The concepts of smart factories and distributed systems

Concepts and focus on the customer
Modularity and connectivity
Centralized, decentralized, and distributed systems, the Edge Computing.
„Top-down“ and „bottom-up“ approaches in implementing industry 4.0 solutions
Virtualization of processes and systems and visualization of production.

Concepts and focus on the customer

Let's ask ourselves once again and reflect...

WHAT IS THE FACTORY OF THE FUTURE – SMART FACTORY?

The factory of the future is a vision for how manufacturers should enhance production by making improvements in three dimensions:

- ❑ Plant Structure
- ❑ Digitalization of Manufacturing Processes (and the entire factory)
- ❑ Business Processes/Factory Processes

Plant Structure

- Flexible, multi-directional layout
  - Individually guided AGVs for the logistics (products and components)
  - AGVs are guided by a laser scanner or an IR camera, markers, and RFID technology throughout the factory layout
  - Such systems enable a quick change of layout
- Modular production lines and cells Setup
  - Use of tool changers, grippers, fast and easy configuration/reconfiguration
  - Easy to change the production lines and equipment
- Sustainable production
  - Efficient consumption of energy and materials
  - Environmentally safe

Plant digitalization

- Implementation of digital twins of production processes for process optimization and material flow.
- Implementation of decentralized and distributed control of production with autonomous production subprocesses and communication among products, machines, and workers.
- Introduction of smart robots.
- Use of collaborative robots.
- Implementation of additive technologies (3D printing).
- Utilization of Augmented Reality (AR).
- Application of "Big Data" analytics (Predictive analytics).
- Intensive targeted training.

Plant processes

The goal is to elevate all processes and factory management to a higher level and harness the full potential of the factory (employees, knowledge, technology, equipment, the entire value chain, ...).

- Customer Centricity
  - ✓ Gaining a better understanding of customer needs through the use of "Big Data" analytics, how customers use the product.
  - ✓ Based on this data, product and production process improvements follow.
- Continuous Improvements
  - ✓ Utilizing new technologies to increase value and enhance the efficiency of production processes.
- Fully integrated Value Chain (suppliers, component manufacturers, customers, etc.)

7 Tips for Implementing a Customer - Centric Strategy

To be fully effective, customer-centric factory should go beyond the sales department (also marketing, customer service, R & D, Technology, production…)

What is a Customer-Centric Strategy?
How Do You Implement Customer-Centric Selling?

1. Believe in IT !
   - be committed to bringing true value to your clients!!!
   - evaluate everything through the eyes of the customer and with the customer's needs, wants, and behaviours in mind.
2. Research the customer
3. Ask Great Questions – and be good listener!

7 Tips for Implementing a Customer - Centric Strategy

To be fully effective, customer-centric factory should go beyond the sales department (also marketing, customer service, R & D, Technology, production…)

4. Be Consultative - focus first on understanding the issue, then on helping to solve it with the most appropriate solution.
5. Use the Customer‵s Communication Style – it will make the customer feel more at ease and will improve it‘s overall experience with your company.
6. Invest in Customer Service Training (R&D, Technology, ...) – achieve the differentiation of your company from the competition
7. Demand Feedback and Adapt to it - feedback from your customers (and even opportunities that you lost) can help you learn what you're doing right, and where you can tweak your approach to be more successful in the future.

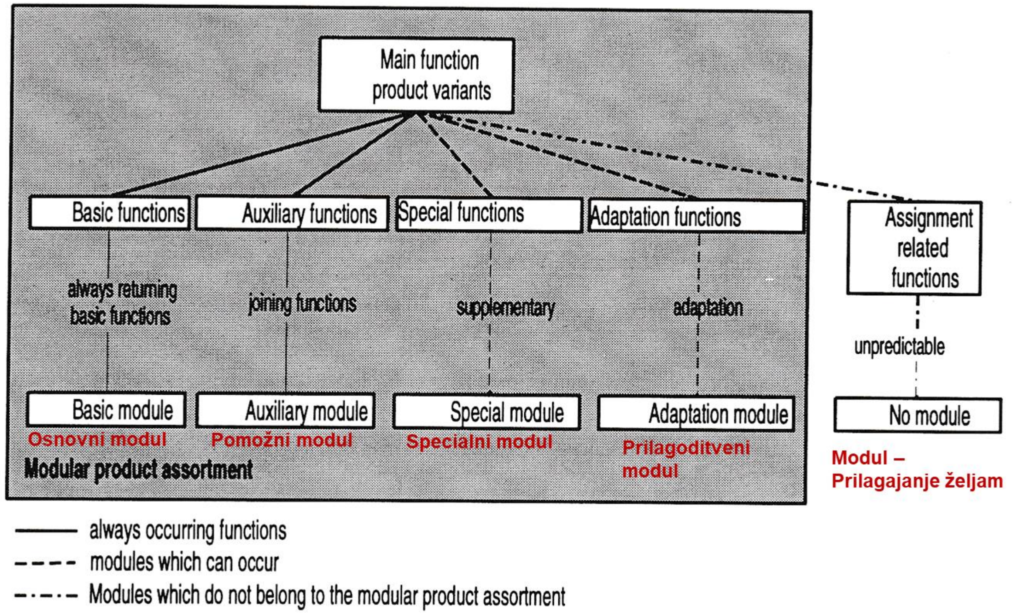
The Three Enablers of smart factory

- Strategy and Leadership
  - The strategy of the factory of the future must become an integral part of the corporate strategy of the company.
  - Companies need to adapt their leadership style to the new way of working.
- Employee Skills
  - Companies must educate and acquire a workforce with the appropriate skills and, above all, competencies for technologically focused manufacturing tasks.
- IT Infrastructure
  - The IT infrastructure must enable connectivity throughout the entire value chain and ensure data security.

Modularity and connectivity

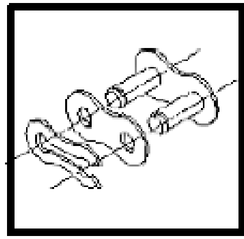
The concepts of modular smart factory

- Starting point: the concept of modular product

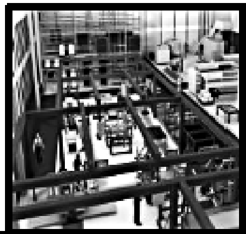


- We apply a similar approach at the level of the factory, as well as individual production systems and processes.
- The modular principle is ESSENTIAL in the Smart Factory concept!!! It reduces the complexity of planning production processes, as well as the time and costs of planning (by 25 to 45%) – the foundation for FACTORY STANDARDIZATION!!!
- Modular factory design enables the FLEXIBILITY and AGILITY of the entire factory or individual production processes and systems.
- The fundamental principle of the modular factory concept is based on relatively independent factory units that exhibit a minimal required level of interaction.

Analogy between product development and factory planning



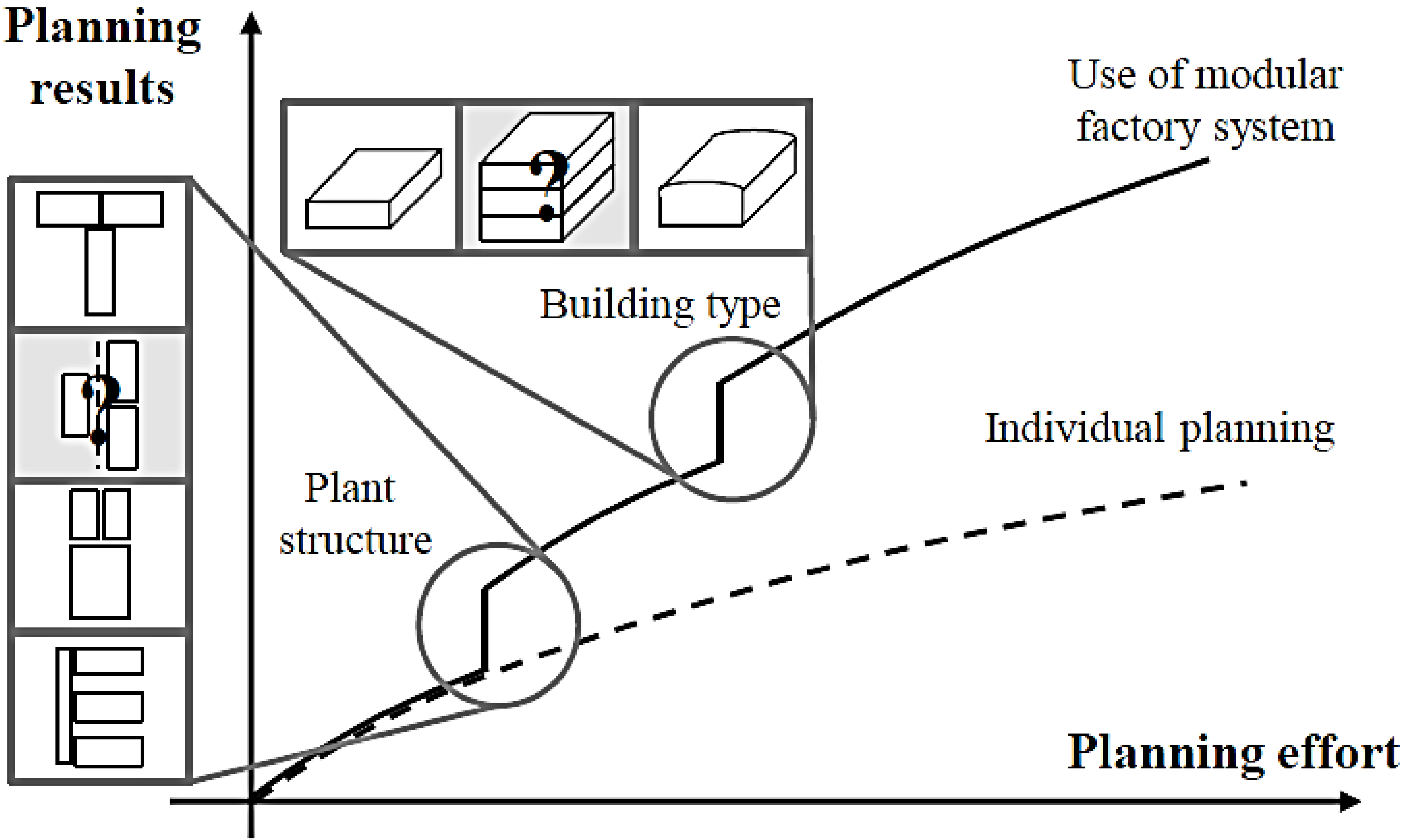
Product development ⟷ **Analogy** ⟷ Factory planning



Product development: low	medium	high	**Scope**	Factory planning: low	medium	high
		●	Degree of concreteness, materiality			●
		●	Individuality of the planning object			●
		●	Complexity of the planning object			●
	●		Durability /life time cycle of the planning object			●
●			Reversibility of the planning results	●		
		●	**Objects**			●
		●	Number of planning objects			●
		●	Interdependency of the planning objects			●
		●	Number of interfaces beyond system boundaries			●
		●	Reusability of planning results		●	

Source: Achim Kampker, Hanno Voet*, Peter Burggräf, Moritz Krunke, Kai Kreisköther, Methodology for the Development of Modular Factory Systems

Modular factory concept – simplify planning and improvments in results



Source: Achim Kampker, Hanno Voet*, Peter Burggräf, Moritz Krunke, Kai Kreisköther, Methodology for the Development of Modular Factory Systems

