DENSE AIR

Mobile Networks Enhanced and Extended

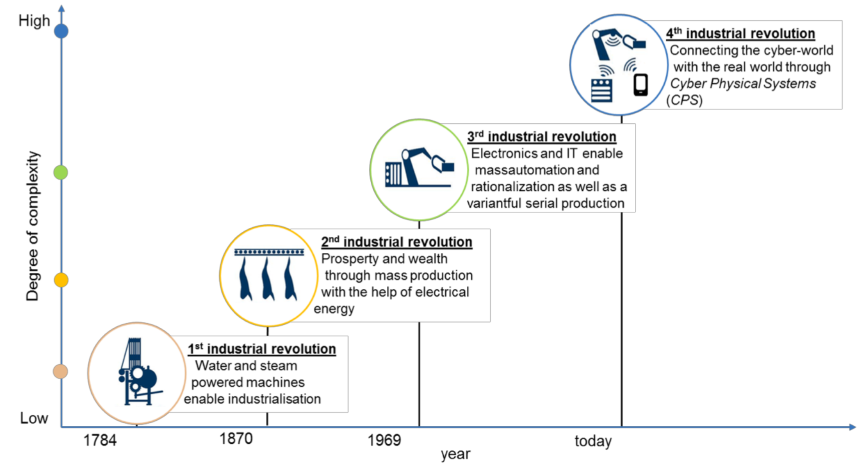
Next Generation Private Mobile Networks for Industry 4.0

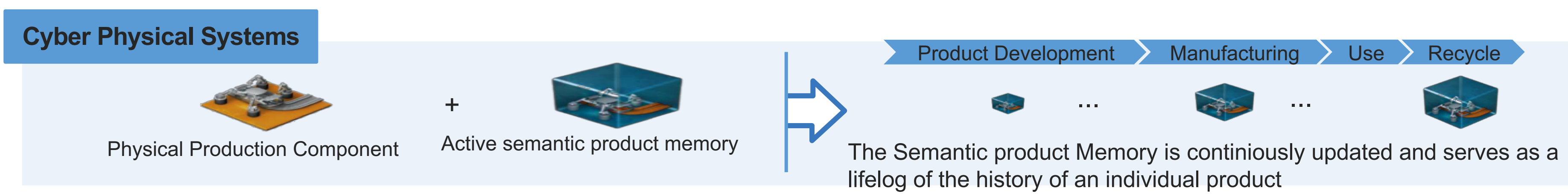
Why industry needs 5G (and 4G) networks and spectrum independently of the Mobile Operators

v1.0

Introducing Industry 4.0

- **A key use case for 5G is to support Industry 4.0 connectivity requirements**
- Investment in hyper-dense indoor networks in manufacturing facilities can **massively improve productivity and enable innovation**.
- Future manufacturing is **underpinned by the way data is analyzed** and utilized to manage complexity and volatility of global markets unlocking huge efficiency potentials
- **Data will flow from customers** via intelligent products to producers enabling quicker product development and novel services
- **Fusion of virtual and real worlds based on Cyber-physical production** systems (CPS) driving restructuring of value creation and supply chains
- **Industry 4.0 is therefore synonymous with the integration of CPS** in manufacturing and distribution as well as the use of the Internet of things and services in industrial processes

