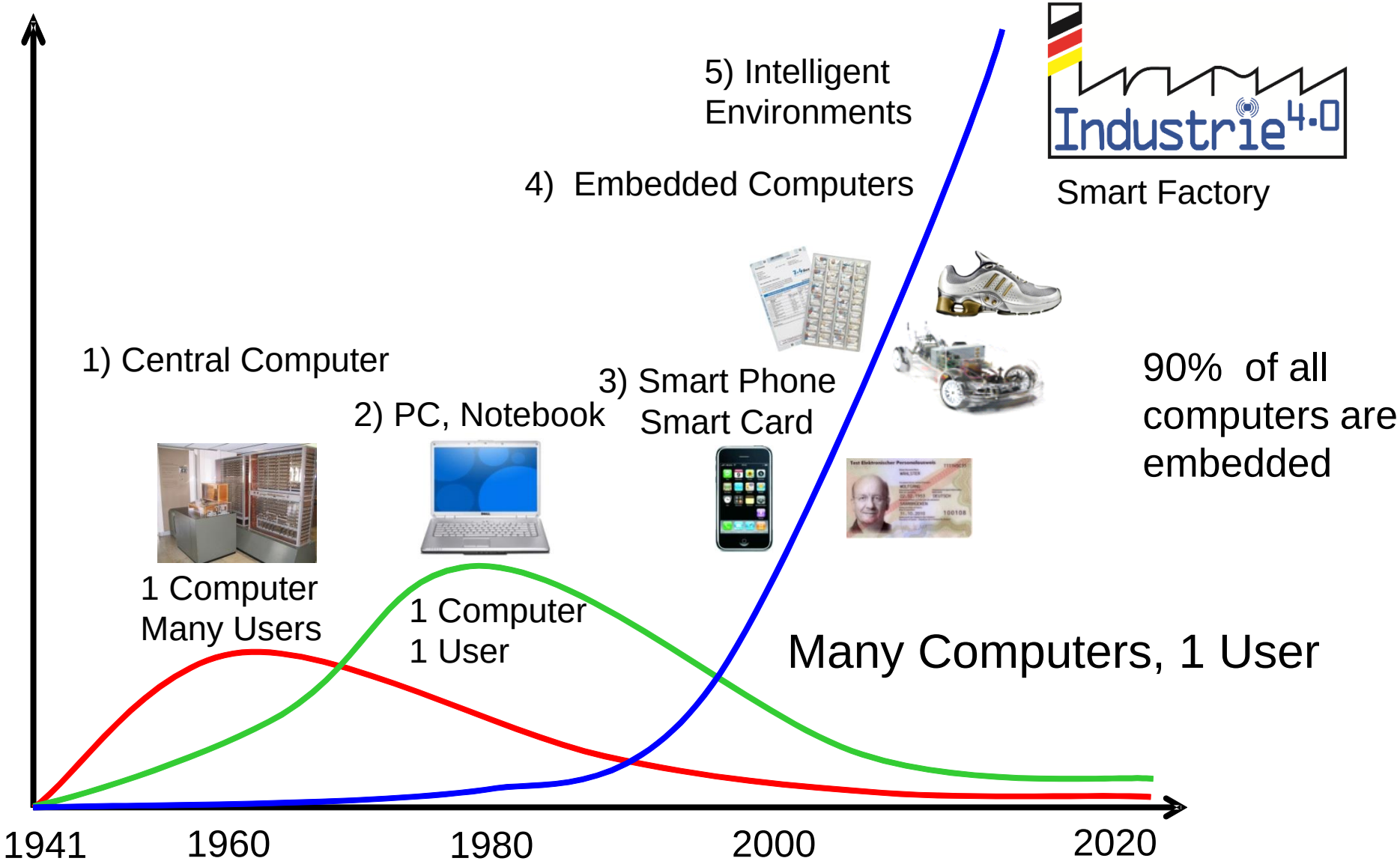
Industrie 2.0

Industrie 1.0

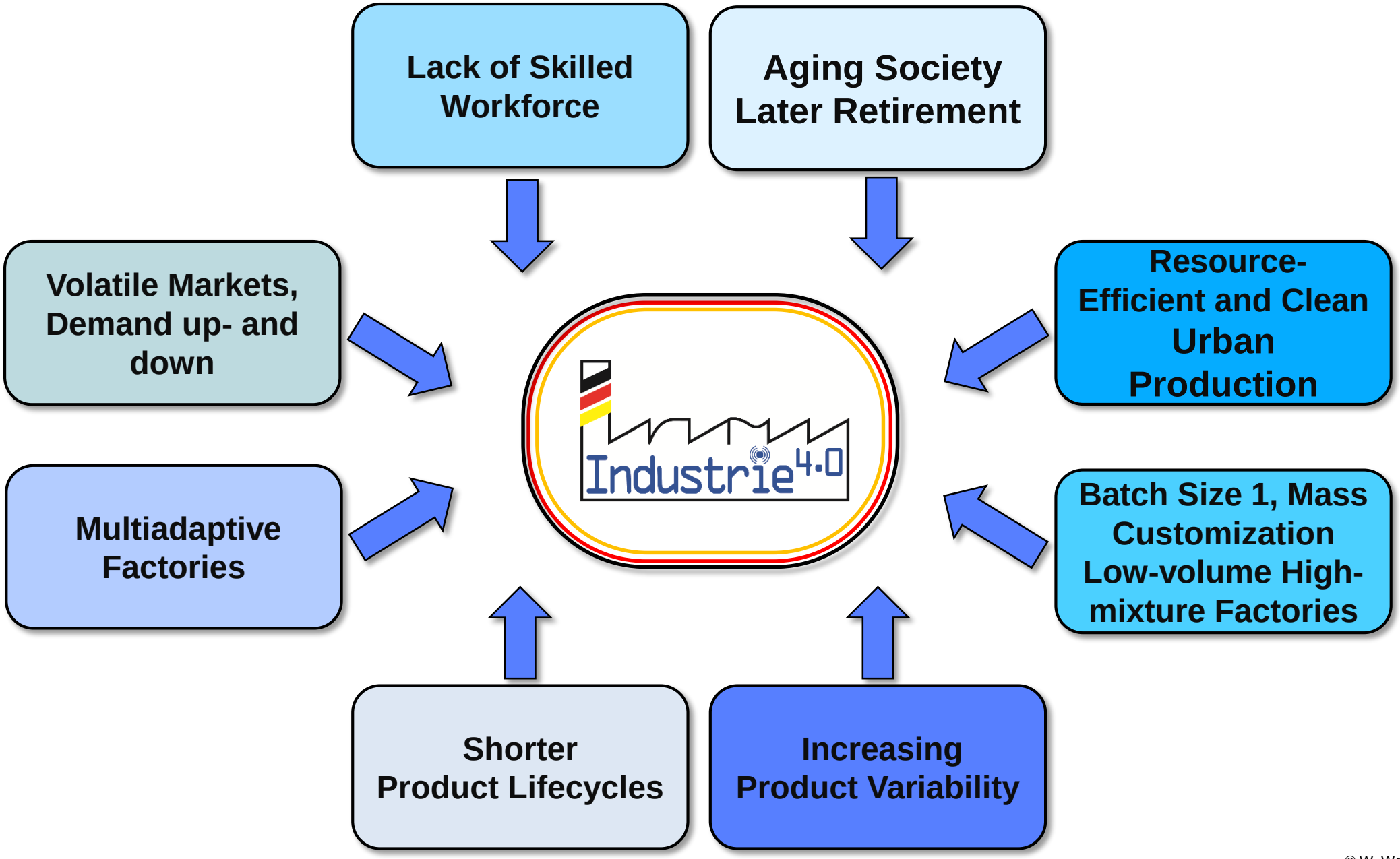
Degree of Complexity

End of 18th Century | **Start of 20th Century** | **Start of 70ies** | **1 April 2011** | t