The developed methodology of modular smart factory systems

Phase 1: Decomposition → **Phase 2:** Synthesis → **Phase 3:** Manifestation

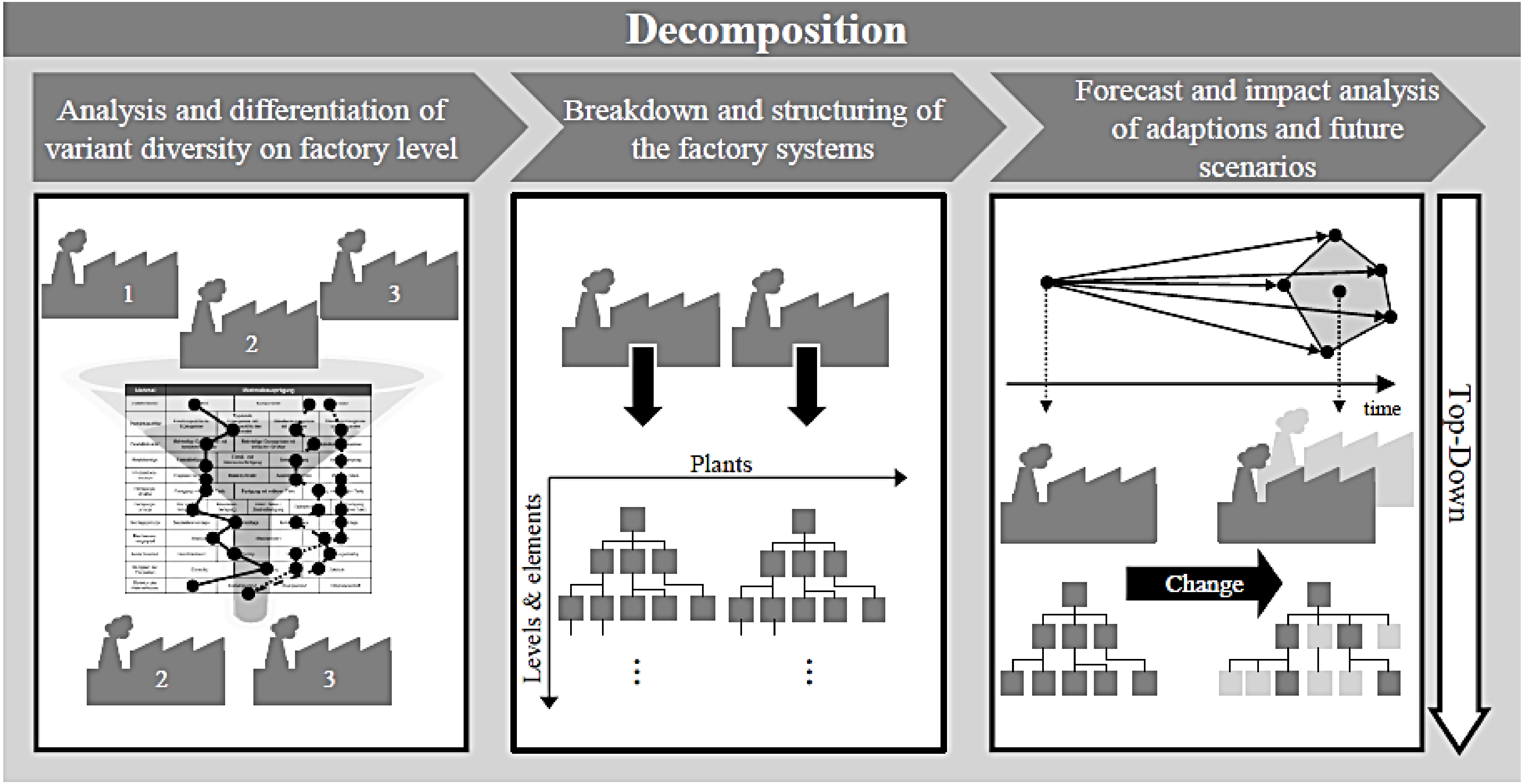
- Decomposition phase:
  - To get an overview of the existing factory element variety in a company.
  - Detailed analysis of individual elements and scenarios of possible future adaptations.

- Synthesis phase:
  - Development of modules and analysis of individual factory elements regarding their potential for standardization.
  - Development and evaluation of various factory module concepts.

- Manifestation phase (documentation, representation)
  - Creation of documentation for developed, selected, and specified factory modules.
  - Internal and external communication.
  - Development of a plan and instructions with information on when each factory module will be used, and if applicable, whether it will be utilized in another part of the factory externally or with a supplier.

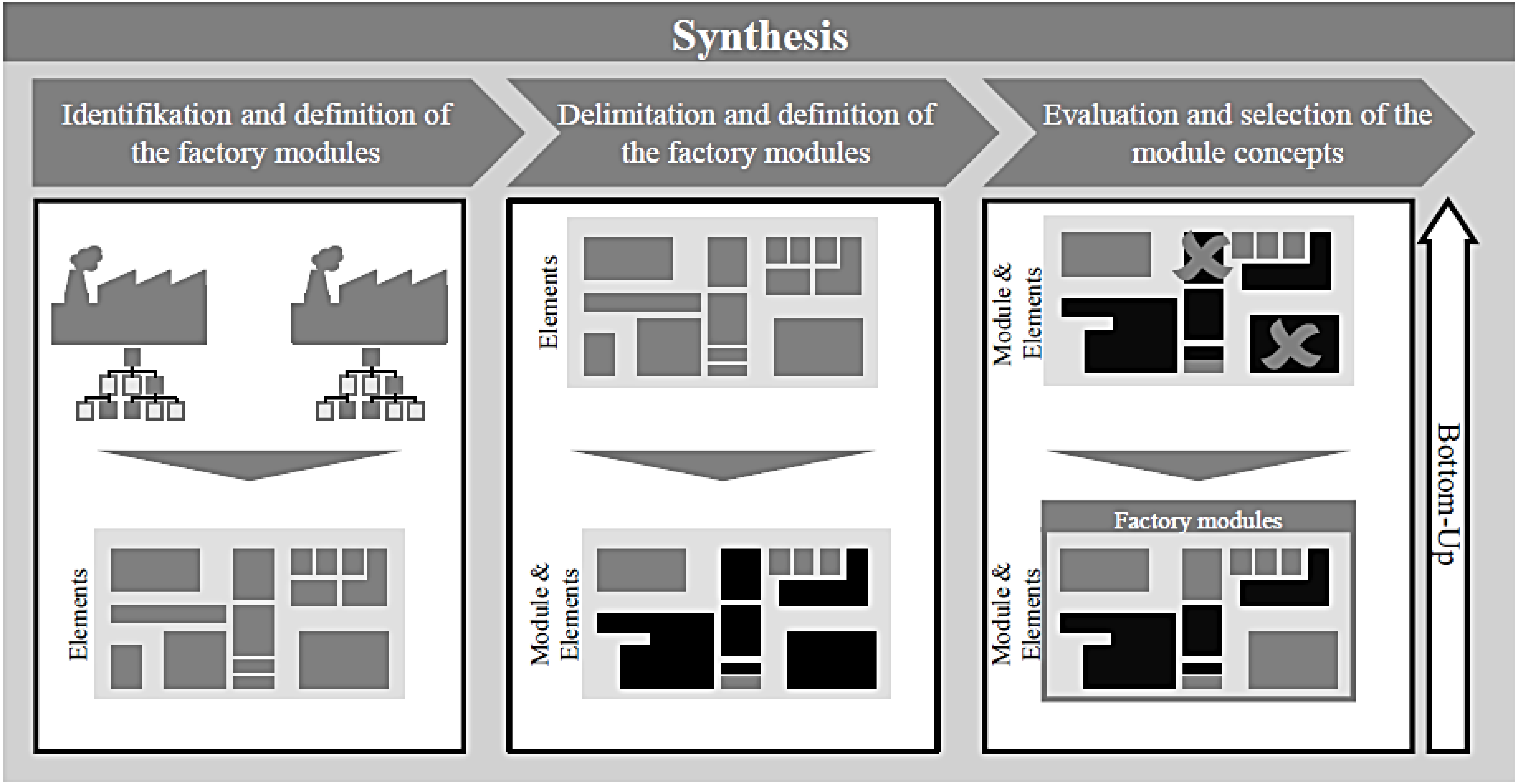
Source: Achim Kampker, Hanno Voet*, Peter Burggräf, Moritz Krunke, Kai Kreisköther, Methodology for the Development of Modular Factory Systems

The developed methodology of modular smart factory systems – Phase 1



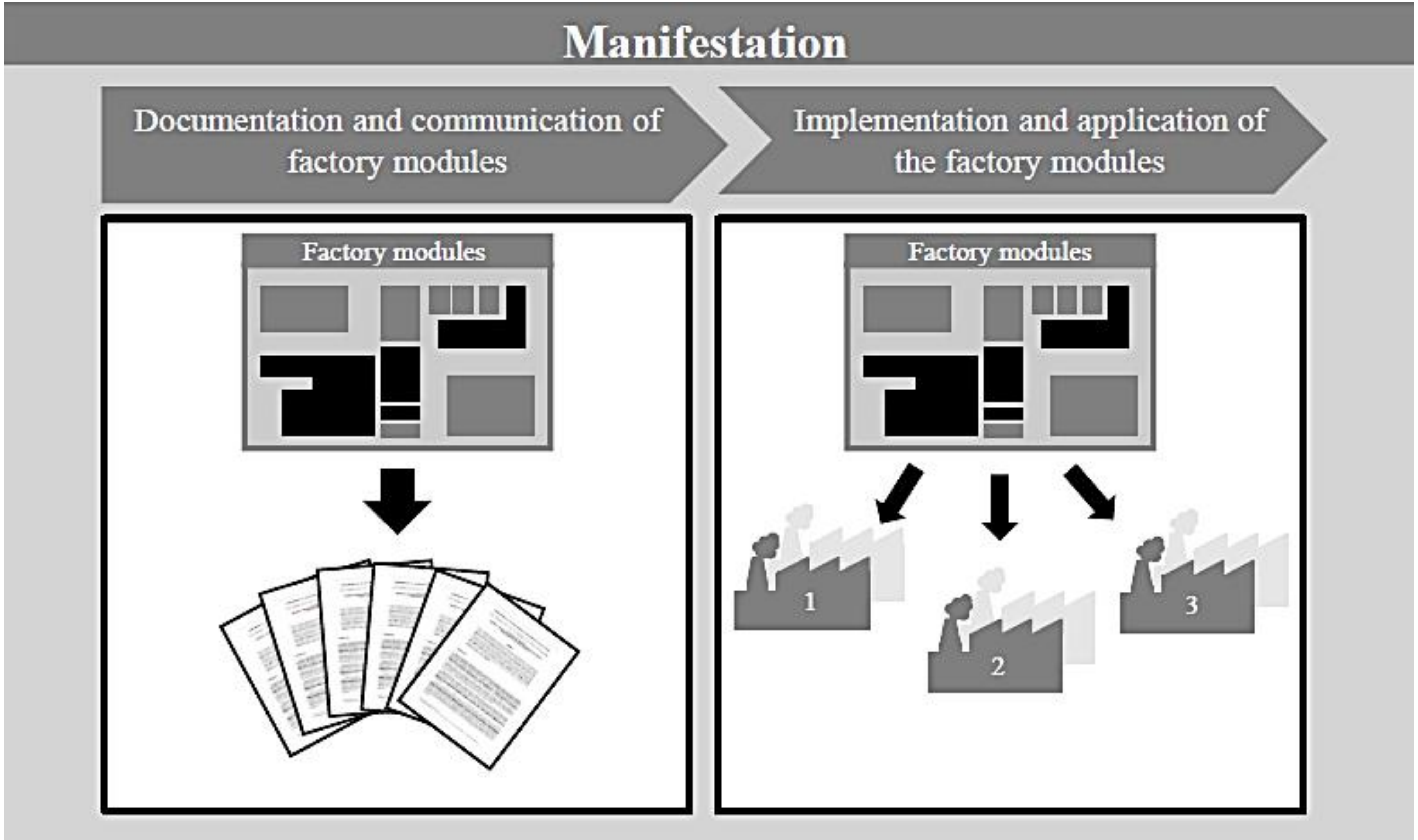
Source: Achim Kampker, Hanno Voet*, Peter Burggräf, Moritz Krunke, Kai Kreisköther, Methodology for the Development of Modular Factory Systems