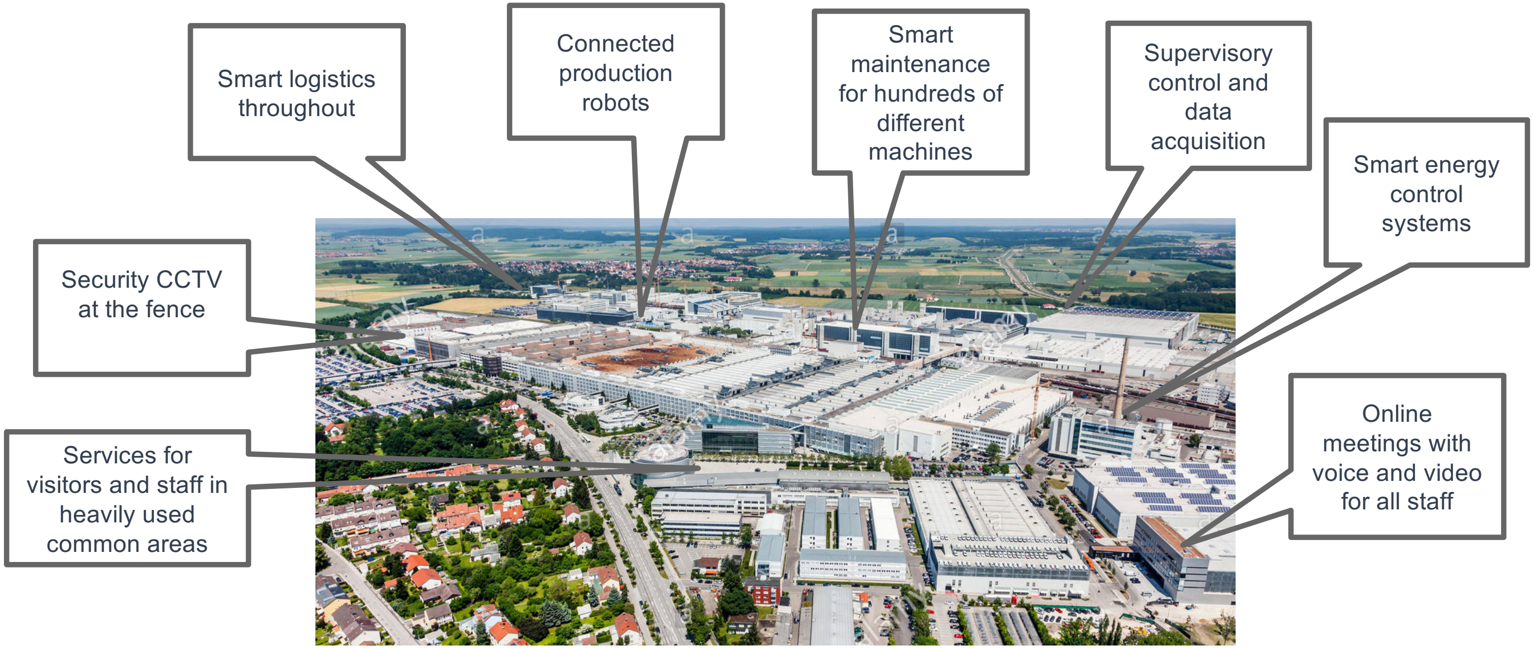




5G can make Industry 4.0 CPS a mainstream reality!

Industry 4.0 and 5G: Key Applications

- Industry 4.0 on industrial sites require appropriate 5G network connectivity



Picture of Audi site in Ingolstadt

Hundreds of different Industry 4.0 applications for different purposes can overlap on the same site. Each requires connectivity, each with different requirements in terms of throughput, latency, reliability and the number of endpoints. Individual use case by themselves are unlikely to provide the business case justification for establishing the network but the combination of all application does. This requires a wireless network that covers the full site, provides the highest level of reliability and low latency, as well as the peak bandwidth for all applications – all with different tailored network slices for different uses.

Industry 4.0: 5G Applications have different needs

Application or Use Case

Private Mobile Network Requirements	Smart logistics	Collaboration robots	Smart maintenance	Predictive big data analysis	Industrial control	Smart energy mgmt.	Site surveillance	Online meetings
Wireless	Major	Medium	Major	Medium	Minor	Major	Minor	Major
High bandwidth	Minor	Medium	Medium	Major	Medium	Minor	Major	Major
Many devices	Medium	Medium	Major	Medium	Major	Major	Medium	Major
Low latency	Major	Major	Medium	Minor	Major	Minor	Medium	Medium
High reliability	Major	Major	Major	Medium	Major	Medium	Major	Minor
Several network slices	Major	Major	Medium	Medium	Major	Major	Major	Major
Increased service levels	Major	Major	Medium	Medium	Major	Medium	Major	Medium
Easy to deploy	Major	Medium	Major	Medium	Major	Major	Medium	Major
Deployment to special sites, e.g. below ground	Major	Major	Medium	Medium	Major	Major	Major	
Pay as you use	Medium	Minor	Major	Minor	Minor			