Towards Intelligent Environments based on the Internet of Things and Services

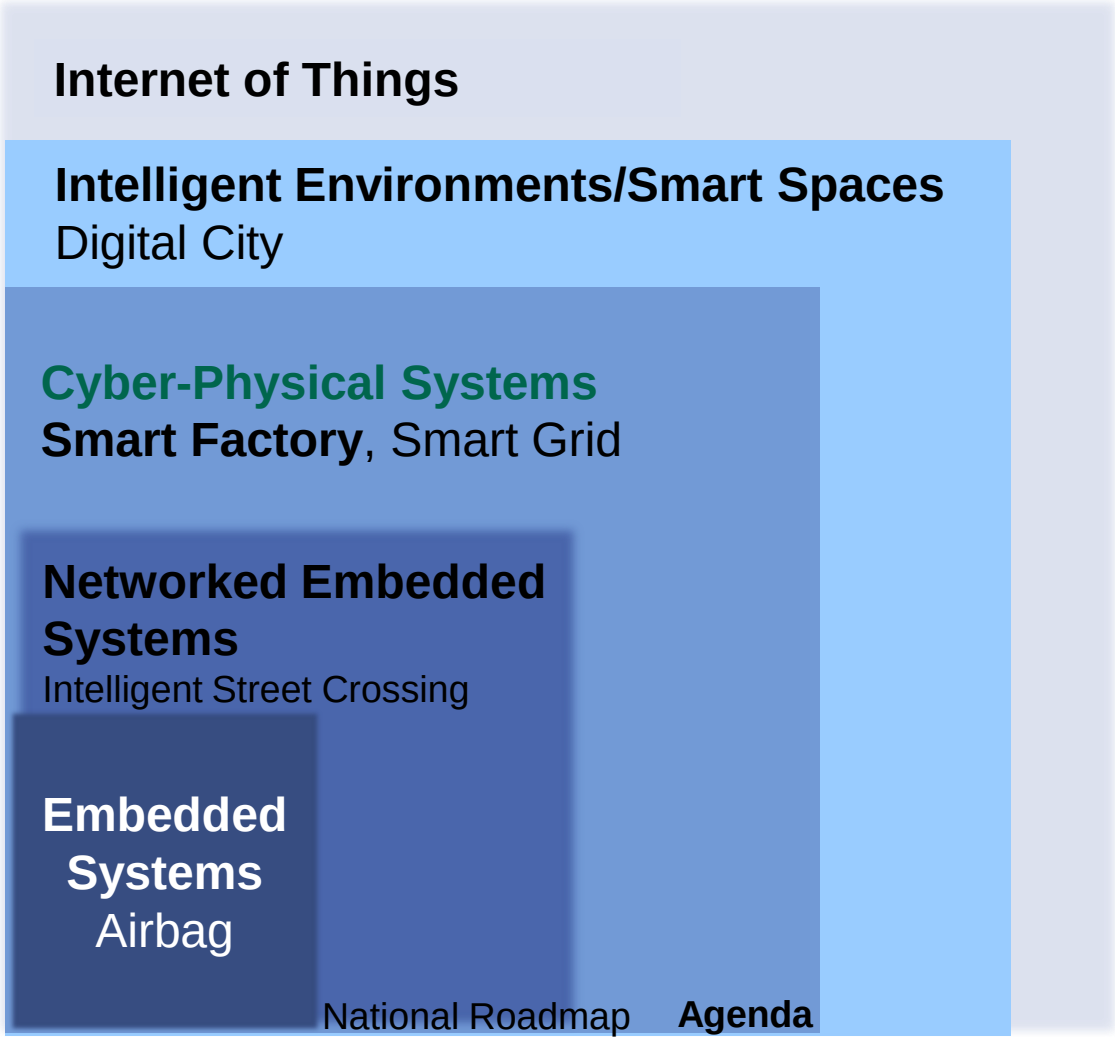


Socio-Economic Drivers of Industrie 4.0

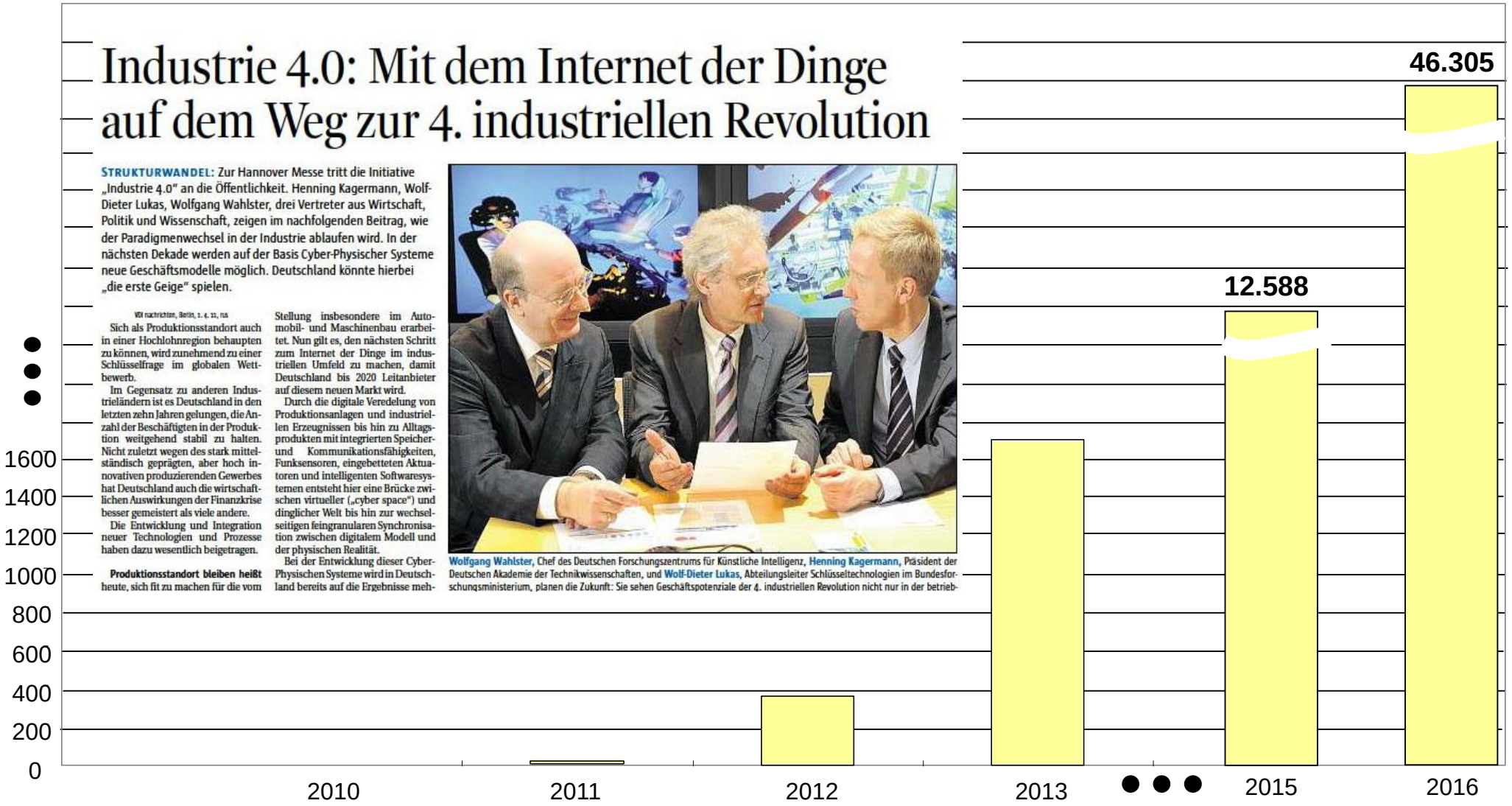


Future Project Industrie 4.0 of German Chancellor Dr. Angela Merkel

Evolution from Embedded Systems to Cyber-Physical Systems



After Our Initial Publication in April 2011 the German Term „Industrie 4.0“ was Propagated Exponentially Worldwide



Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution

STRUKTURWANDEL: Zur Hannover Messe tritt die Initiative „Industrie 4.0“ an die Öffentlichkeit. Henning Kagermann, Wolf-Dieter Lukas, Wolfgang Wahlster, drei Vertreter aus Wirtschaft, Politik und Wissenschaft, zeigen im nachfolgenden Beitrag, wie der Paradigmenwechsel in der Industrie ablaufen wird. In der nächsten Dekade werden auf der Basis Cyber-Physischer Systeme neue Geschäftsmodelle möglich. Deutschland könnte hierbei „die erste Geige“ spielen.

VDI nachrichten, Berlin, 1. 4. 11, rsa

Sich als Produktionsstandort auch in einer Hochlohnregion behaupten zu können, wird zunehmend zu einer Schlüsselfrage im globalen Wettbewerb.

Im Gegensatz zu anderen Industrieländern ist es Deutschland in den letzten zehn Jahren gelungen, die Anzahl der Beschäftigten in der Produktion weitgehend stabil zu halten. Nicht zuletzt wegen des stark mittelständisch geprägten, aber hoch innovativen produzierenden Gewerbes hat Deutschland auch die wirtschaftlichen Auswirkungen der Finanzkrise besser gemeistert als viele andere.

Die Entwicklung und Integration neuer Technologien und Prozesse haben dazu wesentlich beigetragen.

Produktionsstandort bleiben heißt heute, sich fit zu machen für die vom Stellung insbesondere im Automobil- und Maschinenbau erarbeitet. Nun gilt es, den nächsten Schritt zum Internet der Dinge im industriellen Umfeld zu machen, damit Deutschland bis 2020 Leitanbieter auf diesem neuen Markt wird.

Durch die digitale Veredelung von Produktionsanlagen und industriellen Erzeugnissen bis hin zu Alltagsprodukten mit integrierten Speicher- und Kommunikationsfähigkeiten, Funksensoren, eingebetteten Aktuatoren und intelligenten Softwaresystemen entsteht hier eine Brücke zwischen virtueller („cyber space“) und dinglicher Welt bis hin zur wechselseitigen feingranularen Synchronisation zwischen digitalem Modell und der physischen Realität.

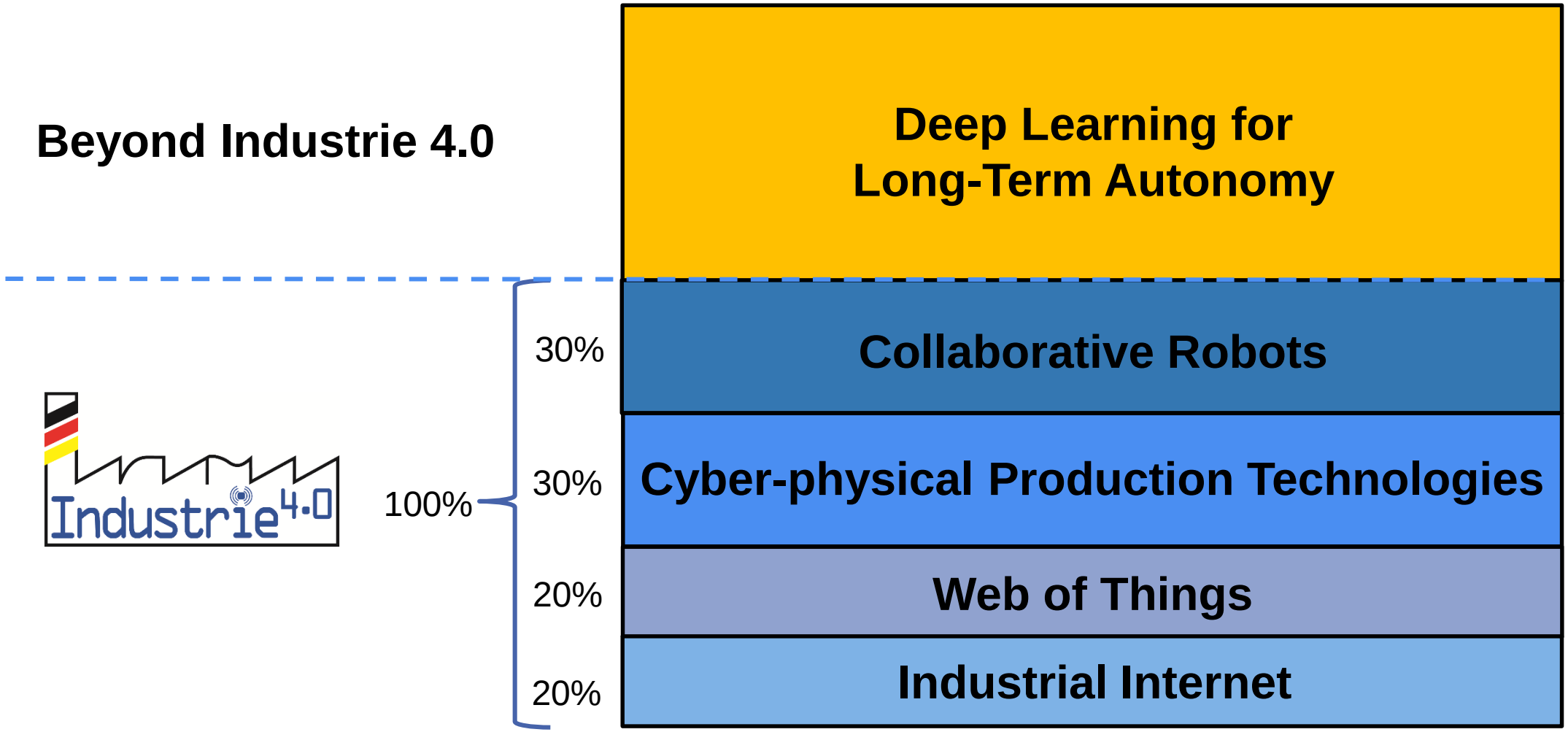
Bei der Entwicklung dieser Cyber-Physischen Systeme wird in Deutschland bereits auf die Ergebnisse meh-

Wolfgang Wahlster, Chef des Deutschen Forschungszentrums für Künstliche Intelligenz, **Henning Kagermann**, Präsident der Deutschen Akademie der Technikwissenschaften, und **Wolf-Dieter Lukas**, Abteilungsleiter Schlüsseltechnologien im Bundesforschungsministerium, planen die Zukunft: Sie sehen Geschäftspotenziale der 4. industriellen Revolution nicht nur in der betrieb-

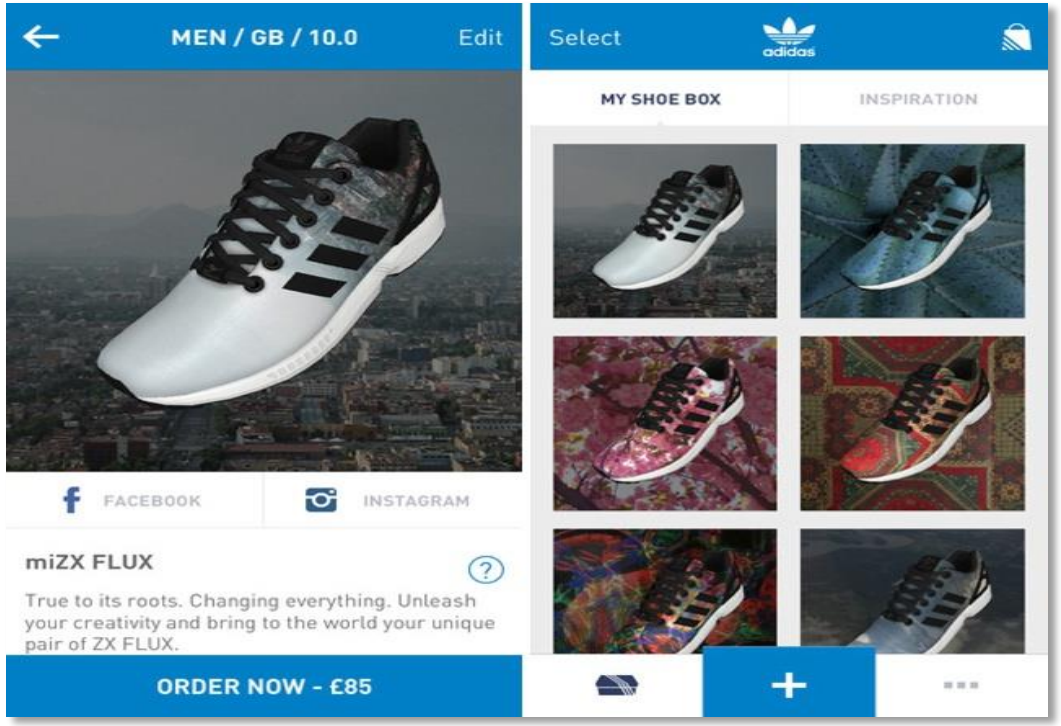
According to GENIOS Data Base of Publications in Germany