The developed methodology of modular smart factory systems – Phase 2



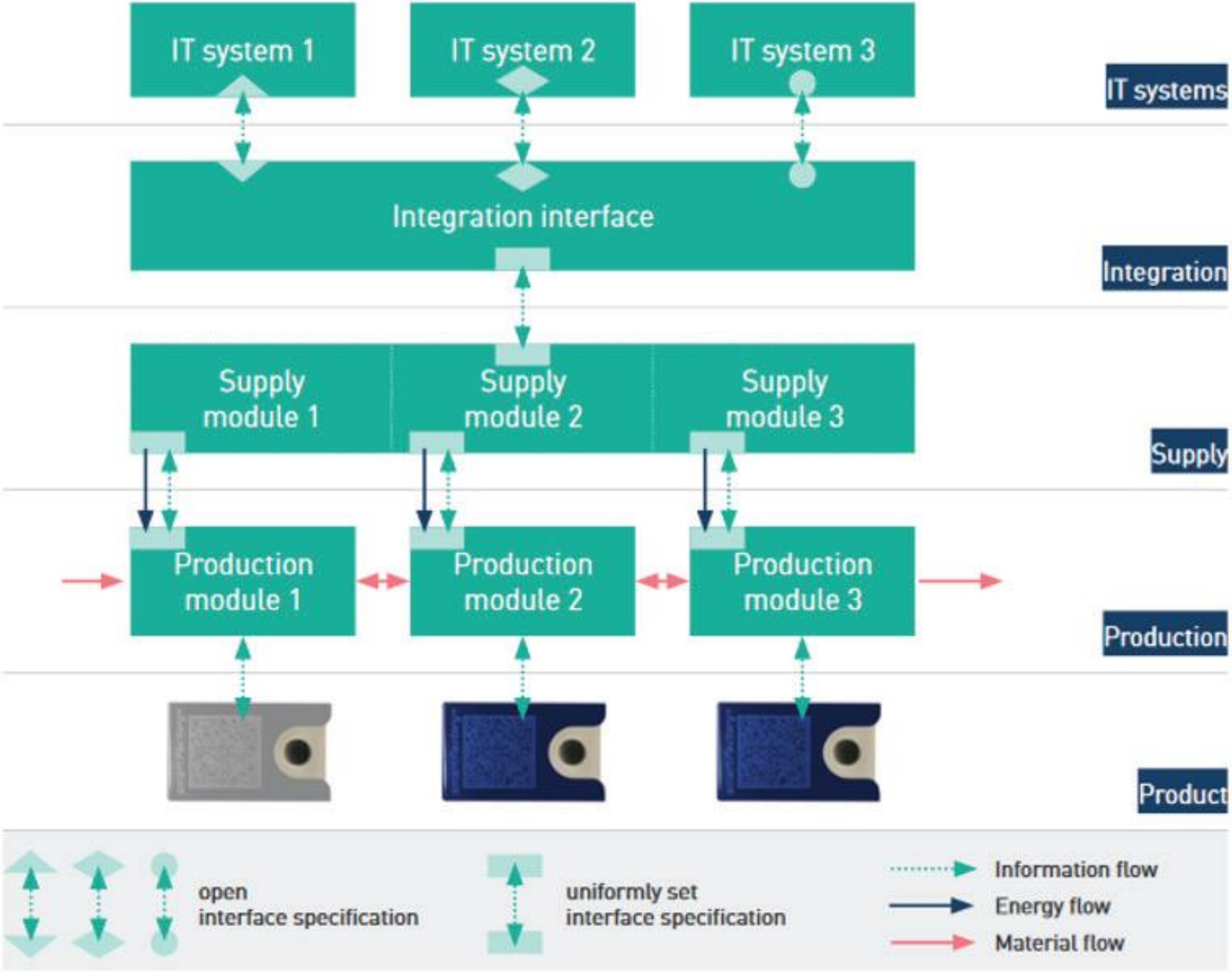
Source: Achim Kampker, Hanno Voet*, Peter Burggräf, Moritz Krunke, Kai Kreisköther, Methodology for the Development of Modular Factory Systems

The developed methodology of modular smart factory systems – Phase 3



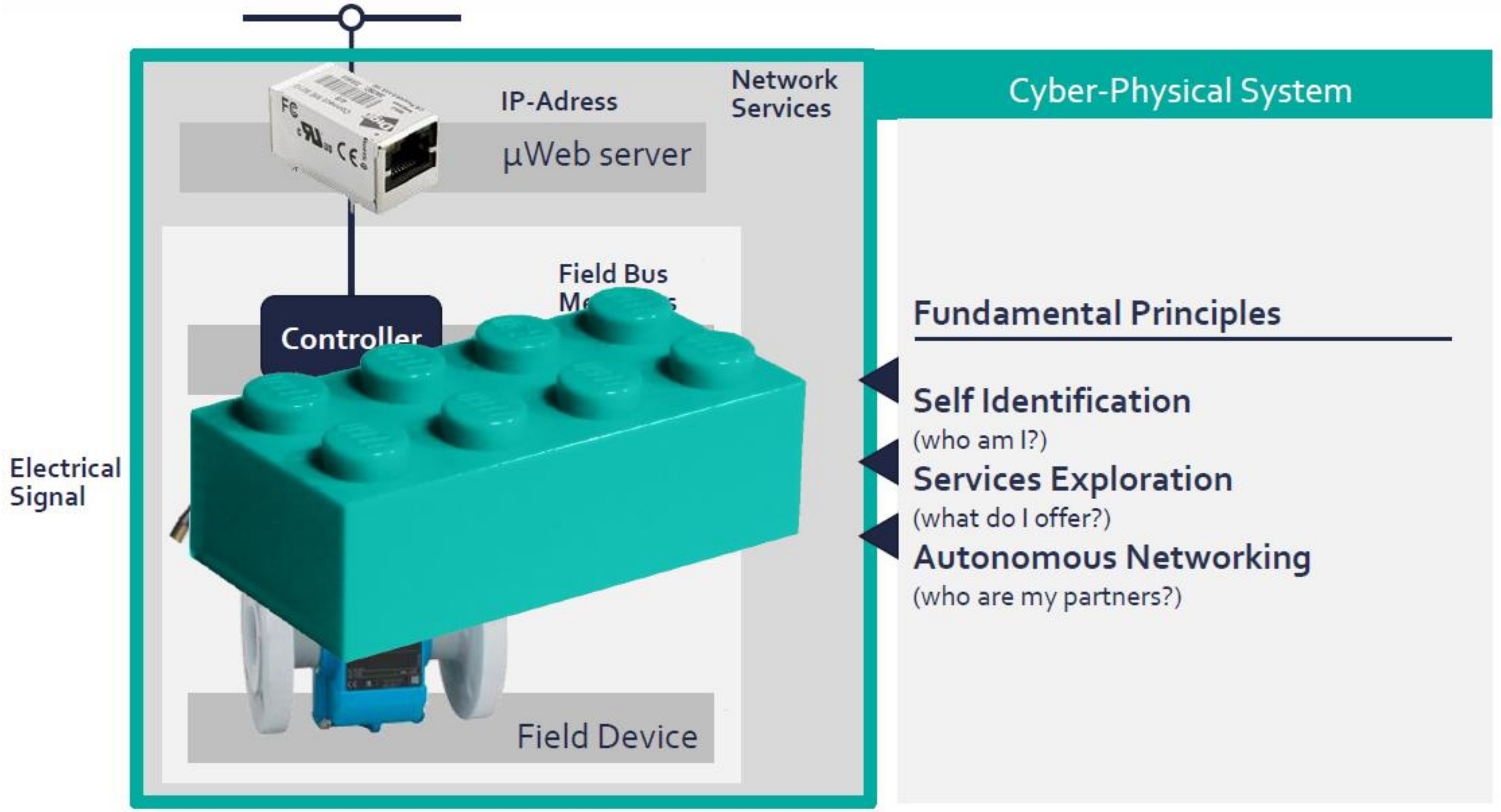
Source: Achim Kampker, Hanno Voet*, Peter Burggräf, Moritz Krunke, Kai Kreisköther, Methodology for the Development of Modular Factory Systems

Concept of system architecture and connectivity of modules for a smart factory



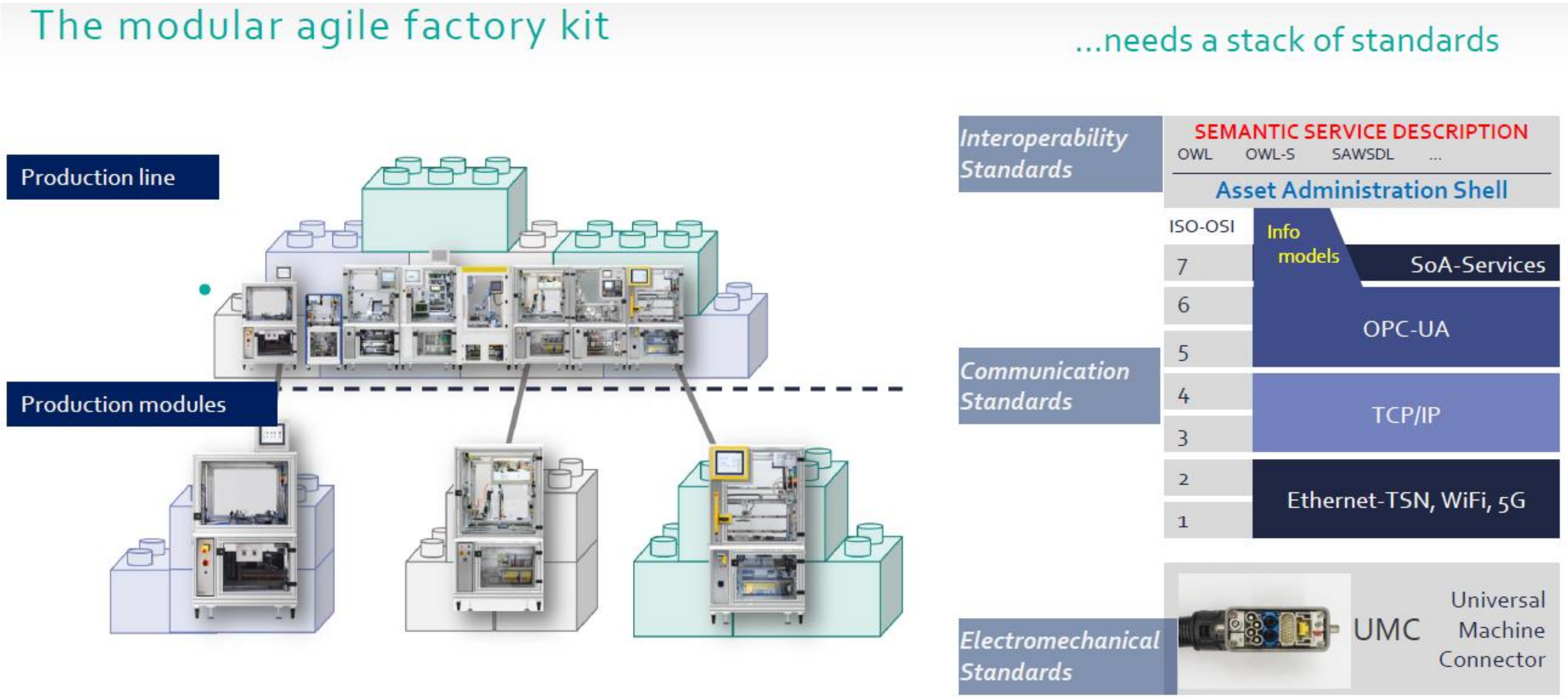
Source: Gorecky at al., DFKI GmbH

Smart modules



Source: Detlef Zuelke, Smart Factory KL

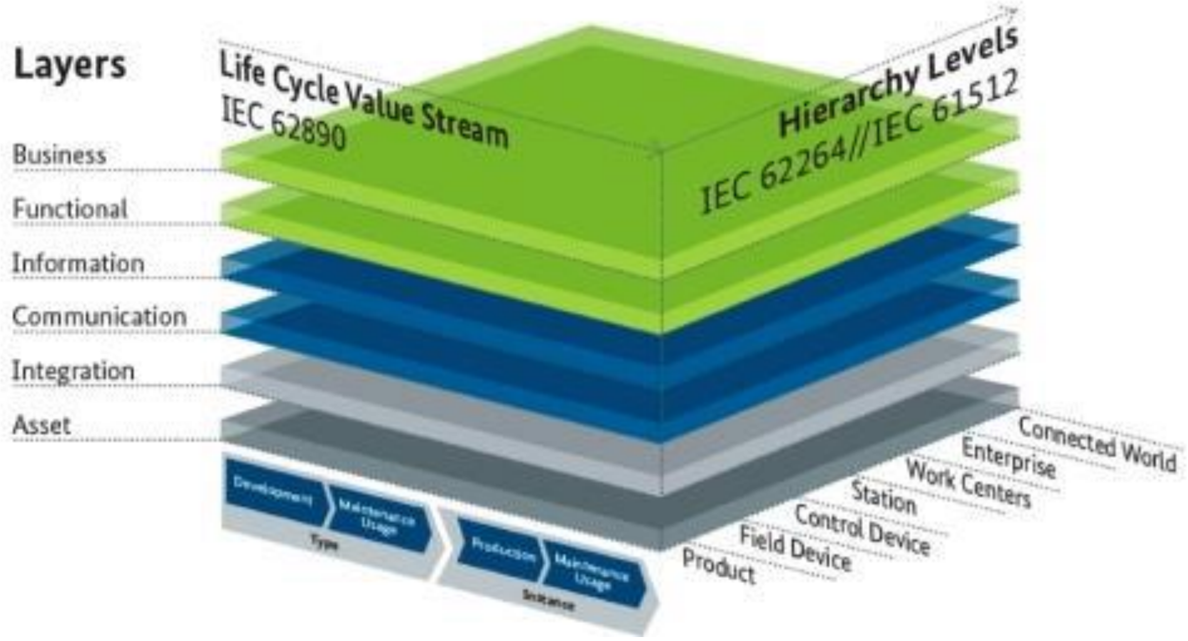
Modular plant, standardization, Plug&Produce