- Major: Network feature has major responsibility for goal achievement
- Medium: Network feature has medium responsibility for goal achievement
- Minor: Network feature has minor responsibility for goal achievement

Perfectly served by 5G (or 4G) in Private Spectrum

"5G-as-a-Service" for Industry 4.0

5G Technology Features
- Low latency
- Ultra-high reliability
- High bandwidth
- Massive number of devices
- Support of new frequencies

5G Small Cell Deployment
- In licensed bands give predictable performance
- Easy-to-install and self organising
- Small cells ideal for site-specific deployments (outdoor, indoor, below ground)

Service Features
- Deployed as a service
- Easy to integrate into corporate and mobile networks
- Mobile network offload

5G-as-a-Service Small Cells provide the solutions for these diverse requirements

Appendix: Industry 4.0 Use Cases for Wireless Connectivity

CONNECTIVITY + INDUSTRY 4.0 PLAYS A ROLE IN VARIOUS INDUSTRIES AND IS BECOMING REALITY

1 Smart Logistics concepts	2 Collaborative flexible robots	3 Smart maintenance	4 Smart control for large plants	5 Virtual manufacturing
Audi, BeeWaTec, Festo, Amazon Air Prime	**Audi, Daimler, VW, BMW, Thiele**	**Audi, Daimler, Advance Auto Parts, IBM**	**Lenze, BMW, Daimler, BASF**	**Audi, Ford, IFF**
…uses smart (intra) logistic systems and devices to support material supply and package delivery	...uses collaborative robots to support humans in production process	…uses predictive and remote maintenance to support maintenance	...uses smart energy and controll management for increased productivity and efficiency	...uses AR and VR for virtual testing of production processes and performance improvement
Under the aspect industry 4.0 it is the goal that the internal transport system acts fully automated and autonomous. The transport robots must be networked with all facilities, the inventories of the facilities must be recorded and the materials must be automatically reloaded.	Trend of flow production is decreasing more and more and the demand for a fully flexible production is strong. Industry 4.0 requires maximum flexibility in production. Flexibility in the use of production equipment is currently technically feasible.	Under the aspect industry 4.0, the objective is to store, evaluate and analyze all relevant data centrally and to ensure a flexible connection of all equipment. Connecting all equipment to the network is one of the key prerequisites for building an smart factory.	The goal is to save resources and increase productivity through Industry 4.0. This is made possible by extensive control options for plants and systems. The risk of failures is reduced by the extensive automation and connection coverage.	The goal is to use virtual reality and augmented reality to test and optimize processes in advance, before they are established and implemented, in order to optimally adapt qualitative aspects and performance.

❶ SMART LOGISTICS CONCEPTS: LOGISTIC SYSTEMS TO SUPPORT MATERIAL SUPPLY MORE EFFICIENT

Current situation

- Material supply within the facility is limited to ground and realised either through conveyor belts or by humans driving carts
- Package delivery between plants and/or consumers is mostly limited to ground vehicles
- Frequent failures, as there is no flexibility to react to situations that are not predictable

I4.0 solution

- Driverless Transportation Vehicles (DTVs) deliver parts autonomously without fixed routes
- DTVs can be upgraded depending on various requirements[2]
- **KIT** developed an autonomous DTV called FIFI, which reacts to human gestures and follows workers if necessary
- **Amazon Prime Air** is a program launched to test package delivery via drones to its customers with a delivery time of 30 minutes
- Use of modern sensor technology to increase the performance of the transport robots (e.g. laser scan sensor, 3D cameras)
- Algorithmic rod adjustment based on processed information
- Drones as a substitute for ground-bound material supply[1]

Benefits

- Full autonomous material supply reduces waiting times as well as movements from workers, enabling both continuous material flow and lot size “1”
- High energy efficiency through modular design of DTV results in a reduced downtime of DTVs[2]
- Reduced delivery times and stock values / less workforce needed
- Lower failure rate / higher flexibility and scale ability