Industrie 4.0: The Fourth Industrial Revolution

Beyond Industrie 4.0: Long-term Autonomy



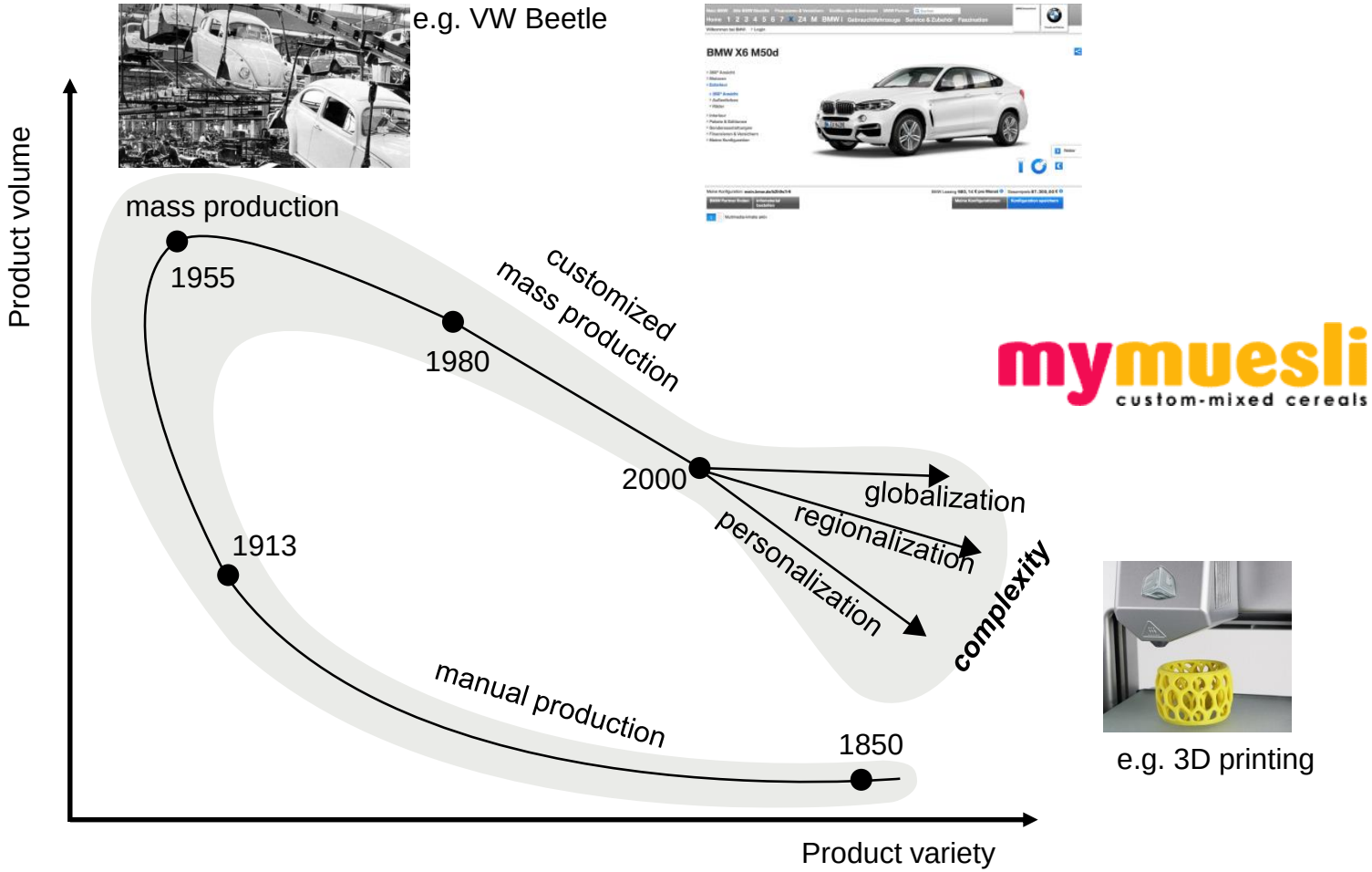
The Adidas Speedfactory: Bringing Sports Shoes Production back to Germany by Industrie 4.0 for Mass Customization



- The costumers can design their own short shoes using an App.
- Since the customer wants to receive his personalized product on the next day or faster, long logistic chains from low-wage countries are no longer acceptable in the era of mass customization.
- Thus, adidas decided to open various "speedfactories" for personlized shoes in Germany close to the customer, using Cyber-physical production systems (CPPS).

From Manual Production via Mass Production to Mass Customization

„People can have the Model T in any color − so long as it‘s black.“
Henry Ford (1913)

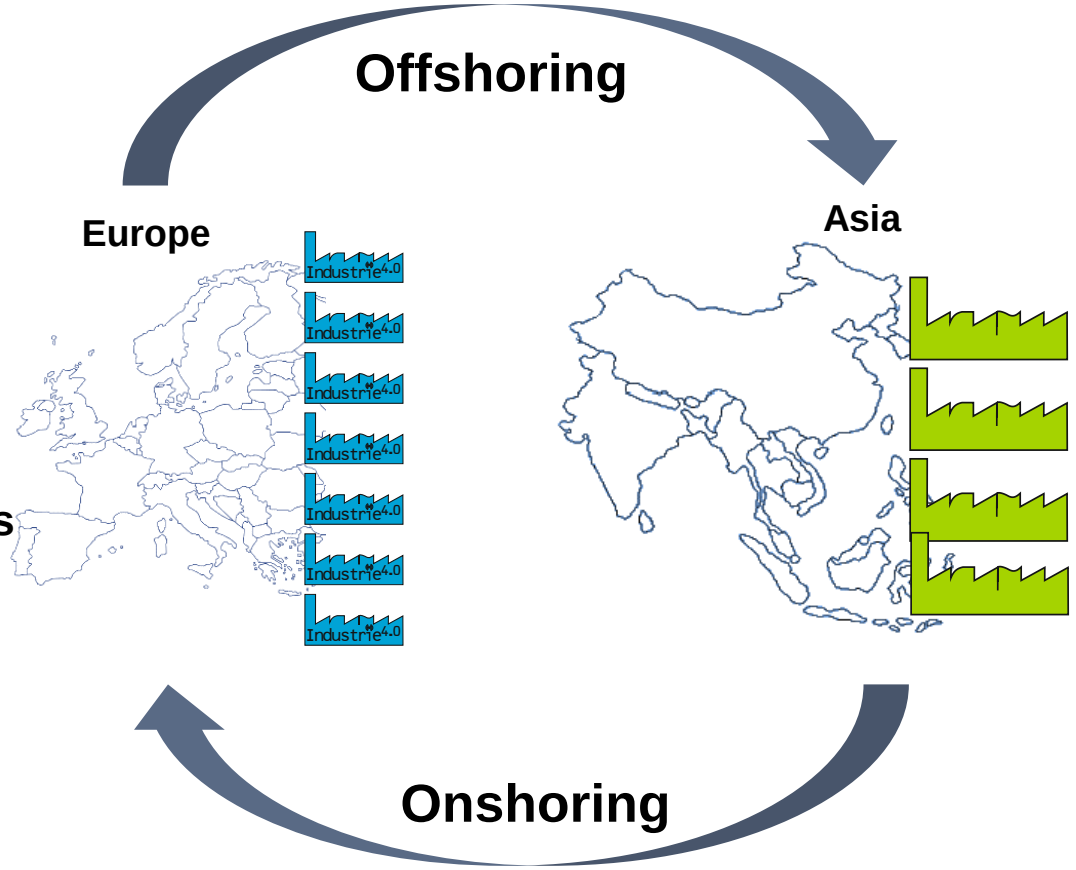


e.g. 3D printing

Based on: The Global Manufacturing Revolution; sources: Ford, beetleworld.net, bmw.de, dw.de

Onshoring in Industrie 4.0 vs Offshoring in Industrie 3.0

- High-wage Countries
- Industrie 4.0
- Mass Customization
- Short and Mobile Chains to Consumers in Europe
- Small Networked Smart Factories



- Low-wage Countries
- Industrie 2.0 - 3.0
- Mass Production
- Long and Complex Logistic Chains to Consumers in Europe
- Big Traditional Factories

For example: sport shoes, clothes, kitchens, appliances, consumer electronics, toys, bikes…

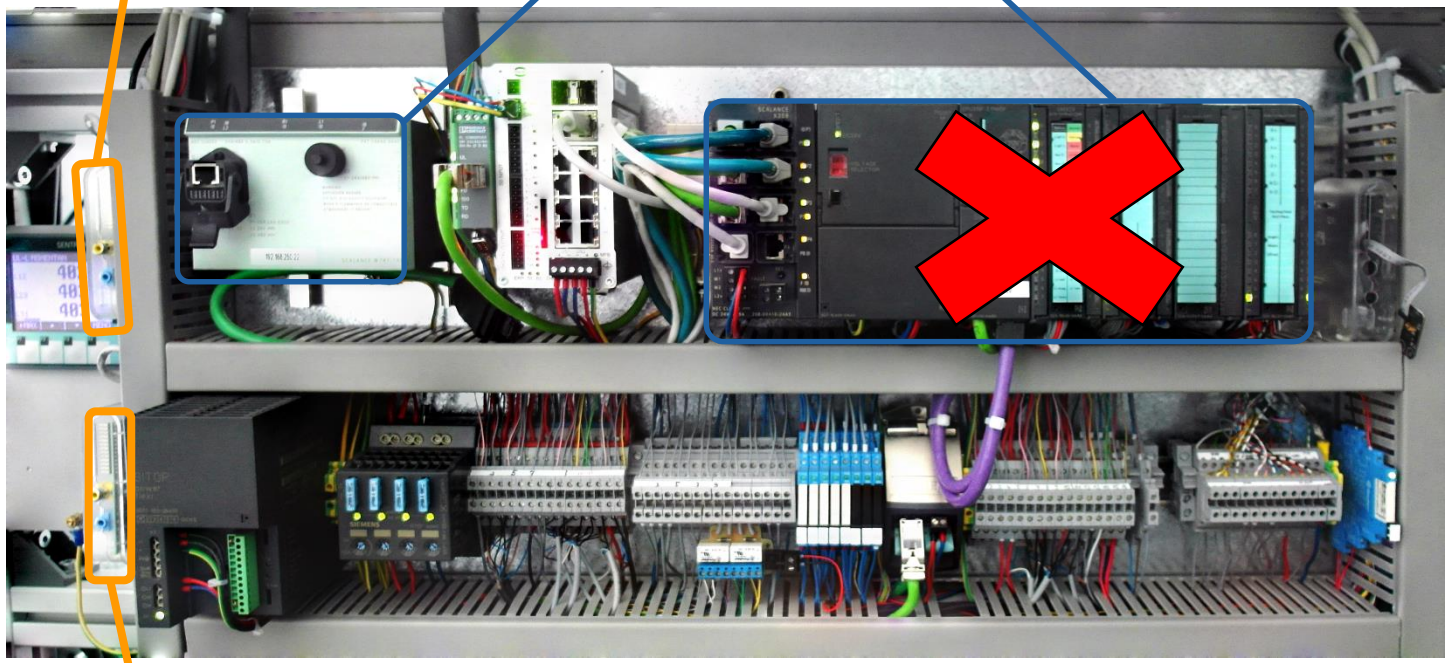
The Retrofitting of Legacy Factories with an Additional Layer of Cyber-Physical Systems