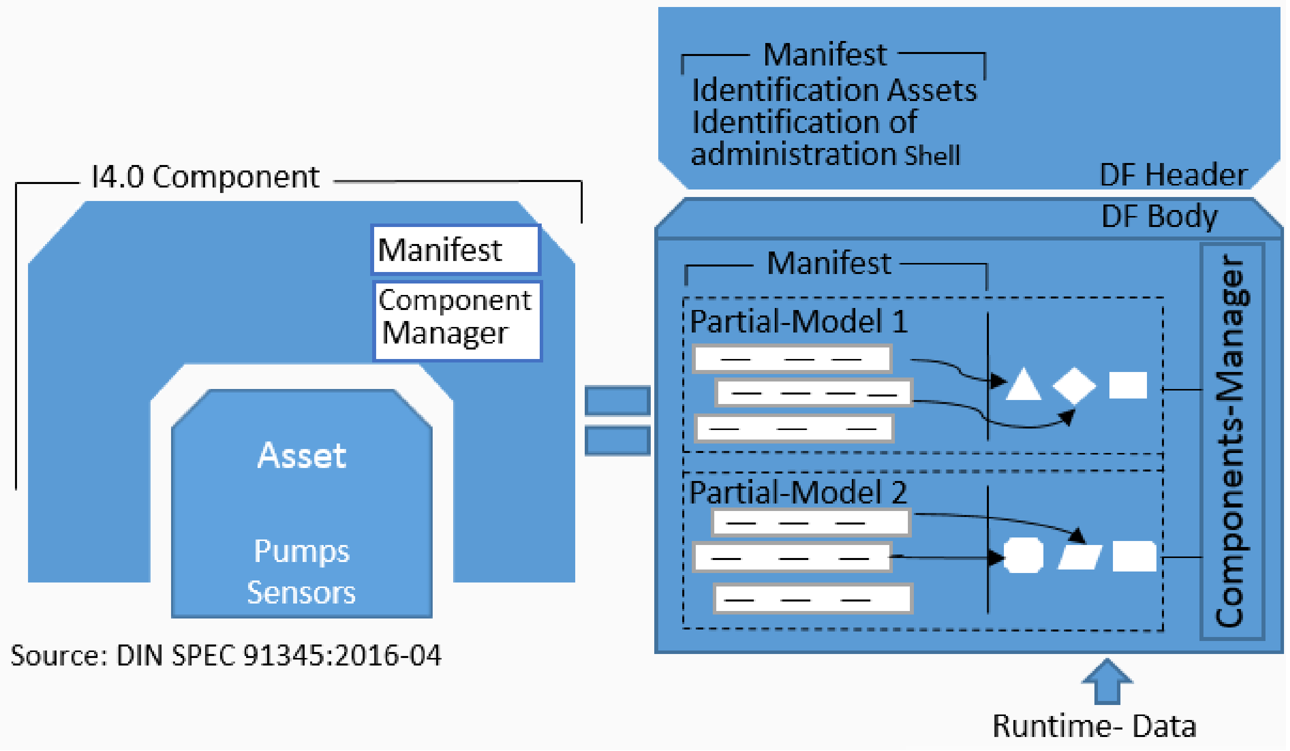
Source: Detlef Zuelke, Smart Factory KL

RAMI 4.0 – helping with standardization of factory modules

Reference architectural model RAMI 4.0



Asset administration shell



Source: Detlef Zuelke, Smart Factory KL

Modularity and connectivity– Plug and Produce

Backbone-Box

Product memory

Module localization

„Maschine-USB"-Connector

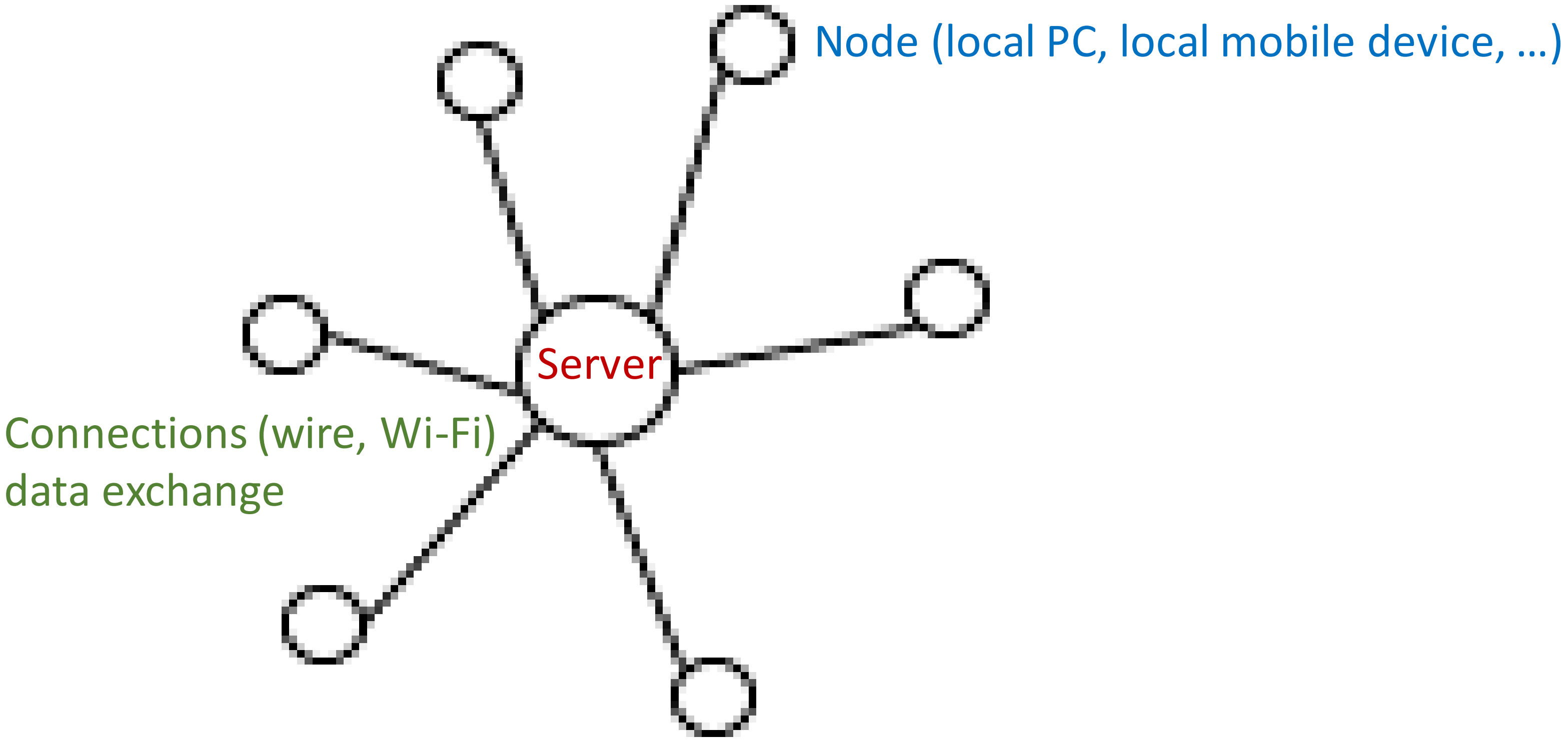
Smart safety system

Flexible conveyor locks

Source: Detlef Zuelke, Smart Factory KL, Jan Jatzkowski et al., Hierarchical Scheduling for Plug and Produce

Centralized, decentralized, and distributed systems → Edge Computing

Centralized production systems



- The characteristic of a **centralized** production, computer, or any other system is that one person, one computer, or one group of people carries out complete control, management, and decision-making from one center/computer.
- **A single central unit (server)**, where all the software is installed, oversees, controls, etc., all elements of the system.
- **The functioning (or non-functioning) of system elements** is dependent on whether the central unit is operational: the shutdown or malfunction of the central unit leads to the shutdown or malfunction of all system elements.

Centralized production systems – advantages / disadvantages

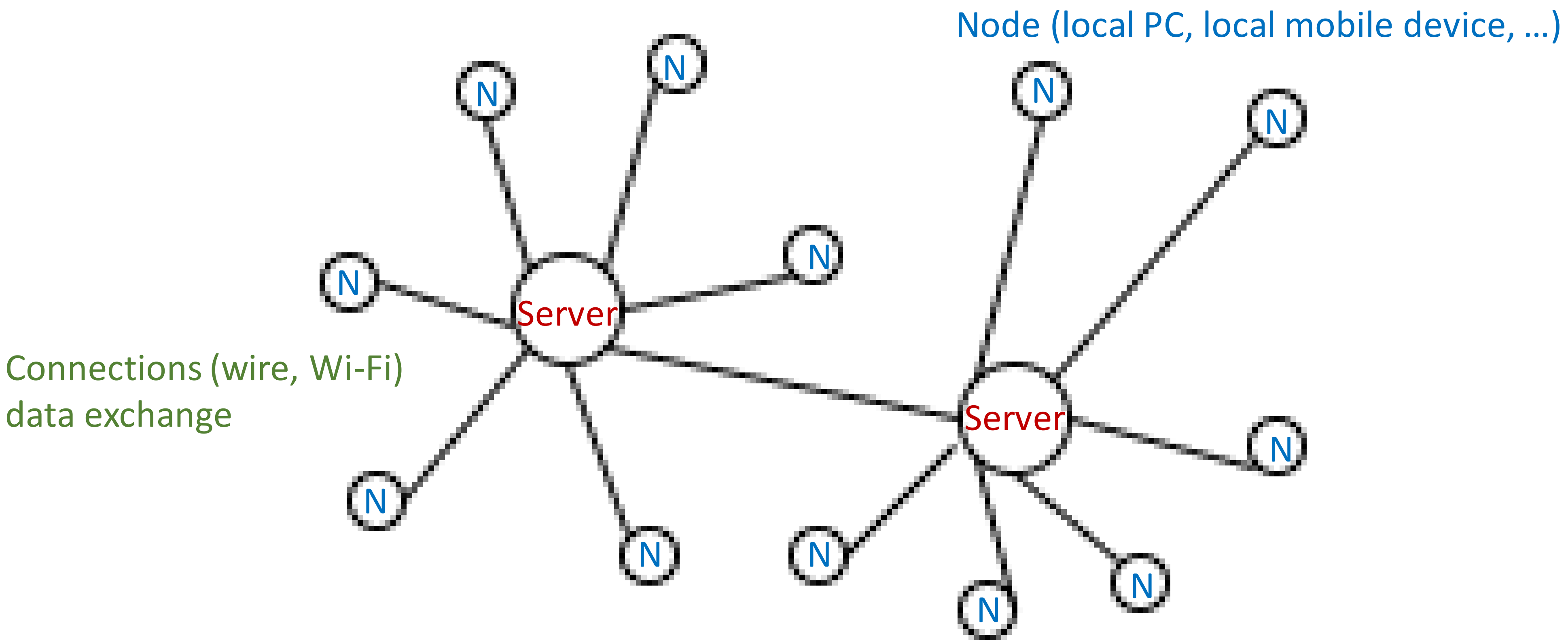
Advantages of Centralized System

- ✓ Easy to physically secure.
- ✓ Smooth and elegant personal experience – A client has a dedicated system which he uses (for example, a personal computer) and the company has a similar system which can be modified to suit custom needs
- ✓ Dedicated resources (memory, CPU cores, etc)
- ✓ More cost-efficient for small systems up to a certain limit – As the central systems take fewer funds to set up, they have an edge when small systems have to be built
- ✓ Quick updates are possible – Only one machine to update.
- ✓ Easy detachment of a node from the system. Just remove the connection of the client node from the server and voila! Node detached.

Disadvantages of Centralized System

- ○ Highly dependent on the network connectivity – The system can fail if the nodes lose connectivity as there is only one central node.
- ○ No graceful degradation of the system – abrupt failure of the entire system.
- ○ Less possibility of data backup. If the server node fails and there is no backup, you lose the data straight away.
- ○ Difficult server maintenance – There is only one server node and due to availability reasons, it is inefficient and unprofessional to take the server down for maintenance. So, updates have to be done on-the-fly(hot updates) which is difficult and the system could break.