Source: Audi, Festo, BeeWaTec, Amazon, KIT

Examples

- BeeWaTec[2]
- Festo: “Motioncube”
- Amazon Air Prime
- Audi[1]: “smart factory pilot”

1 SMART LOGISTICS CONCEPTS: USING SMART DEVICES TO REDUCE PICKING EFFORT AND SUPPORT LOGISTICS

Current situation

- Logistic processes such as picking and delivering are often performed manually and via paper check (some exceptions pick by light and pick by voice)
- (Pick and pack) Employees of logistic companies spend almost half of their time in searching for the right parts
- Productivity limited due to the mainly manual processes

I4.0 solution

- Bechtle is using smart devices (e.g. google glasses, tablets, data glove and voice control) to display relevant information for material supply (destiny, pick-up place, package specifications)
- DHL is using smart devices which can be used to display real time information on package status
- Driverless Transportation Vehicles (DTVs) transport parts / shipments in and across warehouses due to increase productivity
- Milkrun-Systems (DTVs) deliver parts autonomously in the production area without fixed routes and on demand (demand-driven)

Benefits

- Increased picking quality / less errors
- Avoiding improper and improving overall parcel handling
- Efficient navigation by reducing search and delivery time, especially for first time deliveries
- Automated completeness checks

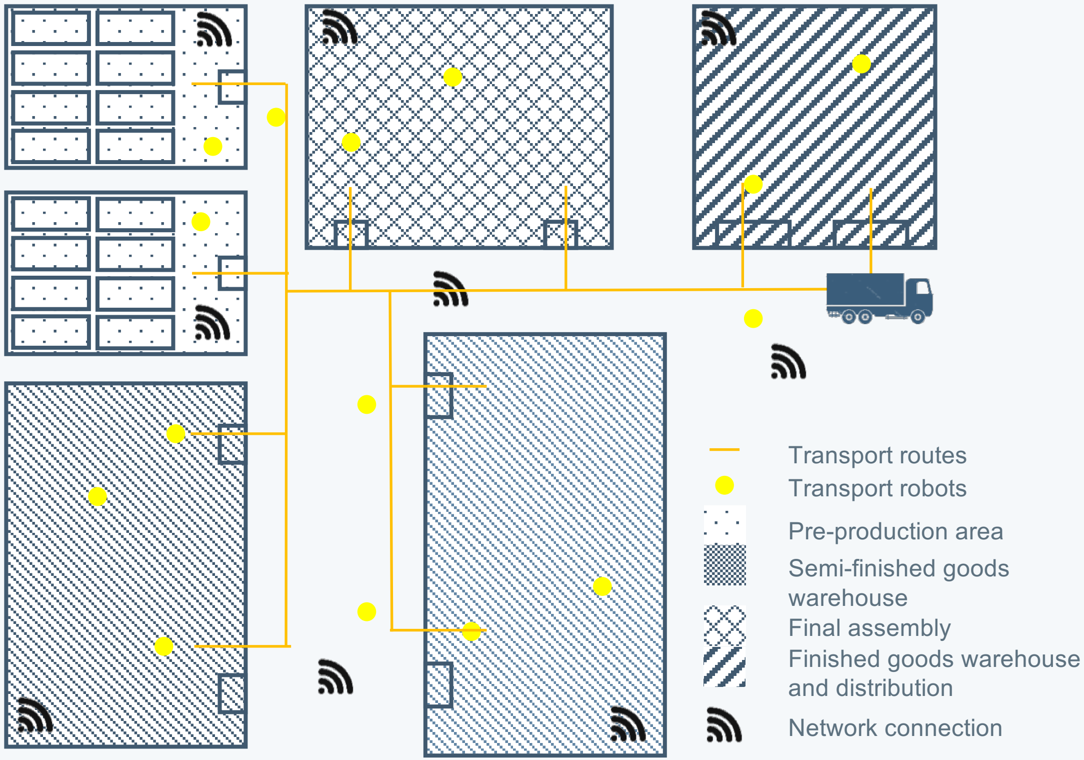
Source: DHL, Bechtle

Examples

- DHL
- Bechtle
- Manufacturing companies
- Consumer (e.g. Zara, Esprit)