Rasberry PI 1
CPS as an Active Product Memory
for the Emerging Product

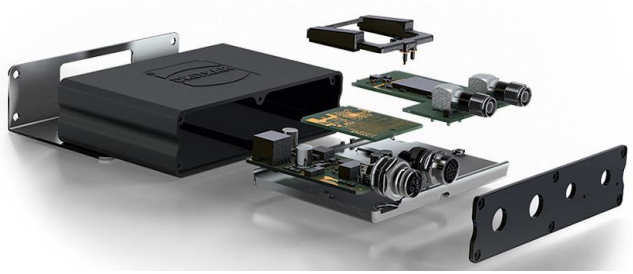
WLAN Router

Classical SPS

Professional Alternative
MICA by
HARTING



Rasberry PI 2
CPS for Processing Sensor Data from
the Additional Sensor Web

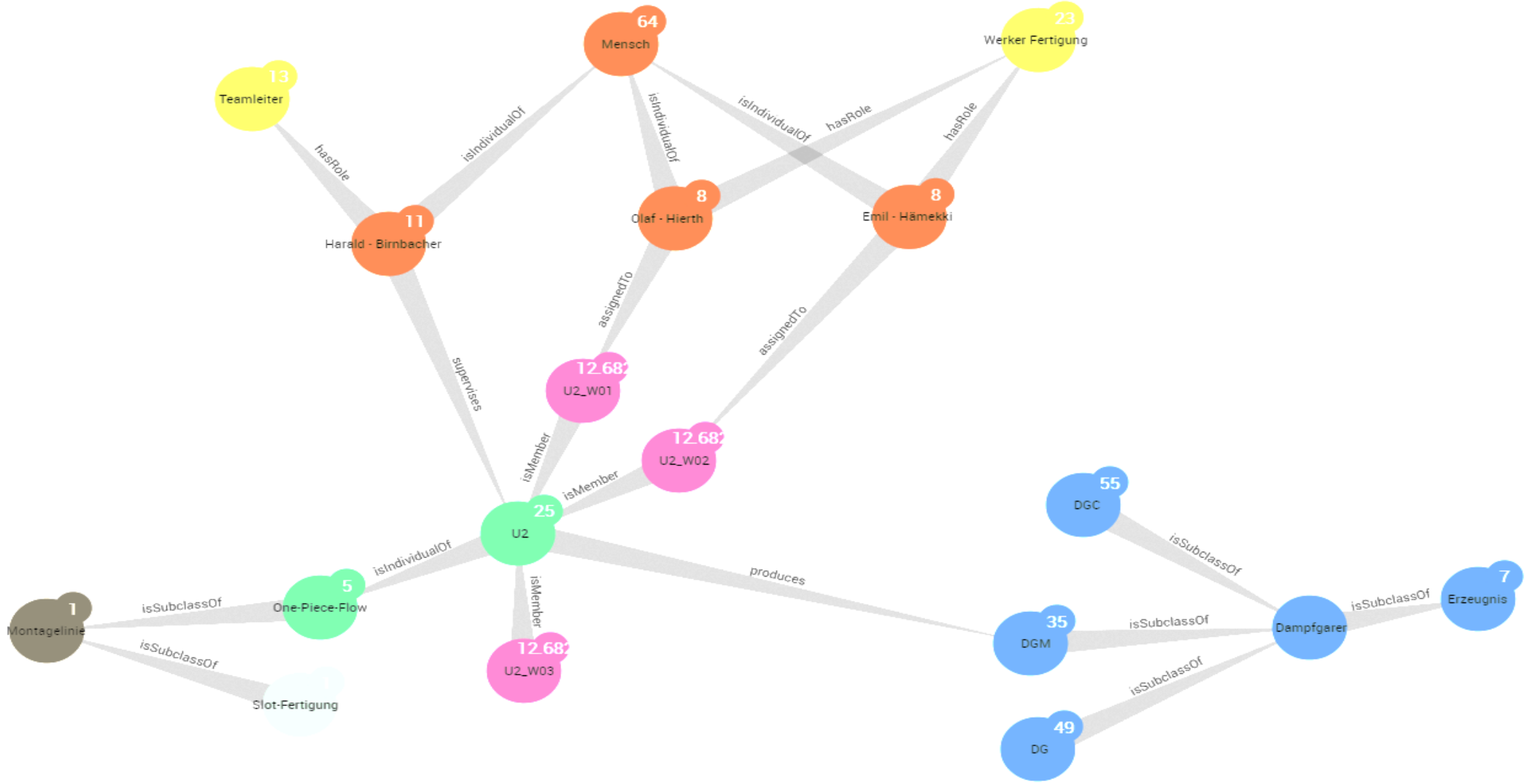


MICA CPS

Thousands of CPS 4.0 Form the Nervous System of a Smart Factory

In Industrie 4.0, conventional field devices and SPS (Storage Programmable Systems) will be replaced by thousands of CPS 4.0 interconnected via industrial internet protocols.

The Semantic Factory Memory: A Graph Database for Relations Between Employees, Machines, Products, Processes, and Tools



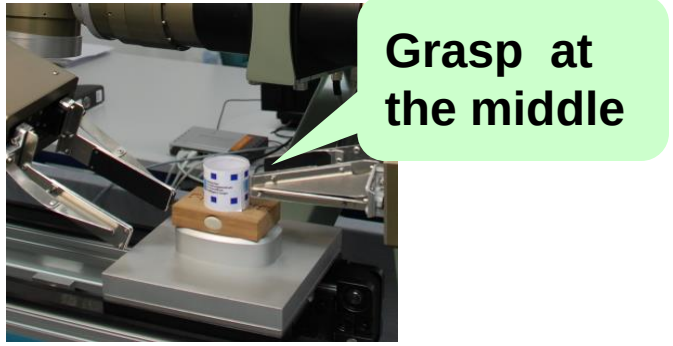
Products with Integrated Dynamic Digital Storage, Sensing, and Wireless Communication Capabilities

⇒ The product as an information container

– The product carries information across the complete supply chain and its lifecycle.

⇒ The product as an agent

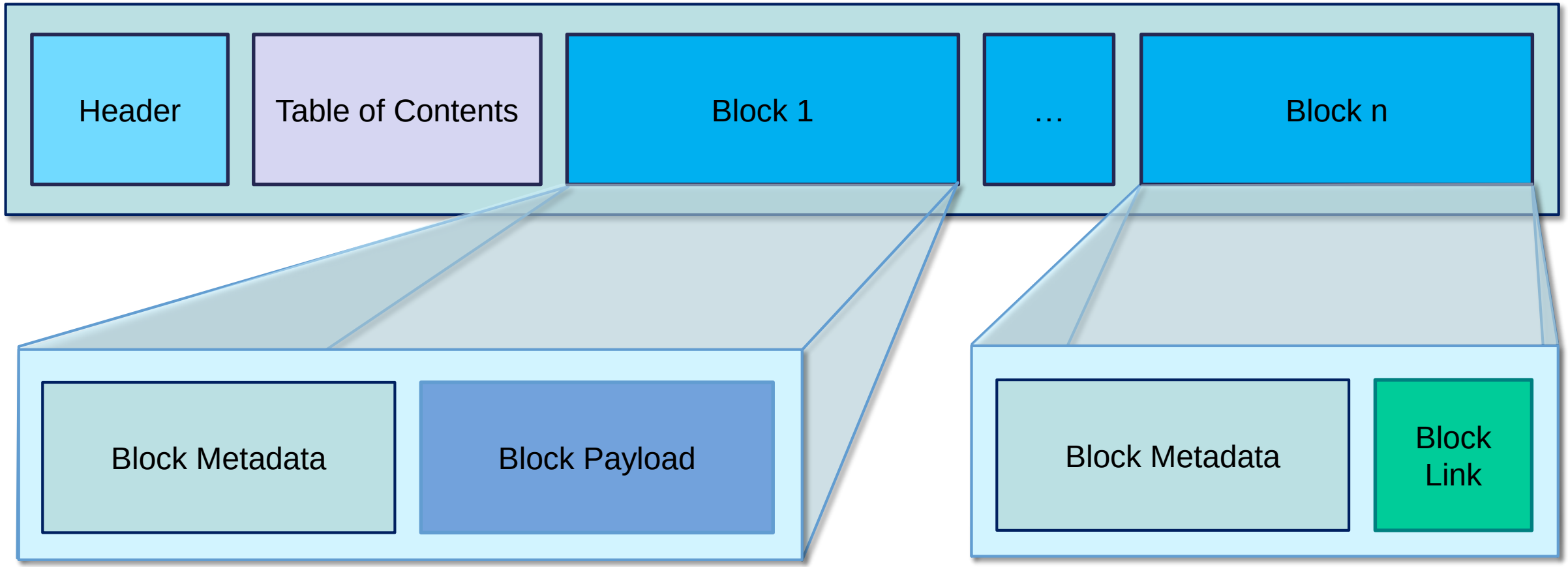
– The product affects its environment



⇒ The product as an observer

– The product monitors itself and its environment

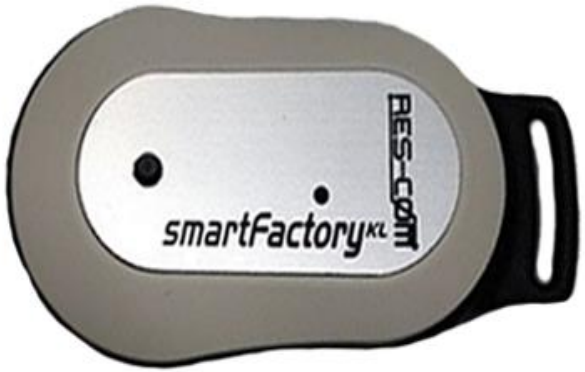
The Structure of the Object Memory Model (OMM, W3C Standardization)



The Smart Keyfinder with its Semantic Product Memory Chip

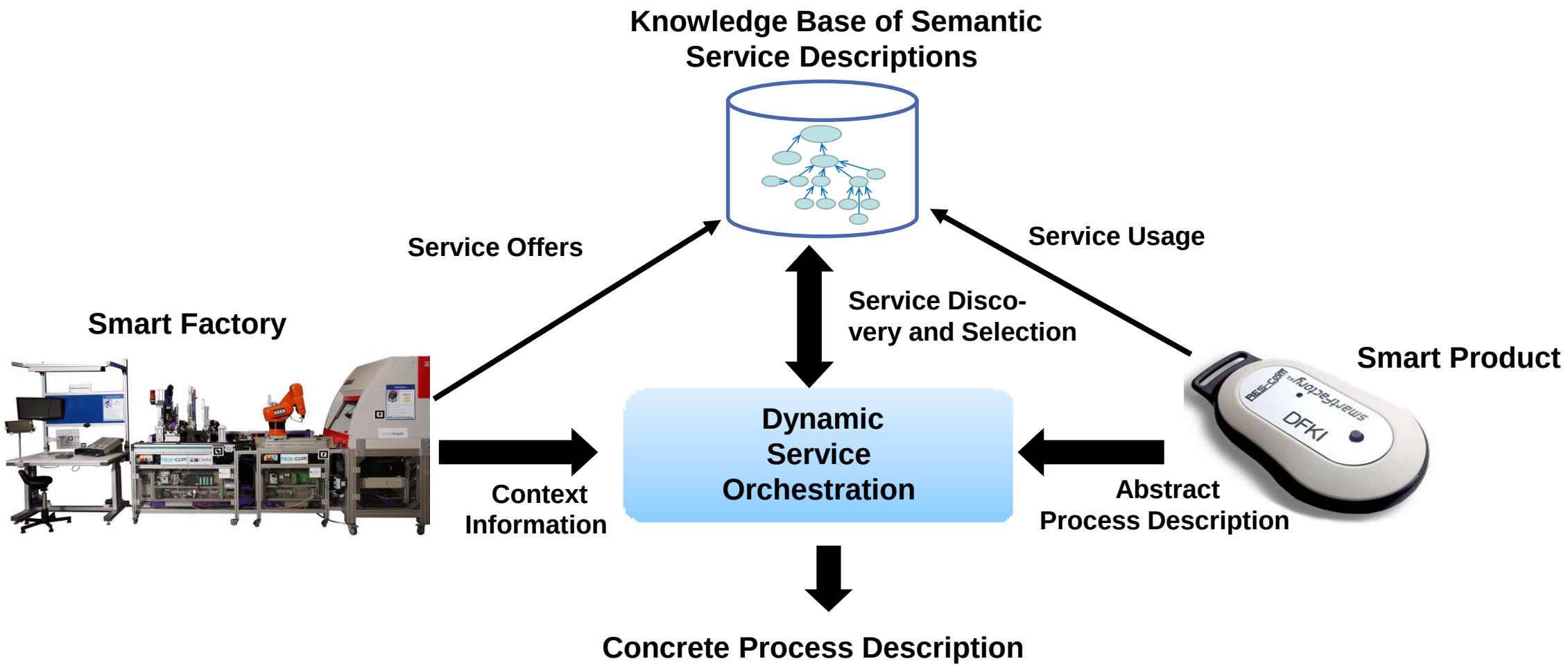
Semantic Product Memory Chip in the backcover plastic frame with product specification