Decentralized production systems



- The characteristic of decentralized systems is that each node makes its own decisions. The overall behaviour of the system is a result of the decisions made by individual nodes.
- There is no common unit that coordinates, accepts, or responds to the requests of individual nodes.
- This can lead to issues in the coordinated operation of the system.

Decentralized production systems – advantages / disadvantages

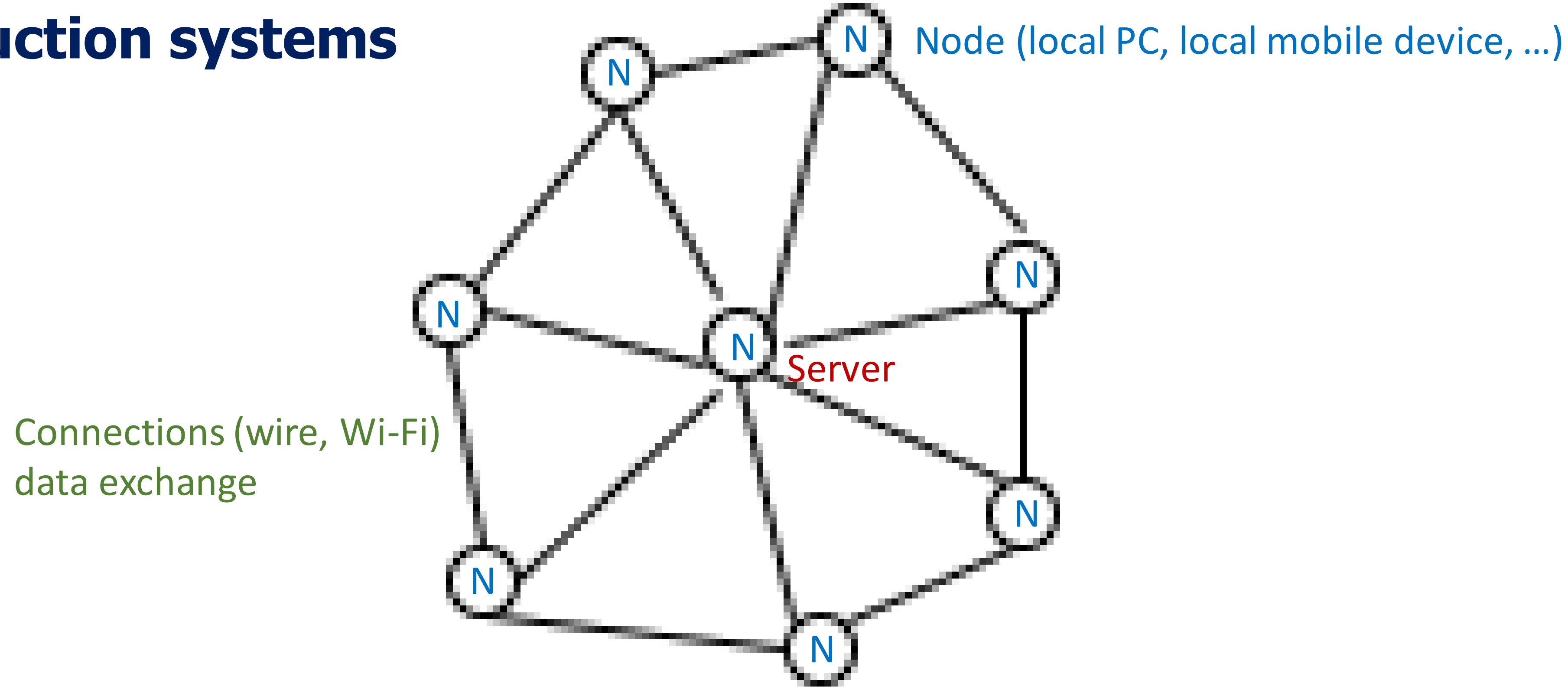
Advantages of Decentralized System

- ✓ Minimal problem of performance bottlenecks occurring – The entire load gets balanced on all the nodes; leading to minimal to no bottleneck situations.
- ✓ High availability – Some nodes(computers, mobiles, servers) are always available/online for work, leading to high availability.
- ✓ More autonomy and control over resources – As each node controls its own behaviour, it has better autonomy leading to more control over resources

Disadvantages of Decentralized System

- Difficult to achieve global big tasks – No chain of command to command others to perform certain tasks.
- No regulatory oversight.
- Difficult to know which node failed – Each node must be pinged for availability checking and partitioning of work has to be done to actually find out which node failed by checking the expected output with what the node generated.
- Difficult to know which node responded – When a request is served by a decentralized system, the request is actually served by one of the nodes in the system but it is actually difficult to find out which node indeed served the request.

Distributed production systems



- **The characteristic of distributed systems** is that each node makes its own decisions in agreement or COORDINATION with other nodes it is connected to, aiming to achieve optimal operation of the entire system.
- **Individual nodes can** distribute tasks and/or process specific tasks in parallel, increasing the transparency of system operation, providing more opportunities for error detection, and enabling scalability to other systems.
- **The possibility of bottlenecks** in the transfer of large amounts of data, as generated by a centralized system, is reduced.

Distributed production systems – advantages / disadvantages

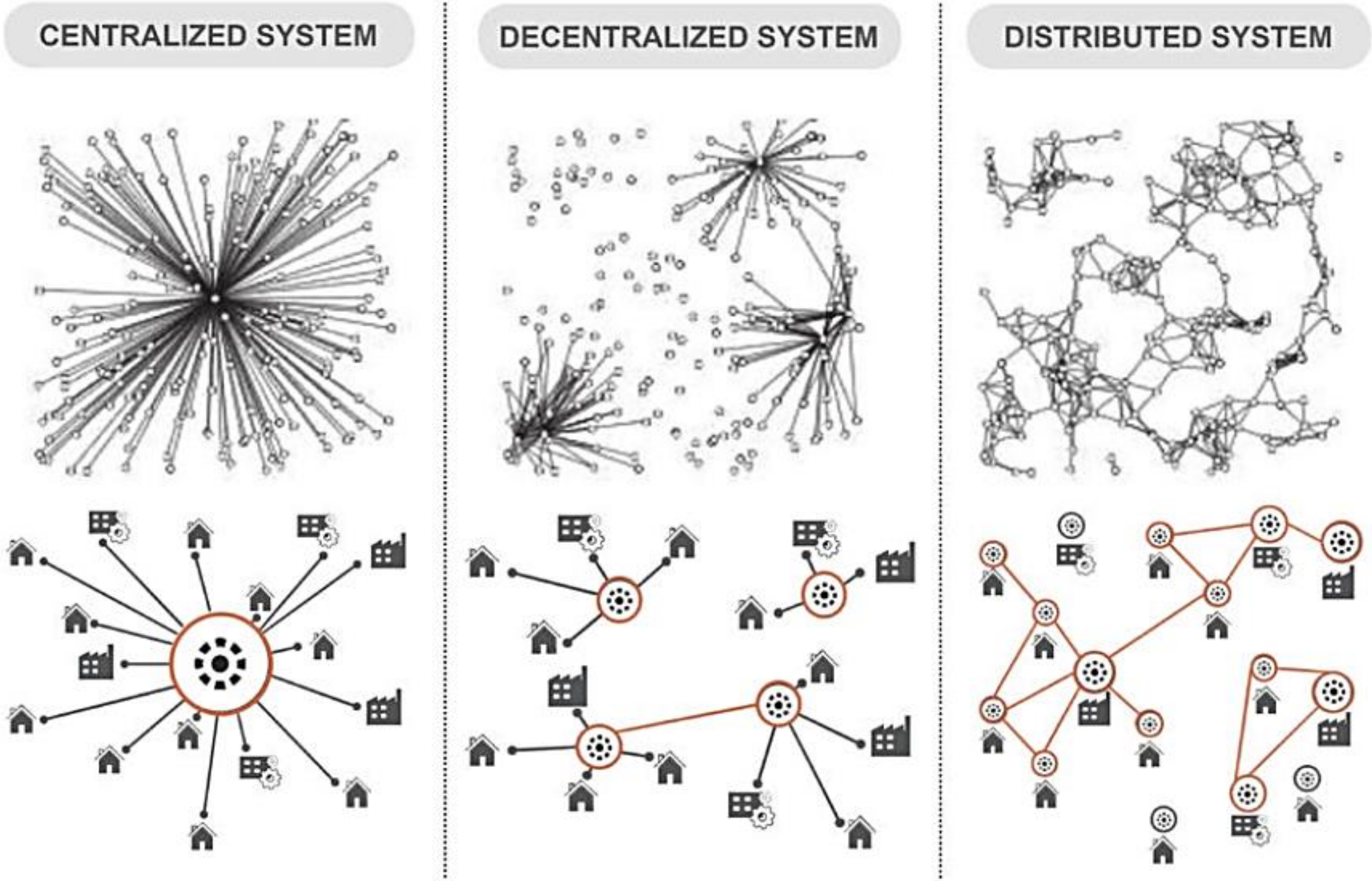
Advantages of Distributed System

- ✓ **Lower latency** than a centralized system – Distributed systems have low latency because of high geographical spread, hence leading to less time to get a response.
- ✓ **Transparency:** A node can access and communicate with other nodes in the system.
- ✓ **Scalability:** The computing and processing capacity can scale up as needed when extended to additional machines.
- ✓ **Error detection:** Failures can be more easily detected.

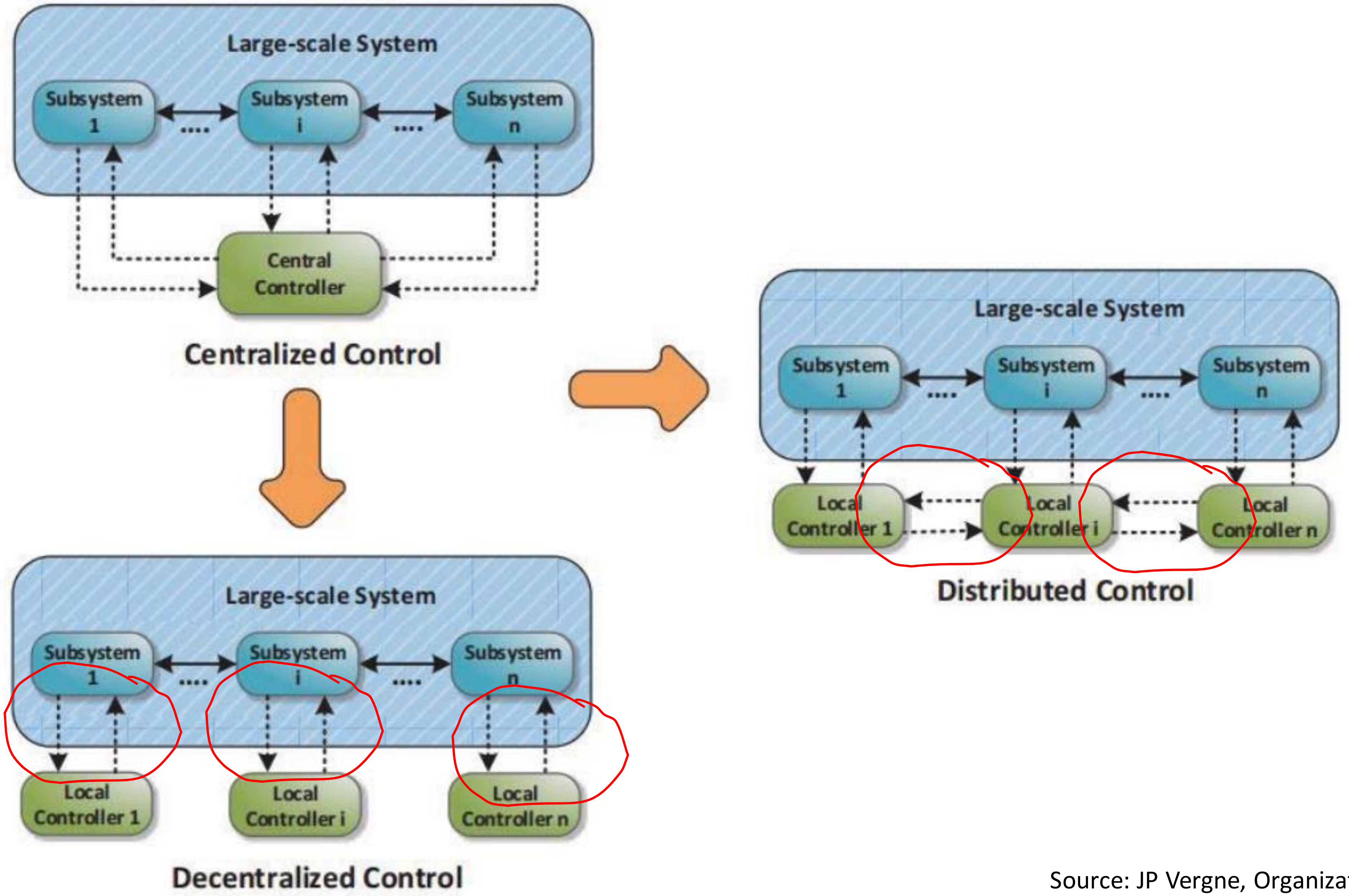
Disadvantages of Distributed System

- ○ Difficult to achieve consensus between nodes.
- ○ The conventional way of logging events by absolute time they occur is not possible here.
- ○ Difficult to design and debug algorithms for the system. These algorithms are difficult because of the absence of a common clock; so no temporal ordering of commands/logs can take place. Nodes can have different latencies which have to be kept in mind while designing such algorithms. The complexity increases with the increase in the number of nodes.
- ○ No common clock causes difficulty in the temporal ordering of events/transactions.
- ○ Difficult for a node to get the global view of the system and hence take informed decisions based on the state of other nodes in the system