1 SMART LOGISTICS USING SELF DRIVING ROBOTS REQUIRES RELIABLE WIRELESS CONNECTIVITY

Schematic representation of an industrial site



Requirements

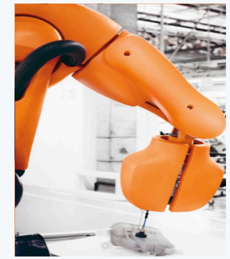
High reliability: Self-driving robots rely on highly reliable networks. No network results in a logistics stop

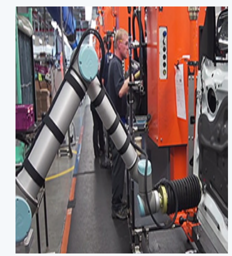
Low latency: Self-driving vehicles must communicate to other vehicles (V2V) or to the infrastructure (V2I) with low latency to avoid collisions. This can be based on P-P V2X or C-V2X

Special coverage: Good wireless coverage on all tracks, incl. below ground, on container parks and in other difficult zones

❷ COLLABORATION ROBOTS: USING COLLABORATIVE ROBOTS TO SUPPORT HUMANS IN PRODUCTION

Current situation	▪ Robots currently work separated from humans and require special fences due to safety reasons ▪ Robots are mostly implemented by big industrial companies and partly used by small and medium enterprises (SMEs) ▪ Programming of robots is rather complex and takes time ▪ Trend of "inline" flow production is decreasing more and more
I4.0 solution	▪ OEMs e.g. Audi are using Cobots with integrated sensors, predictive recognition and foam padding to guarantee safety at work ▪ Cobots adapting autonomously to working speed of humans ▪ Daimler is following the concept of „robot farming", where a worker can deploy several robots at place of need to help him with assembly tasks (e.g. overhead working) ▪ BMW is using cobots in door assembly, which swap tasks with humans to learn from each other ▪ Ferrari is using cobots for high risk production steps e.g. shock freezing of parts for dedicated assembly processes
Benefits	▪ Cobots reduce physical risks and effects on healthy for humans and improve ergonomics ▪ Less production space needed, flexible work space possible ▪ Improved overall productivity ▪ Easy programming due to enhanced roboter learning abilities (AI) and self programming





Source: Audi, Thiele, KUKA, BMW

Examples

- VW / Audi
- Daimler
- BMW
- Semiconductor (Infineon)

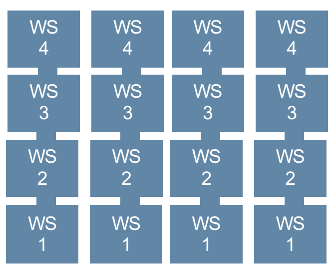
❷ COLLABORATION ROBOTS REQUIRE FLEXIBLE WIRELESS CONNECTIVITY

Schematic representation of a flexible robot production

Production area

Old world

In traditional flow manufacturing, the product passes through several workstations which produce the product step by step. In most cases, the work steps are defined at each station.



WS x = Work station/step

New world

Flexible cell solutions are independent of work steps and can carry out various production steps as required. They offer a maximum of flexibility and allow a better utilization because they are not bound to fixed work steps.