Bluetooth circuit board with key-finder logic packaged inside a plastic shell

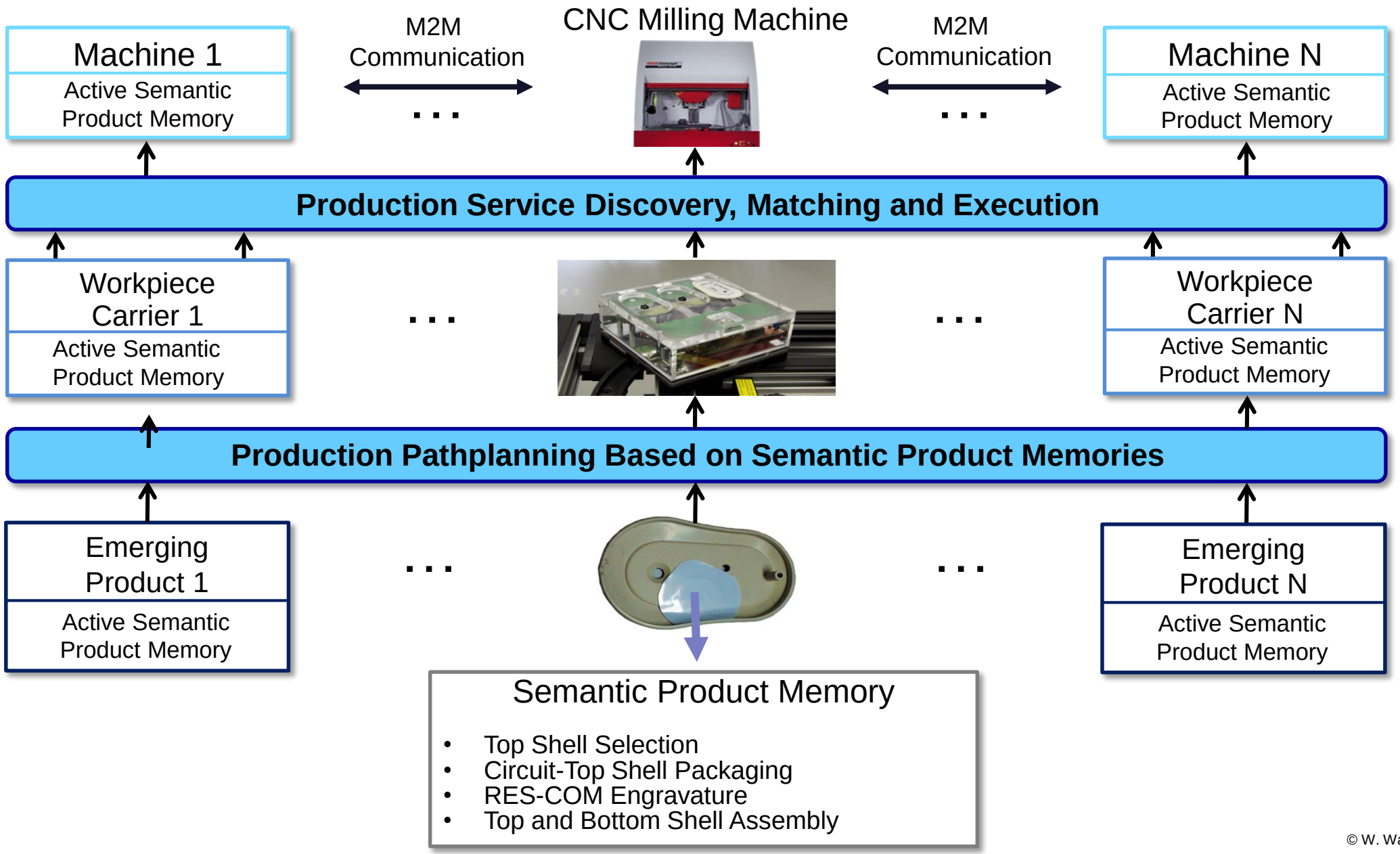


Personalized keychain with custom metal tag on the front produced by an engraving machine

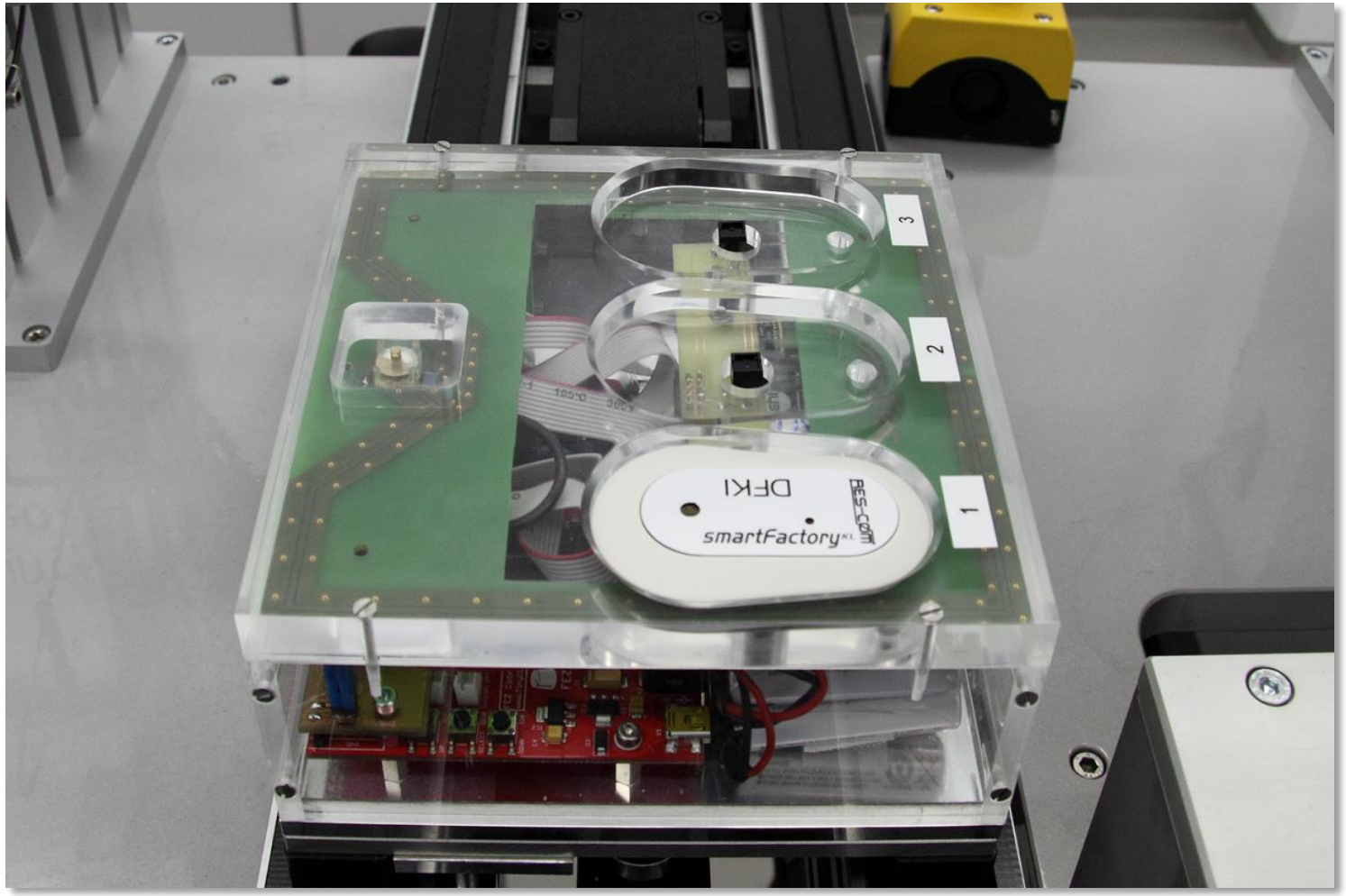
The Service-Oriented Architecture of Industrie 4.0



Key Components of Service-Oriented IoT Production Systems



The Intelligent Workpiece Carrier: A Complex CPS

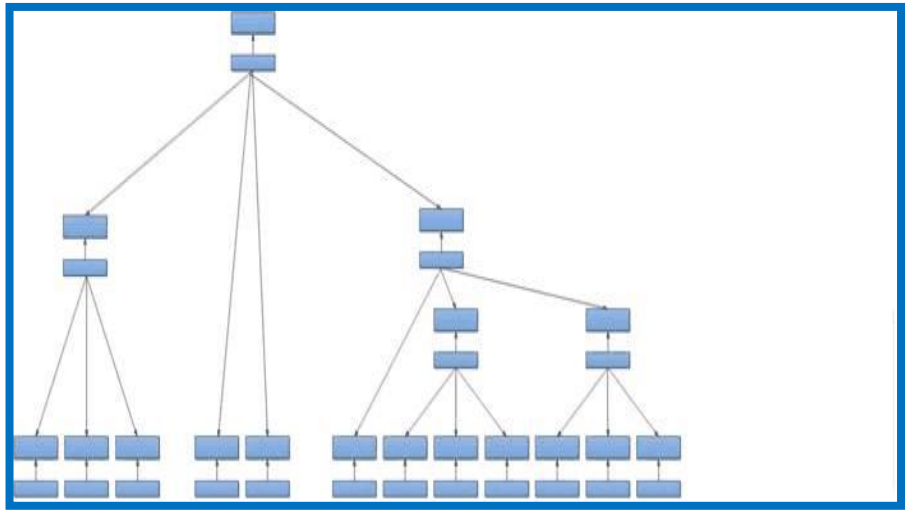


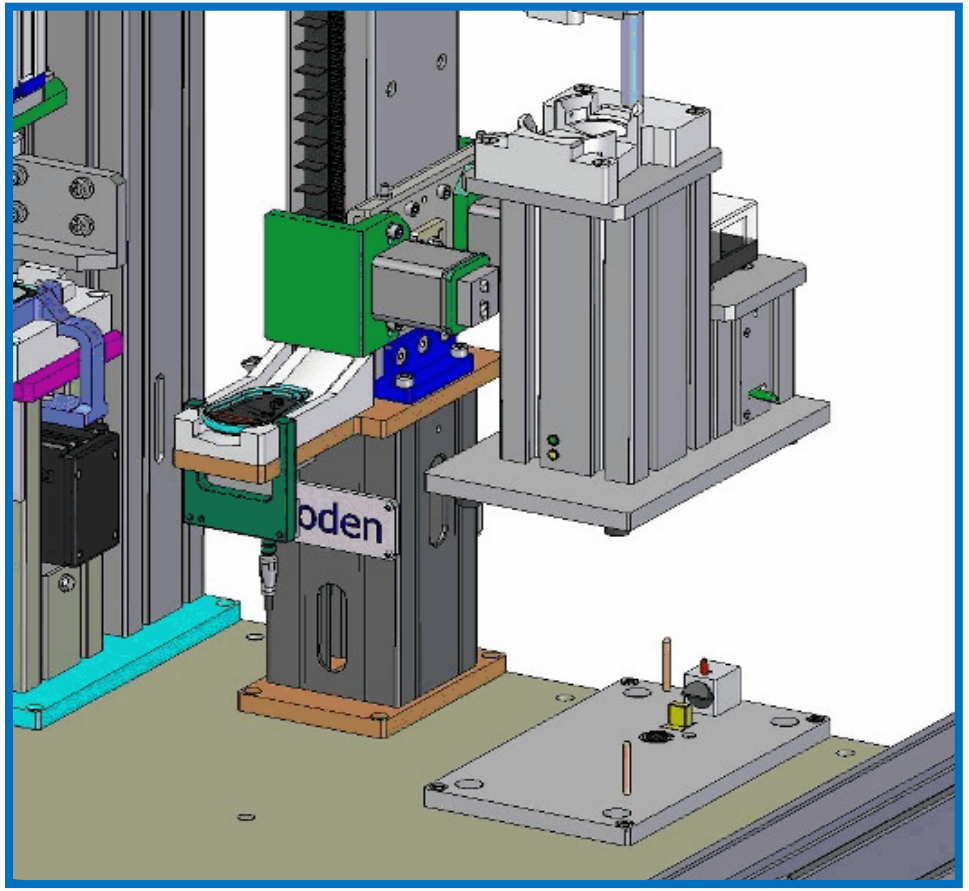
The Taxi to Production Services

Plug&Produce based on Adaptive Service Ontologies

- Plugin of CPS production components on a physical, digital and semantic level

- Automated Expansion of the Service Ontology





New Assembly Component is installed on-the-fly

Dynamic Planning Based on Service Composition in a SOA Architecture for Smart Factories