Centralized, decentralized and distributed production systems

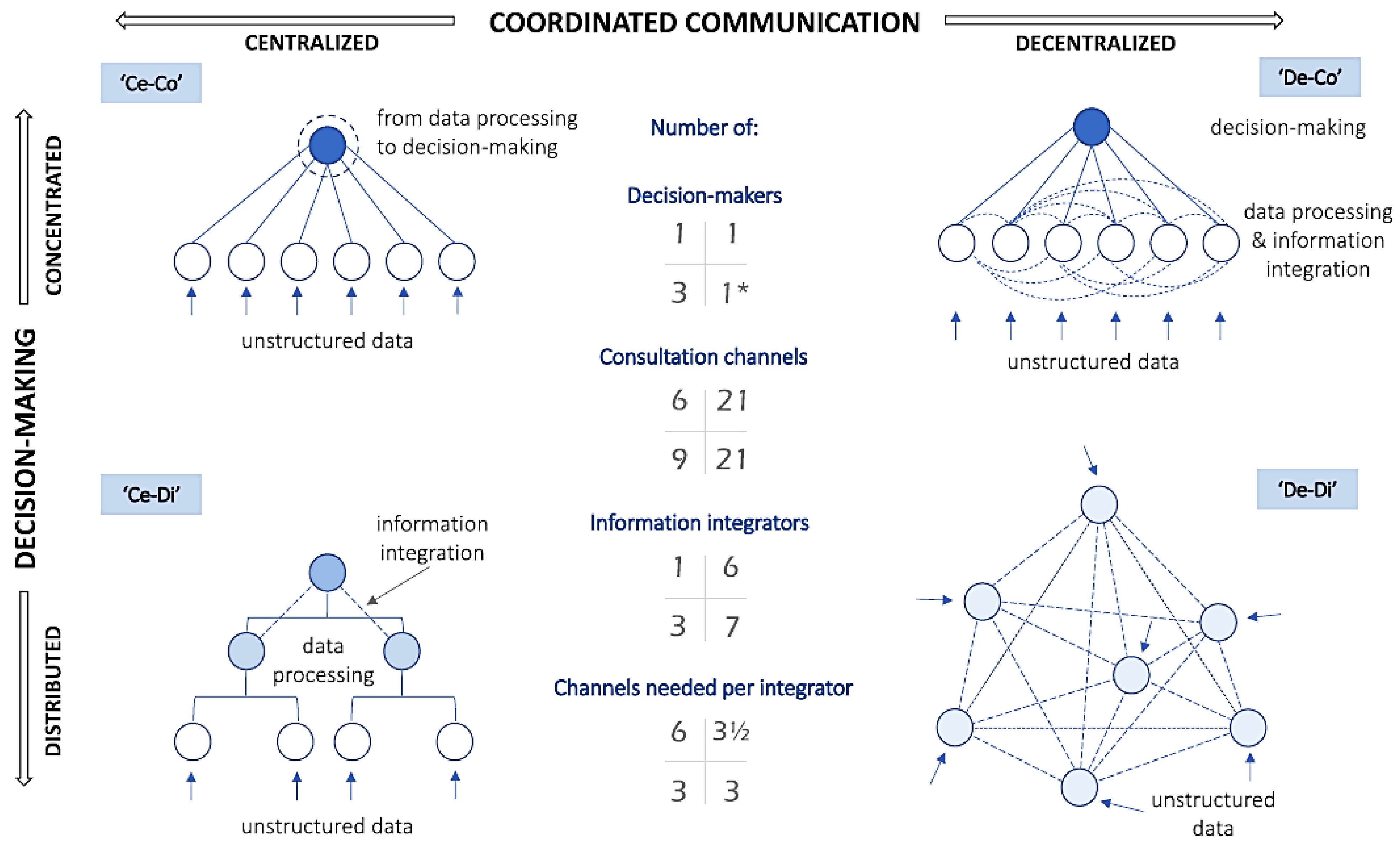


Centralized, decentralized and distributed production systems



Source: JP Vergne, Organization Theory, 2020

Complexity – from centralized towards distributed concepts



Source: JP Vergne, Organization Theory, 2020

What is Edge Computing?

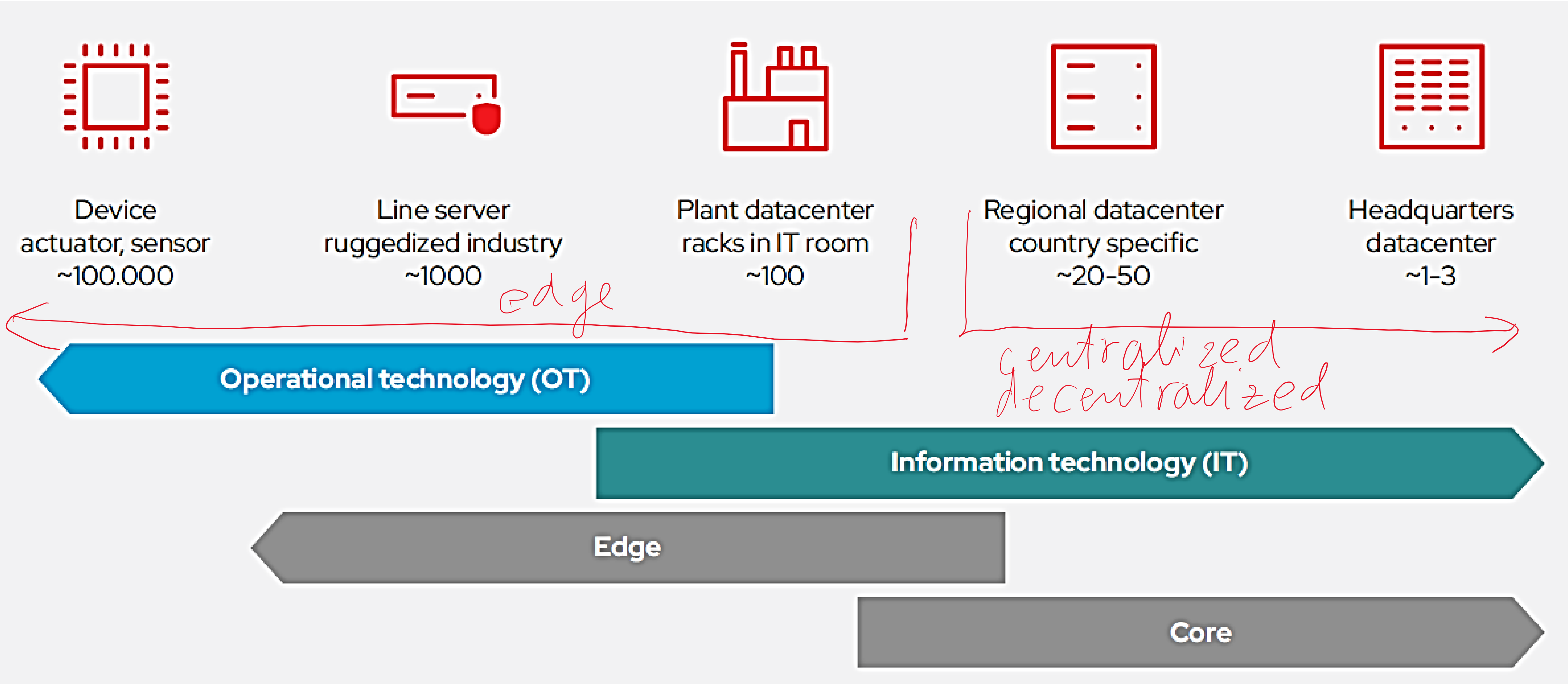
- Edge computing is computing that takes place **at or near the physical location of either the user or the source of the data**.

- By placing computing services closer to these locations, users benefit from faster, more reliable services while companies benefit from the flexibility of hybrid cloud (at least 2 private cloud or mixed) computing.

- Edge computing (as opposed to cloud computing) allows manufacturers to implement automation across factory floor and supply chain processes through advanced robotics and machine-to-machine communication closer to the source, rather than sending data to a server for analysis and response. For example, scanning sheet metal to detect fatigue, monitoring flow through pipes, or keeping track of automated machine cycles, to improve low latency, resulting in faster analysis and correction.

- Gathering, analysing, and acting on data on the factory floor in real-time offers profound benefits. Reducing downtime, accurately predicting maintenance, and improving overall product quality results in higher yield, reduced waste, increased throughput, and lower overall costs.

Industrial Application of Edge Computing



Source: Red Hat

Industrial use of Edge Computing

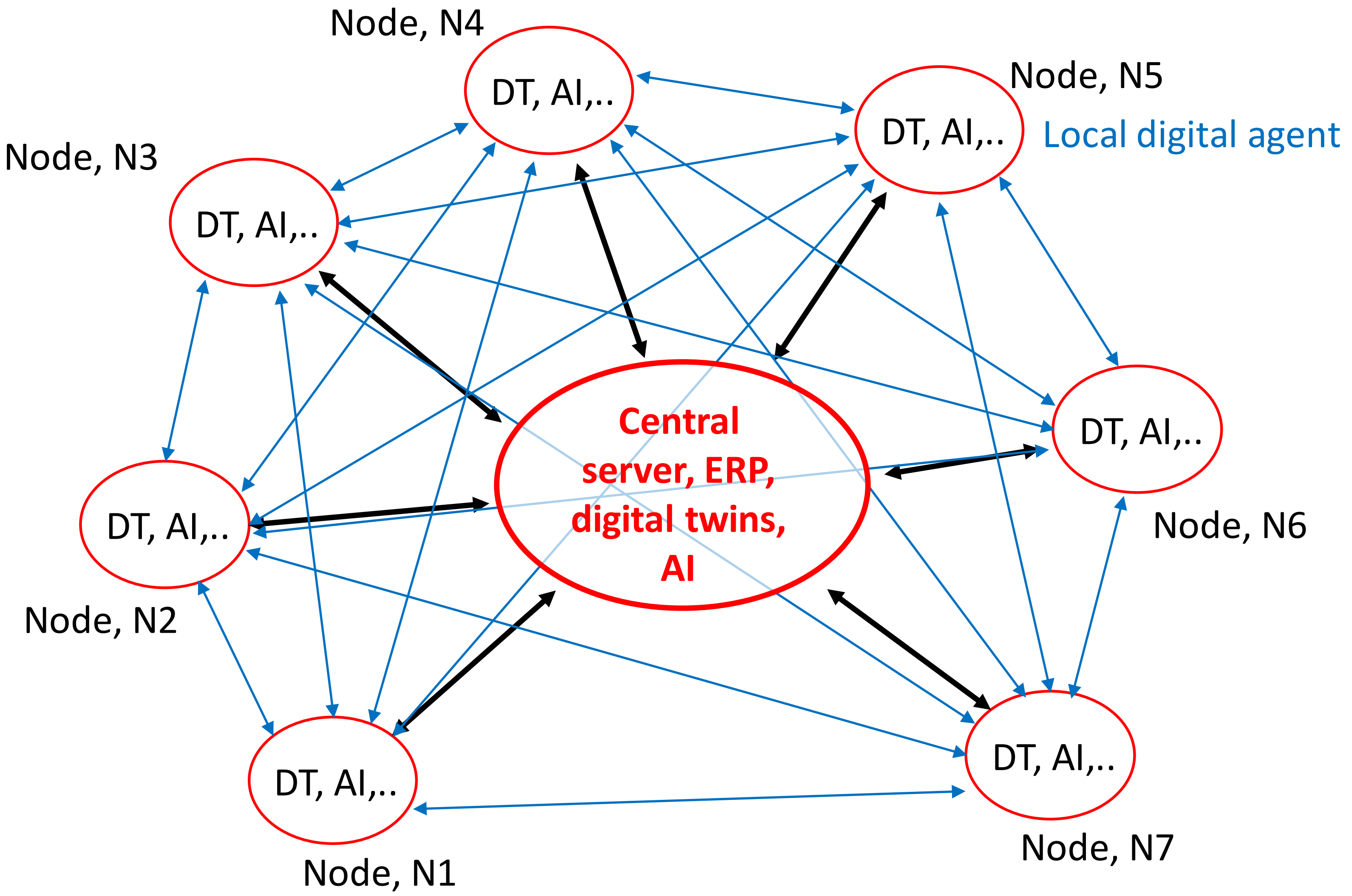
1. Implementing of modern Information and Operation technologies (IT and OT) in companies can help optimize production, streamline core functions, and fuel innovation.