Requirements

- **Flexibility:** Production robots are highly expensive machinery which needs to be used continuously. Easy local repositioning increases efficiency but requires wireless connectivity
- **High reliability:** Production progress is measured in milliseconds. avoiding damage to the product or to people requires low latency connectivity
- **High bandwidth:** Test and scanning data can be highly data intensive and require high bandwidth connection

❸ SMART MAINTENANCE TO INCREASE UPTIME

Current situation

- Planning and control of maintenance operations is often barely integrated in ERP systems
- Maintenance operations are mostly performed either preventive or corrective by external personnel on the site and not remotely

I4.0 solution

- Data analytics software and cloud computing is used to plan maintenance repair operation (MRO) activities and detect causes for technical faults
- Relevant maintenance data is monitored and displayed via smart devices, thus enabling every employee easy access
- Using smart devices and remote monitoring solutions, maintenance operations can be done in-house
- Simple connection option for the equipment to the network

Benefits

- Higher uptime of production equipment
- Increased machine productivity and effectivity
- Reduced maintenance and service costs
- Higher product and service quality
- Efficient spare part use and less stocks

Source: Bundesministerium für Bildung und Forschung

Examples

- BMW: Condition Based Service
- Israel Electric Company (IEC)
- Research Projects: BMBF - SCPS
- Audi: Smart factory

❸ MAINTENANCE USING PREDICTIVE PRINCIPLES BY BIG DATA ANALYTICS

Current situation

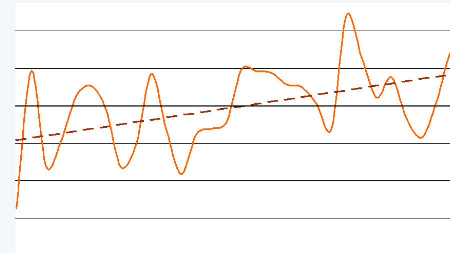
- Automotive OEM e.g. Daimler had a problem with deviations in the production of cylinder-heads, which resulted in defects
- Large retailer sought to reduce its stocks and optimize shares of products in Warehousing to minimize costs

I4.0 solution

- Daimler used a “Big Data” and analytics software to monitor production process and evaluated it over night, pointing out relevant set of thresholds to guarantee process stability[1]
- IBM implemented Big Data solutions at a big automotive parts retailer to optimize warehousing
- Flexible connection of the equipment at any time at any place within the company
- Online evaluation and maintenance including environmental data of the entire network and not of the individual equipment

Benefits

- Using “Big Data” and analytics Daimler increased productivity of cylinder-head production by 25%
- Time to ramp-up process reduced by half[1]
- Increased revenue by USD 109 million[2]
- Reduction of non-working capital as well as stocks[2]