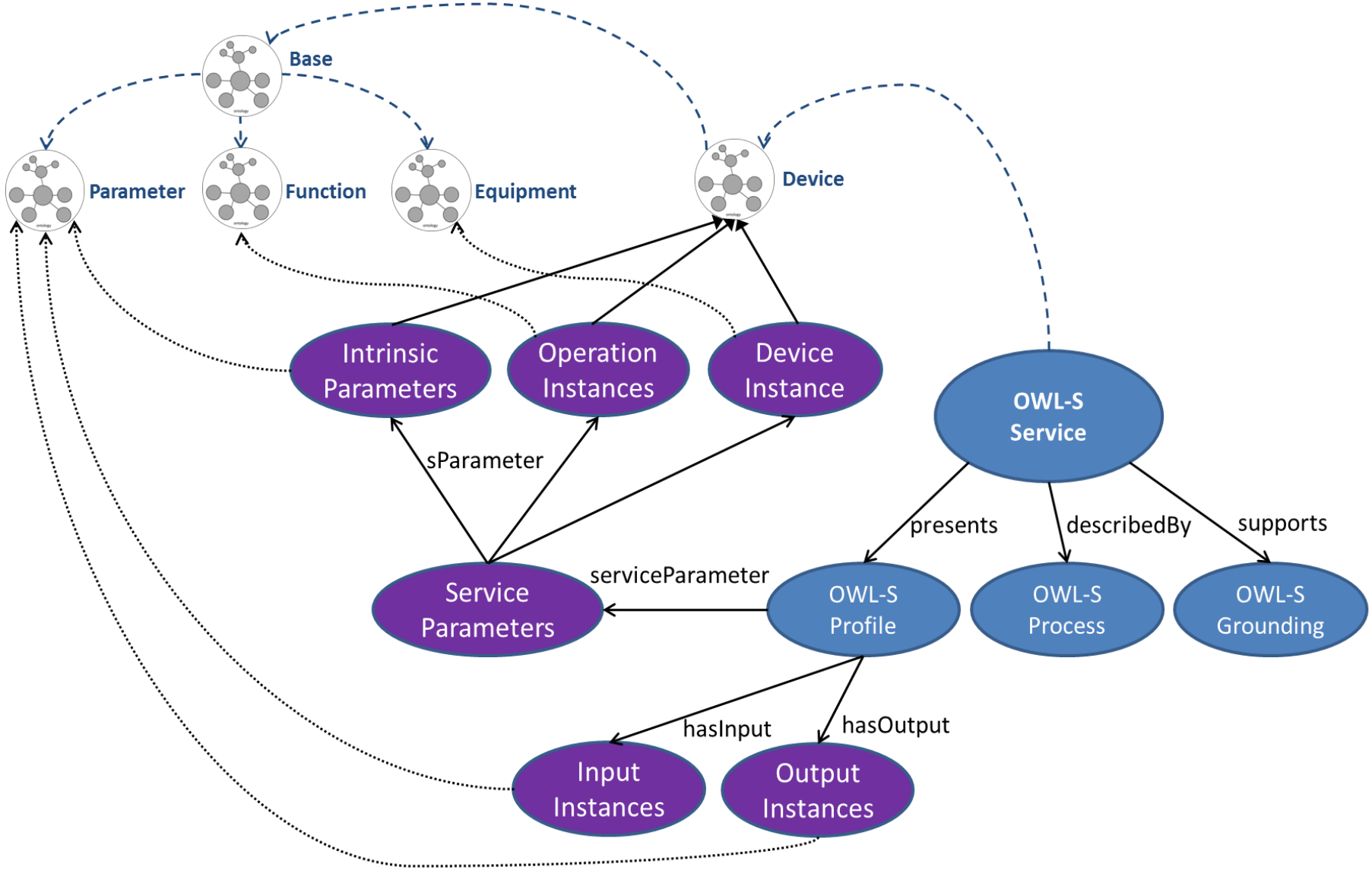
Plug & Produce

Green Production Minimize CO2

Abstract Process Specification

Conveyor1.transport (lowSpeed) → Pick&Place.insertBottom (AssemblyPlace4) → Pick&Place.insertBoard (AssemblyPlace4) → Pick&Place.insertCap (AssemblyPlace4) → AssemblyPlace4.compress

Semantic Description of all Factory Components as Services in OWL-S Ontology



Standardization as a Key Success Factorfor Industrie 4.0

Standardization through Semantic Meta Description Languages

Intefaces between Digital Enterprise and Digital Factory Layer

DIN EN 62264 ISO

Semantic Service Description and Semantic Product Memory

OWL OWL-S OMM++ USDL WSDL W3C®

VDI 2860

Standardization through Interoperability

Communication Standards

7	SOA Services	SoA	✓ OPC® FOUNDATION
6	OPC UA	OPC-UA	
5			
4	IP	TCP/IP	✓
3			
2	Ethernet	RJ45, WiFi…	✓ IEEE 802.11™
1			

Mechatronic Base Standards

HAN-Modular®

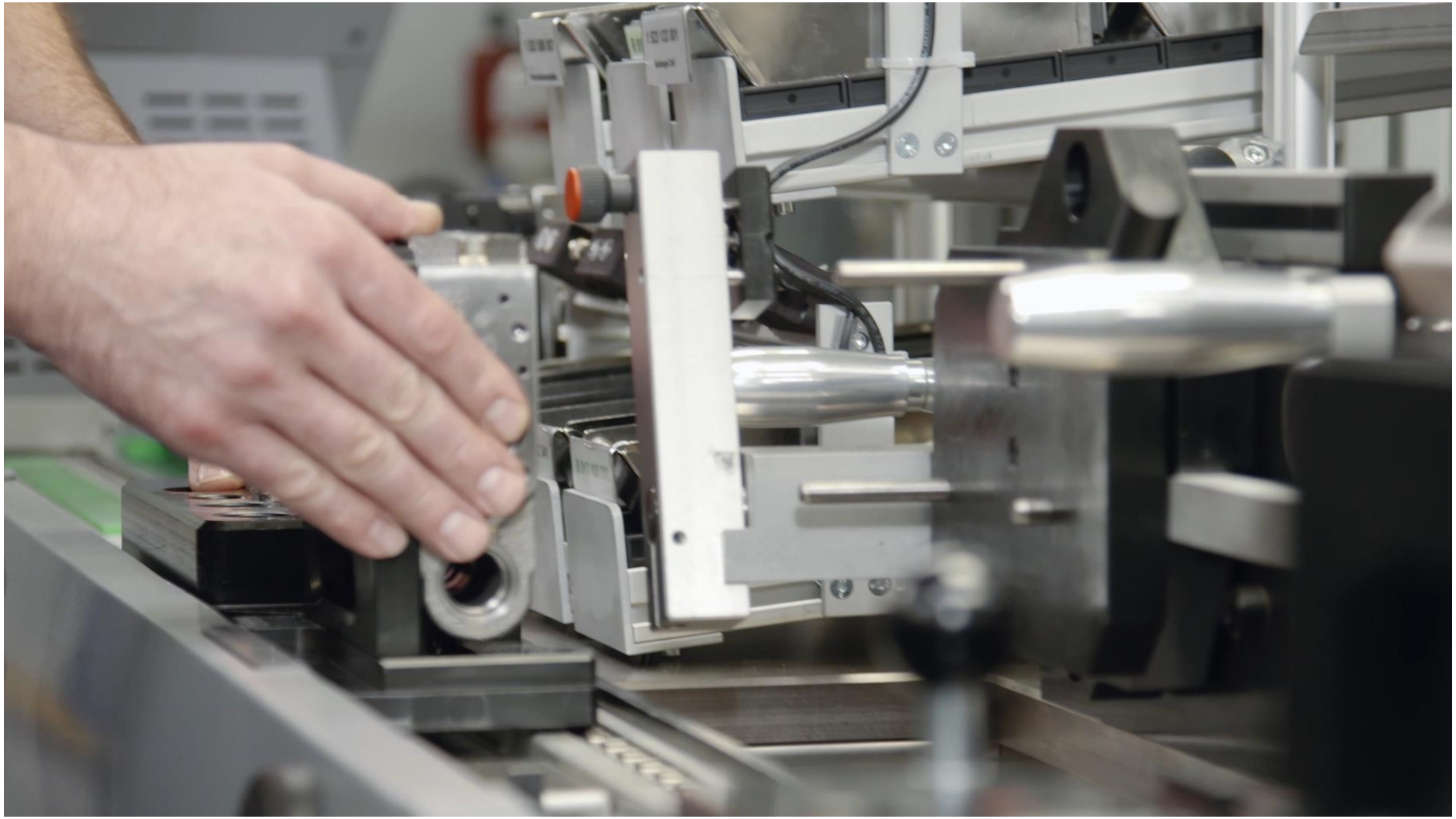
✓

DFKI‘s Multi-Vendor Smart Factory in the Industrie 4.0 Paradigm

Seamless Interoperability, Multiadaptivity, and Plug&Produce

9 Manual Workstation
8 Weighing Module
7 Quality Control
6 Laser Marking
5 Robot Module
4 Force Fitting
3 Production
2 Engraving
1 Storage Module

IoT Technologies in the Smart Automation Line of Bosch-Rexroth at Homburg



Cooperation with DFKI and the Power4Production Center in the SmartF-IT Project

Source: Bosch-Rexroth

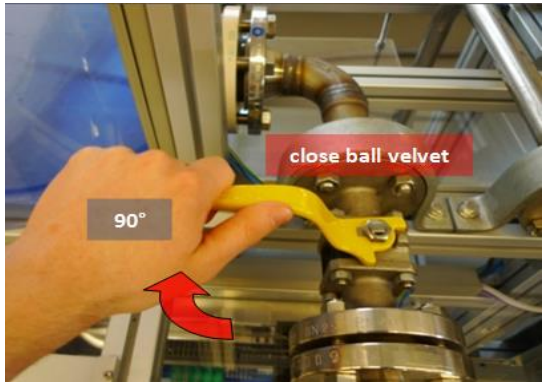
Advanced Industrial Assistant Systems Based on Augmented Reality Technologies

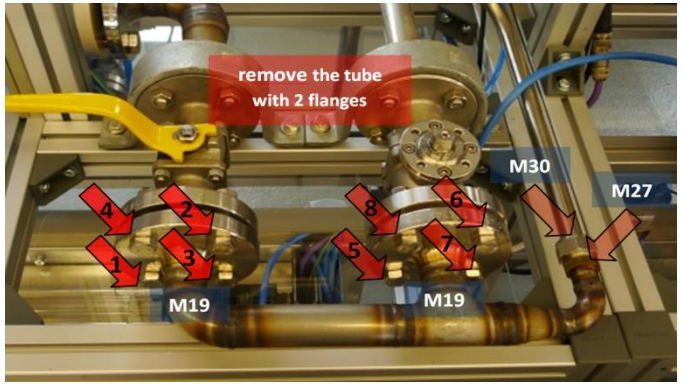
Industrial Environment

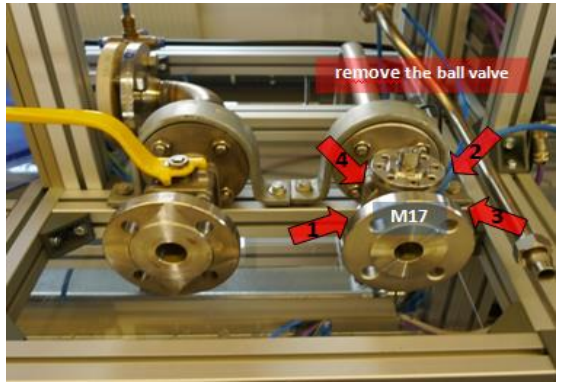
Industrial Worker with Data Glasses

Tools

Mobile, Interactive and Situation-Aware Tutoring







Look-Through Technology Used in the Smart Factory

The Spin-Off Company IOXP of DFKI has revolutionized the Workflow for AR Presentations

Industrie 4.0: Robots are no Longer Locked in Safety Work Cells but Cooperate with Human Workers

The Past

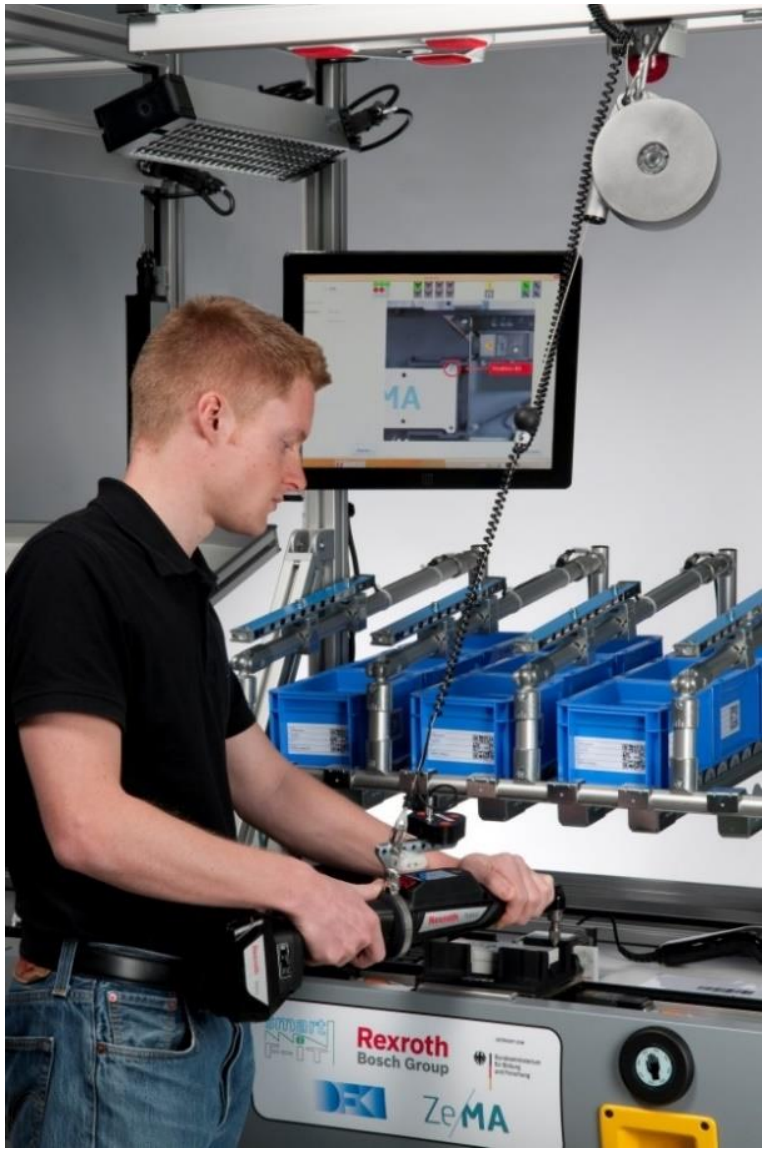
The Future

AUDI BMW

A new generation of light-weight, flexible robots collaborate with humans in the smart factories of DFKI.