2. Through edge computing in the hybrid cloud, IT and OT come together to bring processing power closer to the data source on the shop floor.

3. Edge computing, combined with Artificial Intelligence and Machine Learning (AI/ML) can:

   - Support faster decisions and actions in the plant.
   - Proactively discover potential errors at the assembly line.
   - Reduce equipment downtime through predictive maintenance.
   - Boost product quality.

Possible Distributed structure of the Smart factory



Smart data, filtered/arranged data, structured data

Local direct interconnection

It is good to have two central PCs, servers

Global digital agent

Benefits of Edge Computing

- ✓ Edge computing can mean faster, more stable services at a lower cost with faster computing and lower latency – very appropriate for real-time control and monitoring of production systems and processes.
- ✓ Edge computing can reduce network costs, avoid bandwidth constraints, reduce transmission delays, limit service failures, and provide better control over the movement of sensitive data. Load times are cut and online services deployed closer to users enable both dynamic and static caching capabilities. Applications that benefit from lower response time, such as augmented reality and virtual reality applications, benefit from computing at the edge.
- ✓ Other benefits of edge computing include the ability to conduct on-site big data analytics and aggregation, which is what allows for near real-time decision making. Edge computing further reduces the risk of exposing sensitive data by keeping all of that computing power local, thereby allowing companies to enforce security practices or meet regulatory policies.
- ✓ Enterprise customers benefit from the resiliency and costs associated with edge computing. By keeping computing power local, regional sites can continue to operate independently from a core site, even if something causes the core site to stop operating. The cost of paying for bandwidth to take data back and forth between core and regional sites is also greatly reduced by keeping that compute processing power closer to its source.
- ✓ An edge platform can help deliver consistency of operations and app development. It should support interoperability to account for a greater mix of hardware and software environments. An effective edge strategy also allows products from multiple vendors to work together in an open ecosystem.

Enabling technologies for Edge Computing

- Architectural Models of Distributed Systems and Edge Computing (from RAMI to LASFA)
- Hardware suitable for node operation – two local clouds (servers), small computers, embedded systems, Raspberry PI (RPis), and similar.
- Software
- Digital twins of local production and logistic processes – as less complex as possible to avoid prolonging the computation time of the node computer.
- Decision-making algorithms – Artificial Intelligence (AI). They should be as simple as possible and suitable for the operation of nodes with the shortest computation and decision-making time (Metaheuristic systems?) – Algorithms based on deep learning are more suitable for centralized systems.
- Standard communication protocols – OPC UA, ...
- Private network for data transfer (LTE, 5G) and appropriate equipment.
- Basic technologies – operating technologies and technologies for designing and managing production processes and operations.

„Top-down“ and „bottom-up“ approach in implementing I 4.0 solutions

Bottom Up and Top Down | Two approaches to implement Industry 4.0

Source: FESTO, VDMA

„The conditions for the transition to Industry 4.0 are different. If it is possible in terms of willingness to invest and all ideas for digitization are transformed into a completely new object with new equipment and processes, qualified staff, and a suitable management structure in combination with digitized value chains and completely compatible data. **It is a classic top-down approach.**

If production is in the process and it is not possible to solve the project, so to speak, on a "bare field", or it is not certain whether the considerable resources spent on the transformation process will actually bring the expected benefits, then the assembly system for **Industry 4.0 is moved and designed in smaller and manageable steps and is therefore a bottom-up approach.**"

Source: : R Ružarovský et al 2021 J. Phys.: Conf. Ser. 1781 012030

„Top-down“ approach in implementing I 4.0 solutions

Some methodologies for assessing the level of digitization or maturity of companies on the path to digitalization towards Industry 4.0 or the transition to Society 4.0 include PcW, Forester, ADMA, VDMA, and others.

These methodologies typically rely on questionnaires (answers to questions) and place the company on a scale of maturity for the digitization of the company. They also consider whether the company has developed a digitalization strategy.

Top Down Approach | VDMA Industry 4.0 Manual

In order to promote especially small and medium-sized enterprises to Industry 4.0 solutions and to help them evaluate the existing situation, the Association of German Machine and Plant Builders (Verband Deutscher Maschinen- und Anlagenbauer, or VDMA) prepared a corresponding manual. This was published under the title VDMA Industry 4.0 Manual in 2015.

https://www.pac.gr/bcm/uploads/guideline-industrie-4-0-vdma.pdf

The **VDMA toolkit helps** organizations conduct a self-assessment: “What is our current status, what is the current state of our technology, which technology have we already implemented?” and to set goals: “What direction do we want to head in over the coming years? What level of development do we hope to achieve? What makes sense for our customers, markets, and industry?” Thus, in a first step, the current state is determined and defined in the respective toolbox. The desired state must then be defined.

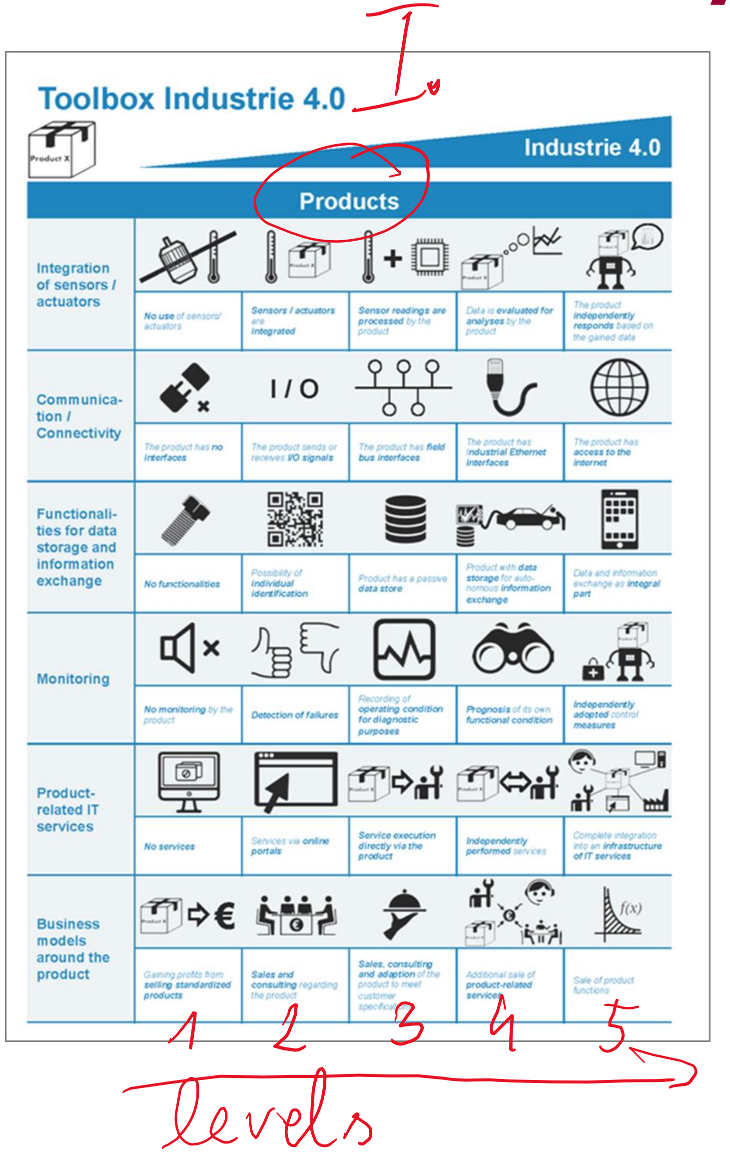
Source: VDMA

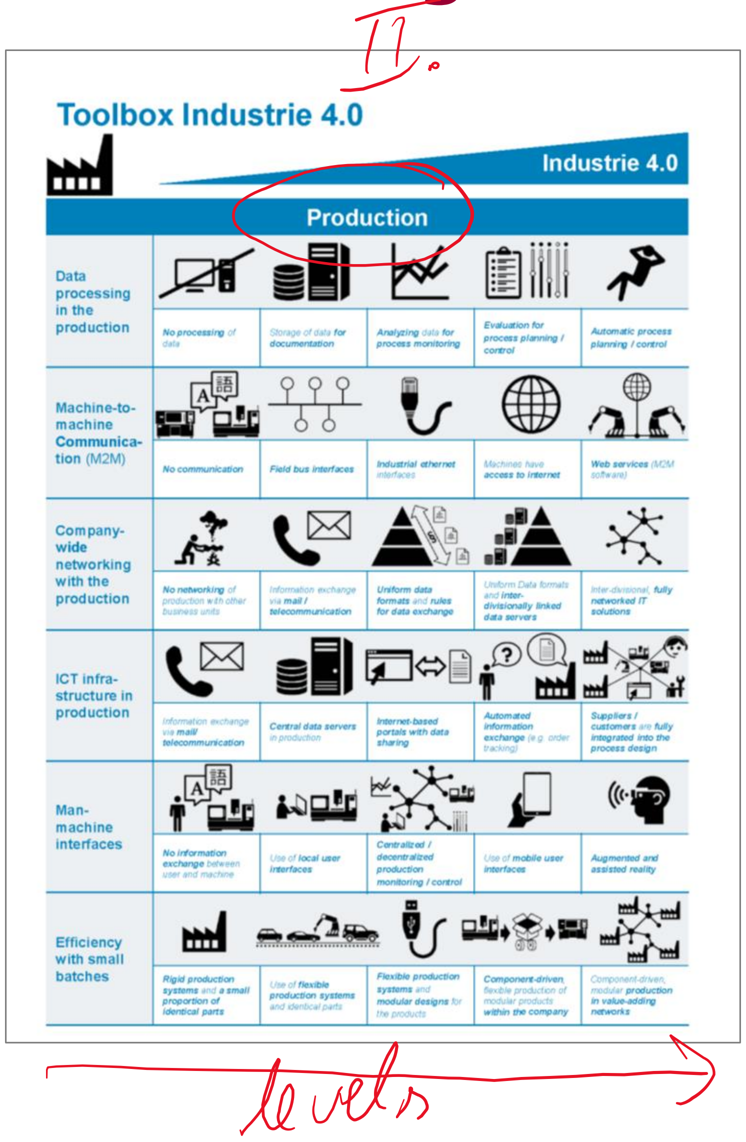
Toolbox Industry 4.0 | Structures for Industry 4.0 thinking

Guideline for small- / medium sized companies to implement Industry 4.0

Central statement: Implementing step by step & only the elements that are needed!