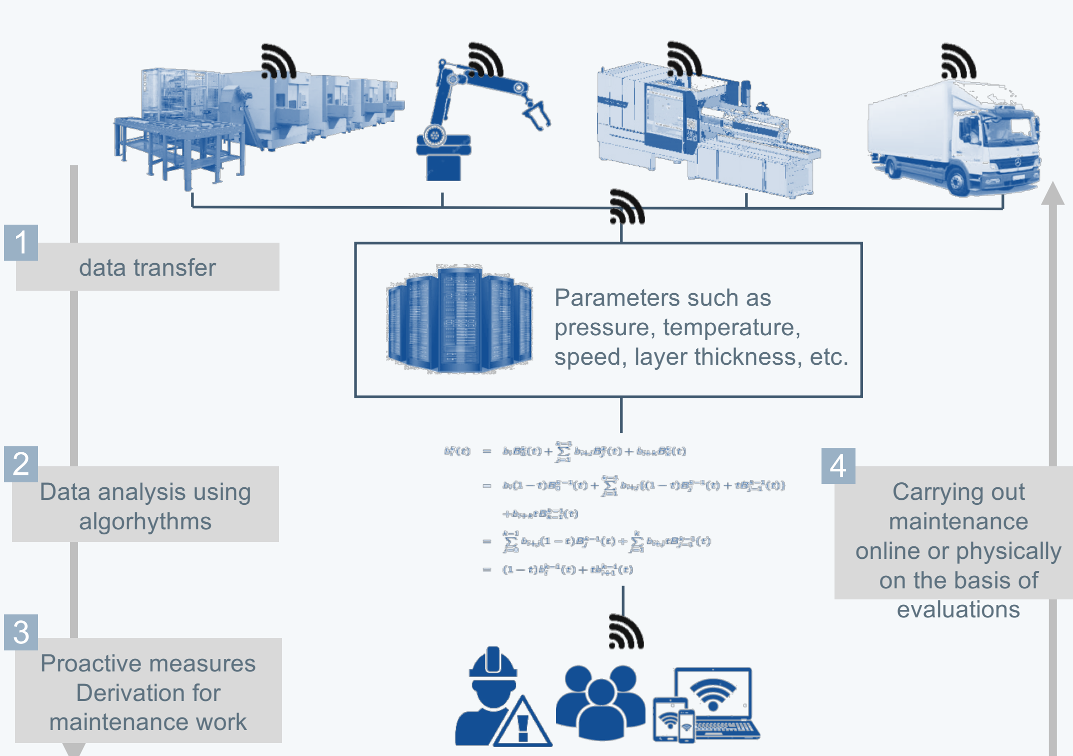
Source: Big Data-careers

Examples

- Daimler[1]
- Advance Auto Parts[2]
- IBM

3 APPLICATION EXAMPLE AND REQUIREMENTS FOR PREDICTIVE AND REMOTE MAINTENANCE

Schematic representation predictive maintenance functionality



Requirements

- **High bandwidth:** Needed to transfer all relevant parameters for the algorithmic calculation.
- **Many devices:** Potentially a large number of machines and sensors need connecting throughout a factory
- **Secure remote connection:** Remote management access to expensive machinery in high value production lines requires the highest level of confidentiality
- **Low latency:** To initiate measures earlier to avoid damaged equipment by inadequate maintenance

❹ EXTENSIVE SUPERVISORY CONTROL AND DATA ACQUISITION WITH A PLETHORA OF SENSOR SYSTEMS

Current situation

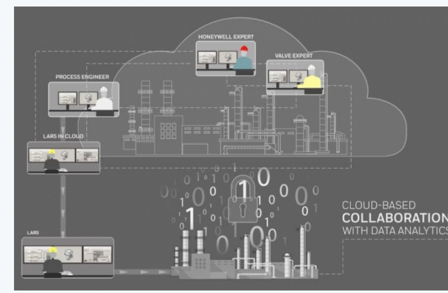
- Large-scale production facilities already have existing supervisory control and data acquisition applications
- Control parameters are e.g. temperature, pressure, density, acidity and flow in the various plant components. On the site itself, the central control rooms are the digital heart of e.g. refinery
- Fully integrated control system is difficult or very costly to implement

I4.0 solution

- Full connection of all relevant production sensors and equipment, adding in new AI-based ones, e.g. via speech control
- Control of valves across the hole production site can be easily implemented for full transparency of production status
- Outlook: Collect data such as "noise" within the systems to identify upcoming defects on equipment. The existing connections and the existing degree of digitization can be enriched by more flexible connection and new interfaces.

Benefits

- Parts of large-scale production facilities can be controlled (central control tower) and checked fully automatically - especially from long distances
- Connection errors and thus also risk situations are avoided through spacious connection areas



Examples

- BASF
- Water and electricity grids
- Airports
- Container terminals

❹ SMART ENERGY SOLUTIONS TO INCREASE ENERGY EFFICIENCY

Current situation

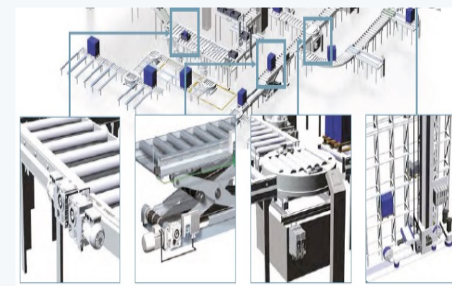
- Current intra logistical transportation systems consist of fully automated storage and supply units, whose energy consumption results primarily through their electric drives
- Smart energy management plays minor part in production processes

I4.0 solution

- Using smart load management to optimize warehouse in real time regarding load peaks in order to level out energy consumption
- Modular transportation systems are used to create an ecological as well as efficient solution
- BMW is using a smart energy management data system to monitor energy consumption and compare it with a "Big Data" network
- Refrigerated warehouse management to reduce energy consumption and optimize temperature in all sectors of the warehouse (variable cooling system)