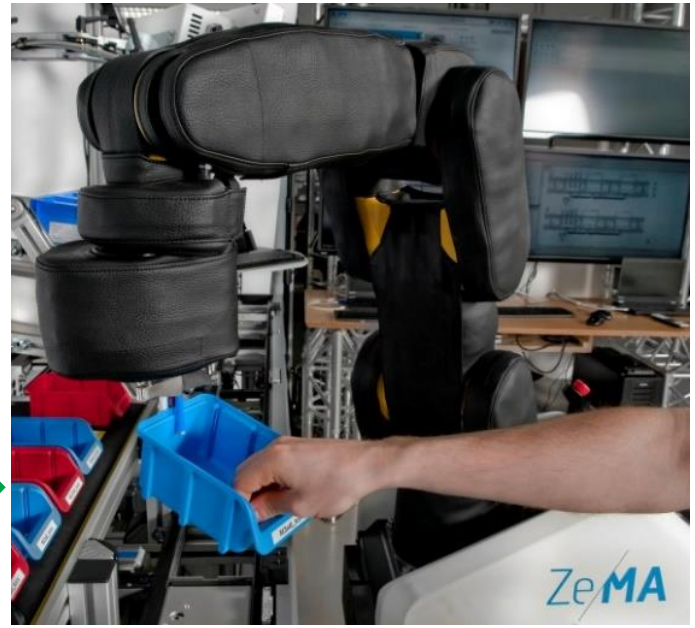
Intelligent Human-Robot-Collaboration in the Smart Production Lab of VW in Cooperation with DFKI

IoT Technologies for Better Quality and Higher Productivity: Connecting Workers, Robots, and Tools (ZeMA in SmartF-IT)



- The Collaborative Robot APAS provides the worker with the right screw type according to the workflow.
- The use of the screw driver (which is connected via Internet to the CPS middleware) is monitored by ultrasonic sensors.

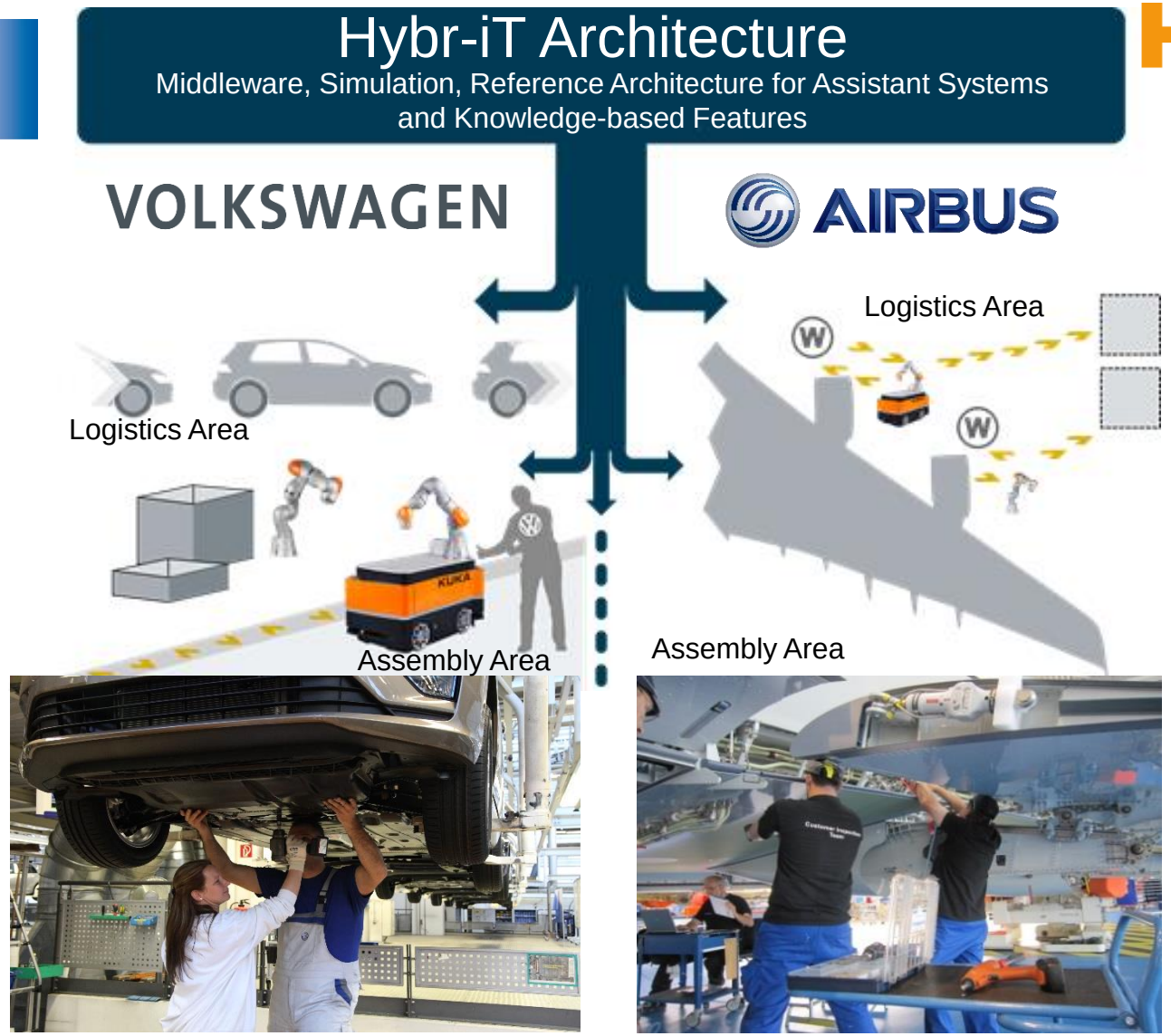
Collaborating APAS Robot



Monitoring of Screwing

Bosch‘s APAS Cobot in DFKI‘s SmartF-IT Assembly Line with an Internet-Enabled Screwdriver (ZeMA)

Hybrid Teams: Robots Collaborate with Humans in Physically Challenging Overhead Assembly Tasks (Hybr-iT)



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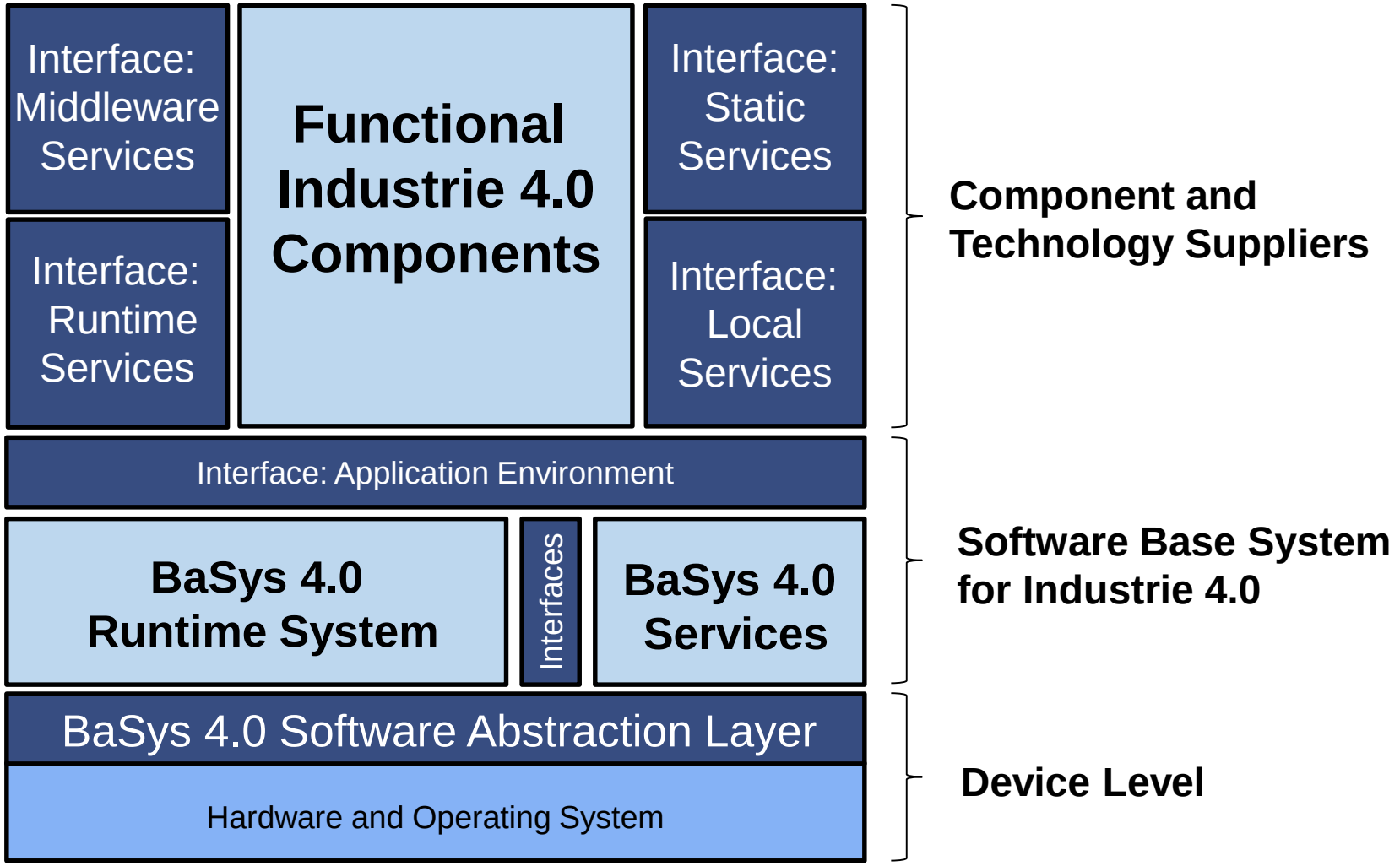
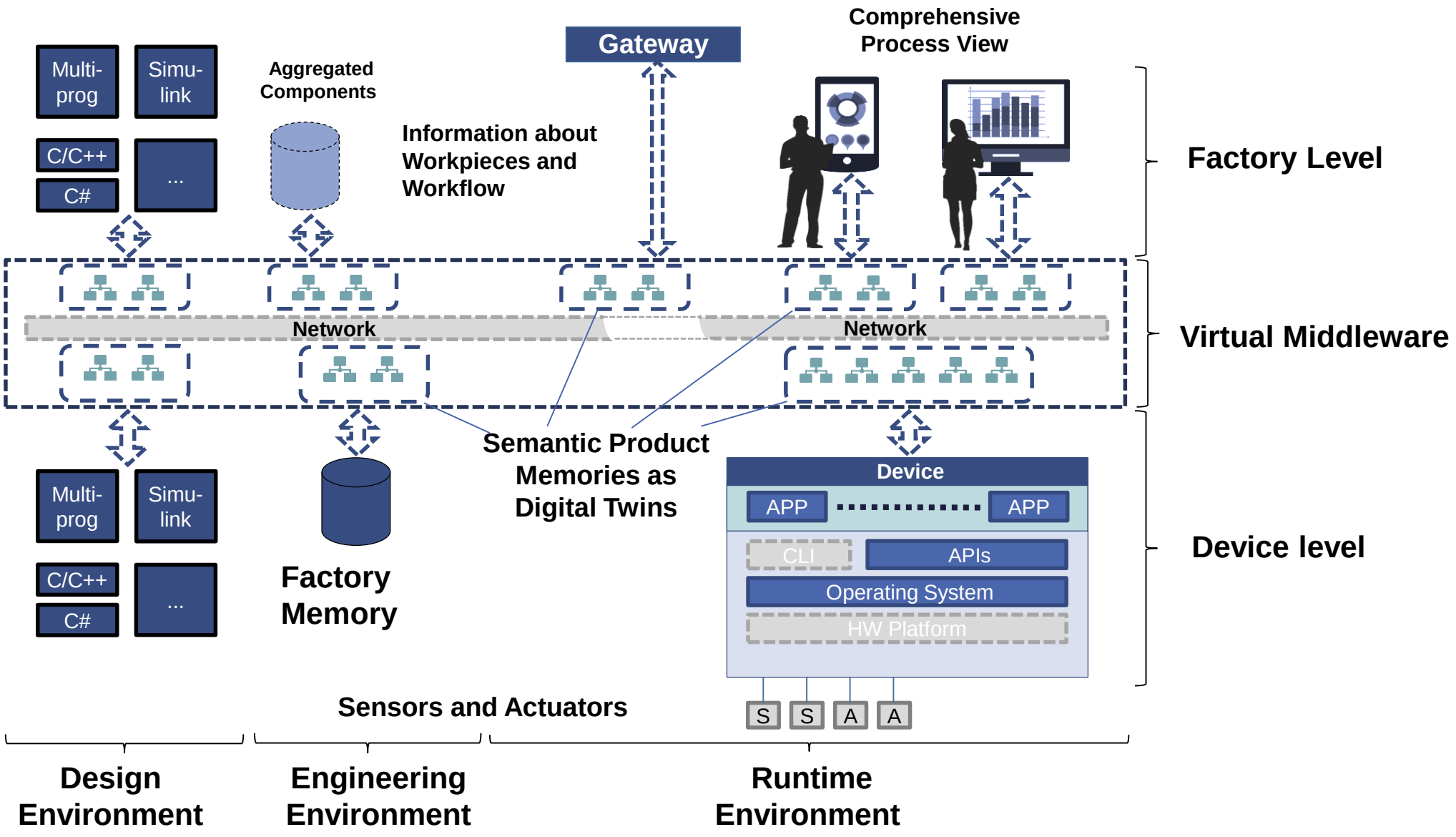
BaSys: an open system architecture for Industrie 4.0

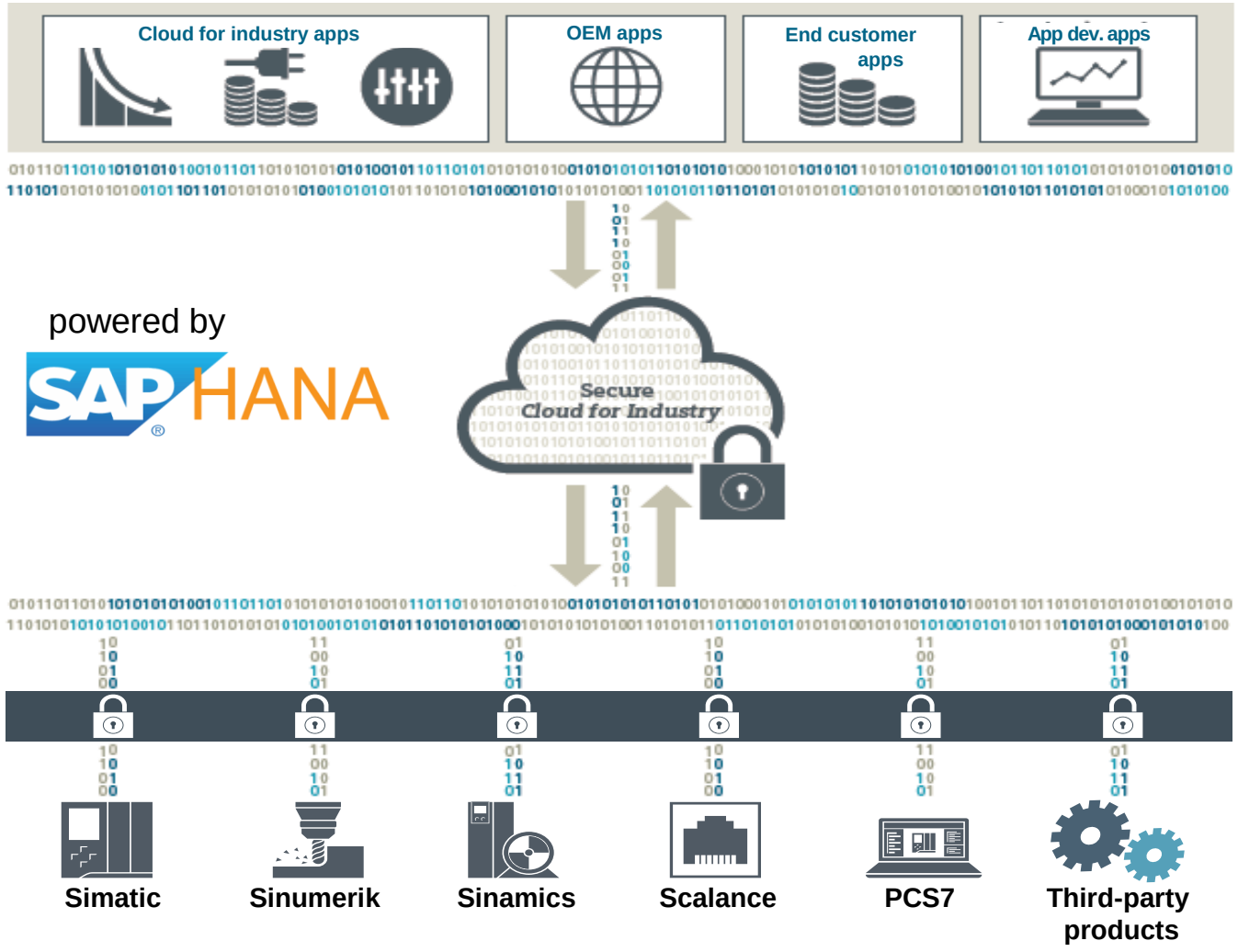
like AUTOSAR for vehicle manufacturers



The Anatomy of BaSys 4.0



MindSphere: Siemens-SAP Cooperation on Industrie 4.0 Cloud Platform



Optimization of plants and machines as well as energy and resources

- **Open standard (OPC)** for connectivity of Siemens und third-party products
- **Plug and play connection** of Siemens products (engineering in the TIA Portal)
- **Cloud for industry** with open application interface for individual customer applications
- Optional **cloud infrastructure** – public cloud, private cloud or on-premise solution
- Transparent **pay-per-use pricing model**
- Opportunities for completey new **business models** (e. g. selling machine hours)

New Joint Innovation Laboratory MRK4.0 for Human-Robot Collaboration in Industrie 4.0

Czech PM Bohuslav Sobotka and Chancellor Dr. Angela Merkel at the signing ceremony with Prof. Marik and Prof. Wahlster in Prague

CZECH INSTITUTE OF INFORMATICS ROBOTICS AND CYBERNETICS CTU IN PRAGUE

MRK4.0 Power4 Production

German Research Center for Artificial Intelligence

Investment Grant for Equipment

Lightweight Robots and Wearables 1 Mio. €

Living Lab for Support of Small and Medium Enterprises

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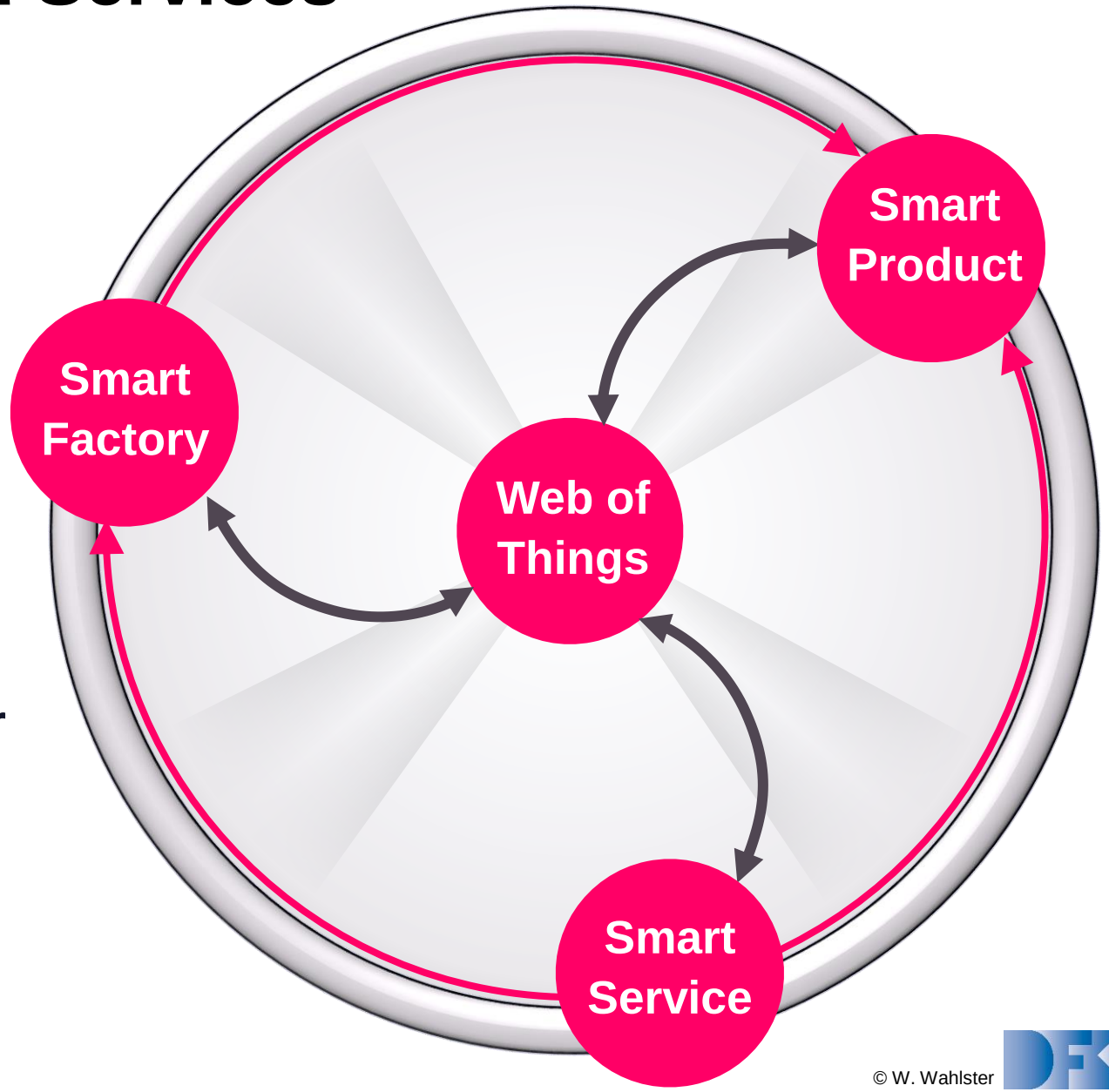
The Web of Things as the Industrie 4.0 Jet Engine for Smart Factories, Products and Services

Take-away Lessons:

- The Web is essential for realizing the full potential of the IoT.
- The Web provides a unifying framework for semantic interoperability.
- The Web acts as a global marketplace for suppliers and consumers of industrial services.



10 German Competence Centers for Industrie 4.0

Helping SME's during the transition phase to Industrie 4.0

Federal Ministry
for Economic Affairs
and Energy

Core Centers selected In First Round in 2015

Secondary Centers selected in 2016

First Smart Factory Living Lab founded in 2005

Conclusions

- **Industrie 4.0 is a success story of a strategic public-private partnership and secures Germany's economic power as a leader in manufacturing.**

- **Industrie 4.0 brings the Web of Things to the job floor of factories and allows mass customization of smart products for a reasonable price based-on semantic technologies and semantic service matchmaking.**

- **Cyber-physical production systems and semantic product memories enable Plug&Produce and multiadaptive smart factories. Collaborative robots and hybrid teams of robots and human workers are key for low-volume high-mixture factories.**

- **Factory Workers will be assisted by a new generation of collaborative robots and intelligent industrial assistance systems using multimodal dual and augmented reality.**

- **Systems based-on long-term autonomy and deep learning go beyond Industrie 4.0 and enable autonomous smart factories.**

Thank you very much for your attention.

Design by R.O.