Benefits

- Improved production planning regarding energy consumption and equipment efficiency
- Reduced energy costs through optimization of intra logistic processes (e.g. number of cars used)
- Using "Big Data" applications to optimize logistic processes according to certain factors (e.g. energy price…)
- Increased energy efficiency through optimized steering process



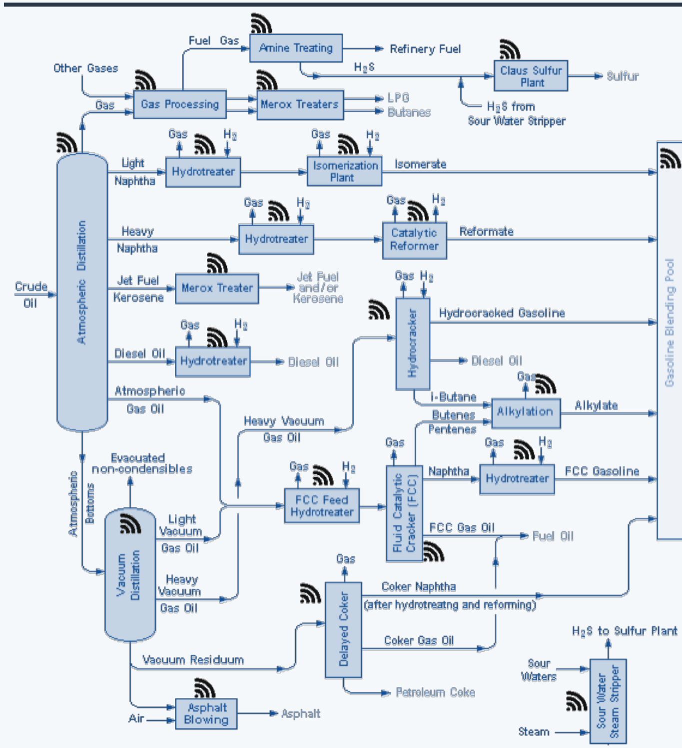
Source: Lenze; its OWL research cluster, BMW

Examples

- Lenze: Smart load management
- BMW: "iEDMS"
- Daimler

❹ APPLICATION EXAMPLE AND REQUIREMENTS FOR LARGE-SCALE CONTROL

Schematic representation of large-scale plant (refinery) and control



control center

In large-scale operations such as refineries and pharmaceutical plants, a long-range connection of all plant components must be established in order to be able to perform all control tasks centrally.

Requirements

- **Full site coverage:** In order to be able to connect all parts of the plant within the company premises
- **Many devices:** The network must be able to connect many devices as a large number of components are available
- **Low cost per connection:** Connecting many additional sensors only becomes feasible once this is done cost effectively
- **Ultra-high reliability**: Sensor-based control actions affecting major processes are only possible once there can be a high reliance on data availability

5 USING VIRTUAL REALITY AND DIGITAL FACILITIES TO OPTIMIZE THE PRODUCTION PROCESS

Current situation

- Global collaboration is limited to classical interaction e.g. phone calls, emails and ERP-systems
- Studies investigating the physical effects of production processes on employees are often performed manually
- Production layouts and movements are rarely simulated before production starts

I4.0 solution

- Motion capturing used to collect data on physical stress e.g. FORD
- Smart Devices are used to connect the operator facilities worldwide e.g. Audi, allowing him to walk virtually to the same
- Plants are simulated virtually even before they are built to ensure correct production layouts and processes e.g. Audi/VW
- Software solutions e.g. IntoSite (Siemens AG) enable employees around the world access to production sites e.g. FORD and sharing documents

Benefits

- Virtual testing of production processes before real start (up to 3 years), ensuring ergonomics, efficiency and fast production ramp-up
- Increased product quality, due to lower deviations and clear and understandable production processes
- Improved global collaboration through virtual connection of production facilities

Source: IFF, Audi, Ford

Examples

- Audi/VW: Virtual factory
- Ford: Virtual manufacturing
- Frauenhofer IFF: Elbe Dom

Thank you