Core elements

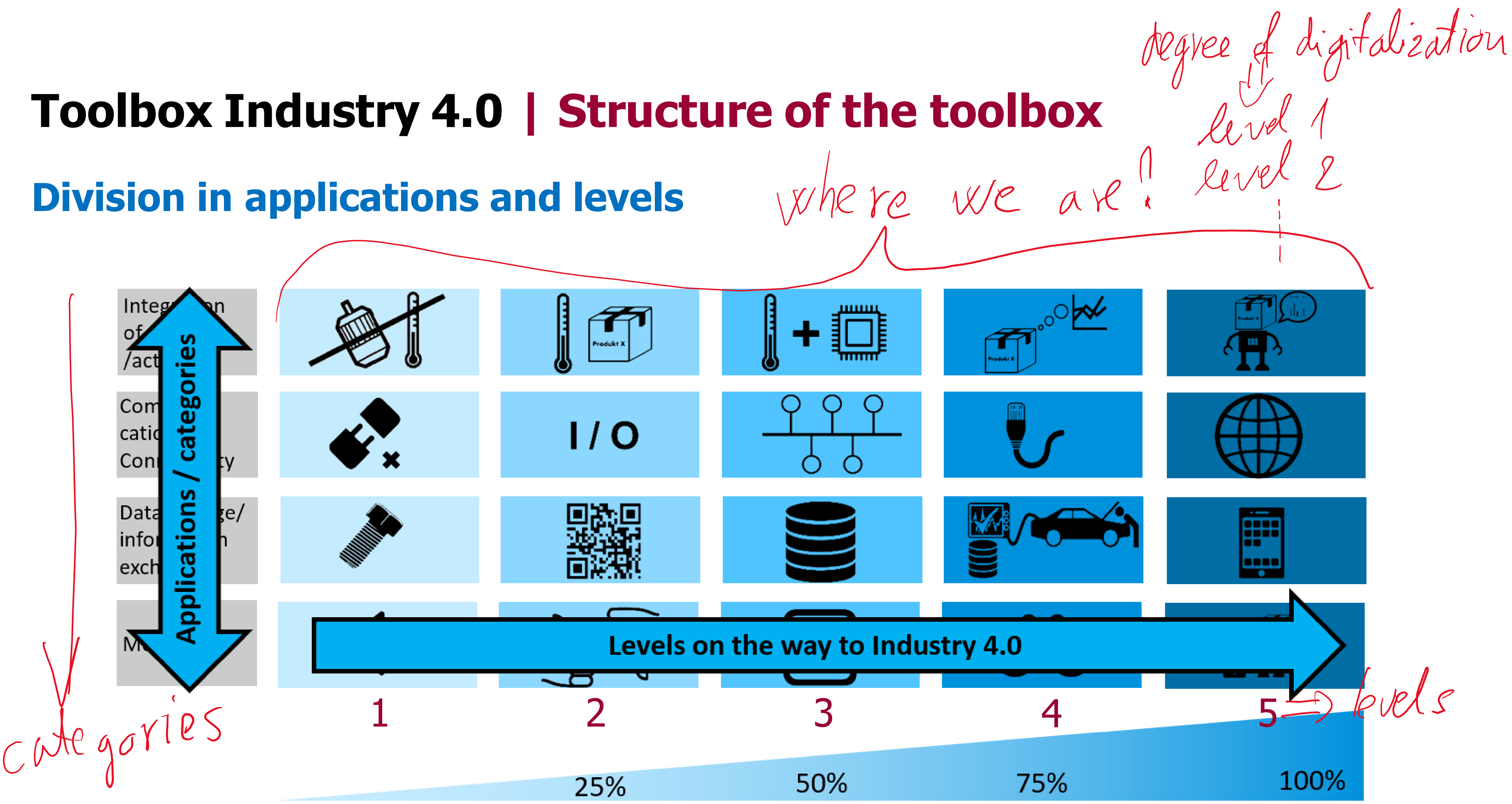




Source: FESTO, VDMA

Toolbox Industry 4.0 | Structure of the toolbox

Division in applications and levels



Source: VDMA

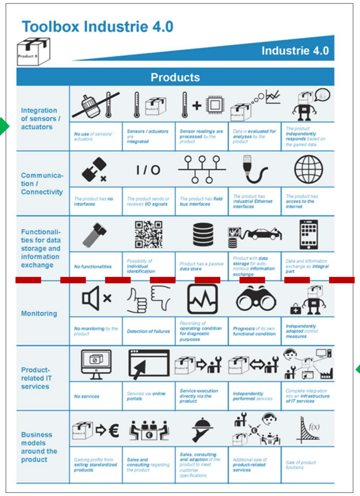
Toolbox Industry 4.0 | Products

Toolbox Industrie 4.0

Industrie 4.0

Products

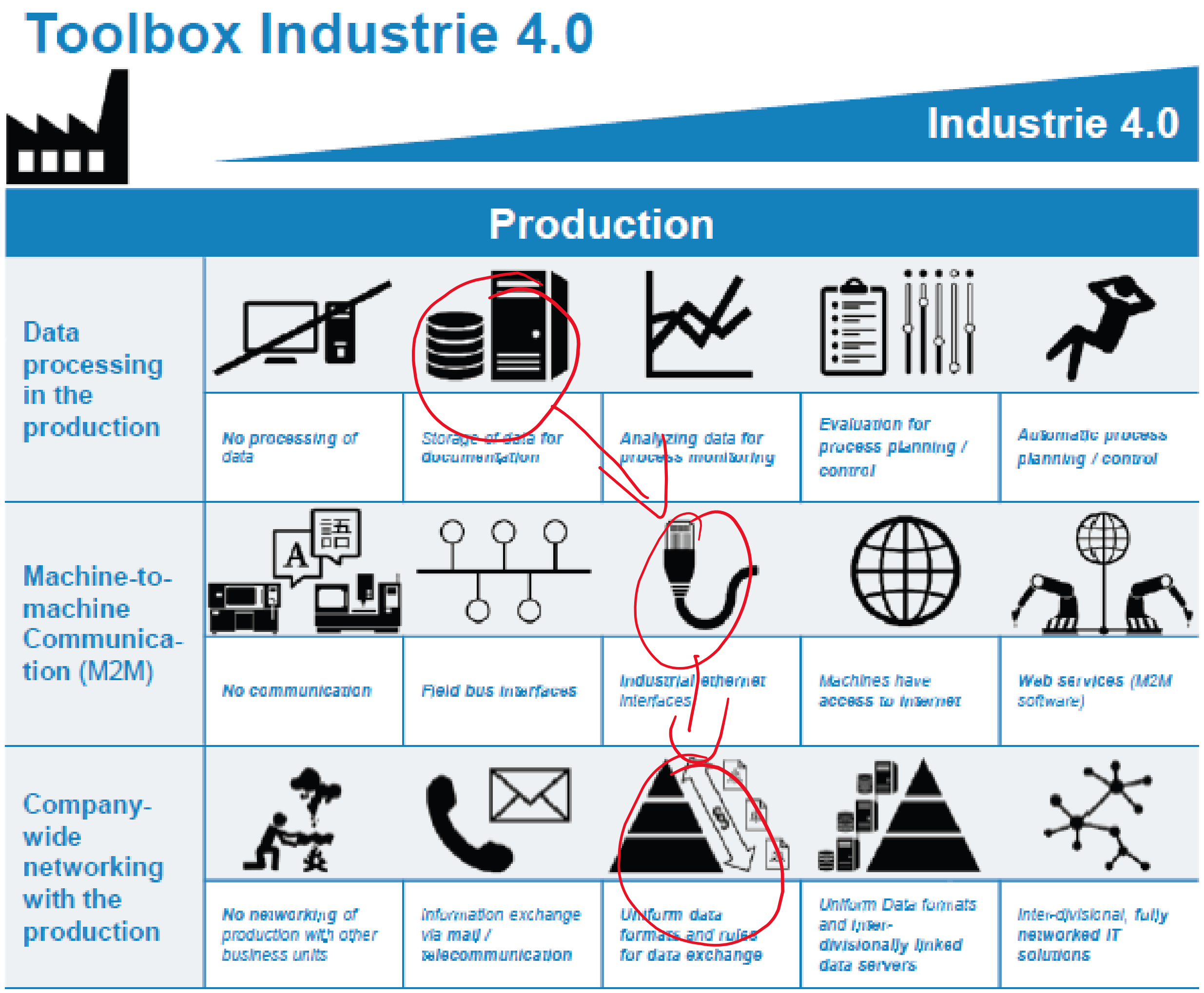
	1	2	3	4	5
Integration of sensors / actuators	No use of sensors/ actuators	Sensors / actuators are integrated	Sensor readings are processed by the product	Data is evaluated for analyses by the product	The product independently responds based on the gained data
Communication / Connectivity	The product has no interfaces	The product sends or receives I/O signals	The product has field bus interfaces	The product has industrial Ethernet interfaces	The product has access to the internet
Functionalities for data storage and information exchange	No functionalities	Possibility of individual identification	Product has a passive data store	Product with data storage for autonomous information exchange	Data and information exchange as integral part

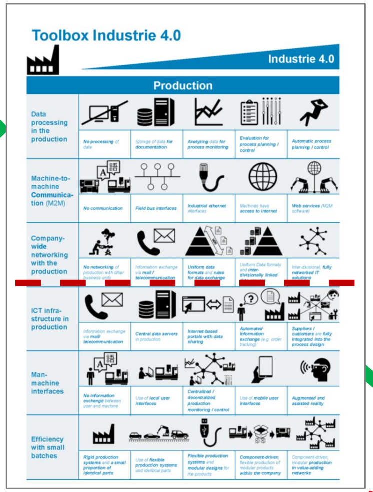


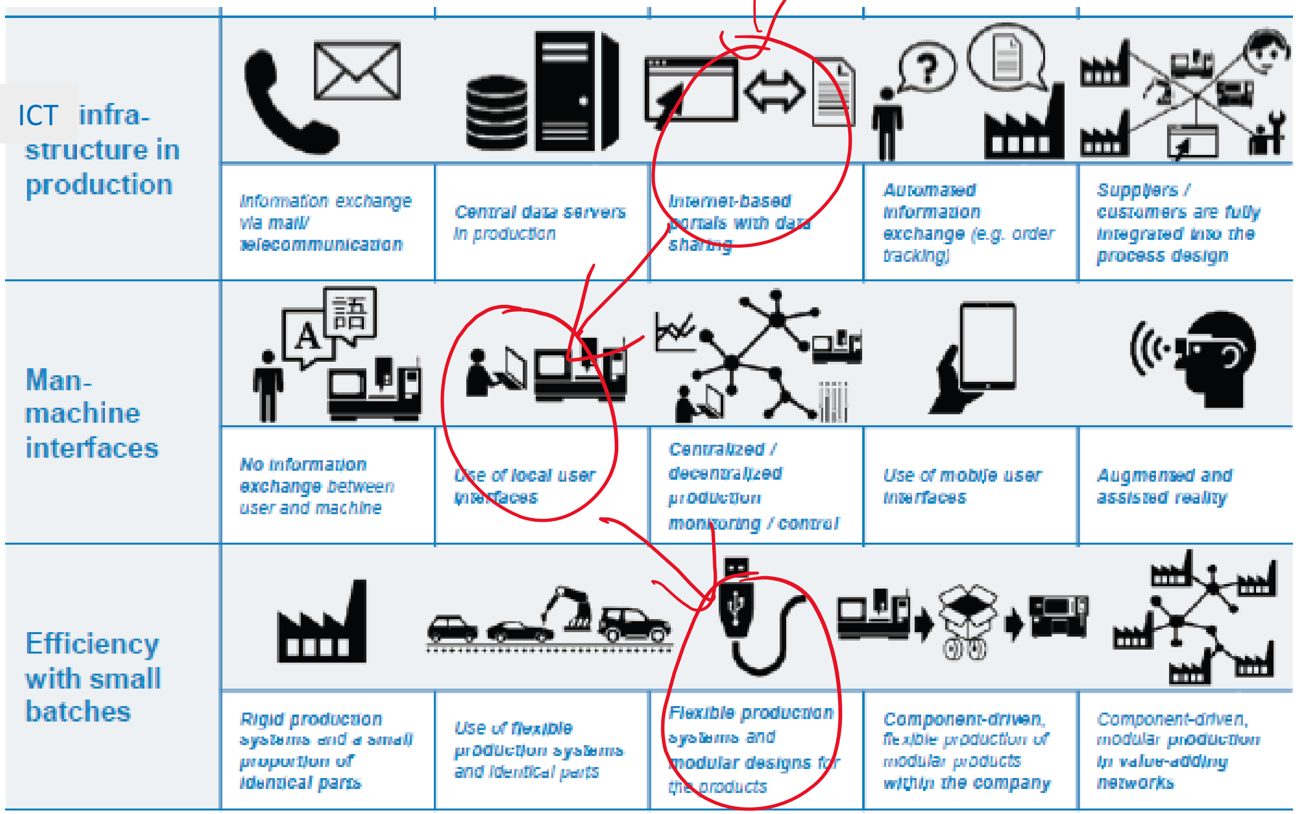
Monitoring	No monitoring by the product	Detection of failures	Recording of operating condition for diagnostic purposes	Prognosis of its own functional condition	Independently adopted control measures
Product-related IT services	No services	Services via online portals	Service execution directly via the product	Independently performed services	Complete integration into an infrastructure of IT services
Business models around the product	Gaining profits from selling standardized products	Sales and consulting regarding the product	Sales, consulting and adaption of the product to meet customer specifications	Additional sale of product-related services	Sale of product functions

Source: VDMA

Toolbox Industry 4.0 | Production

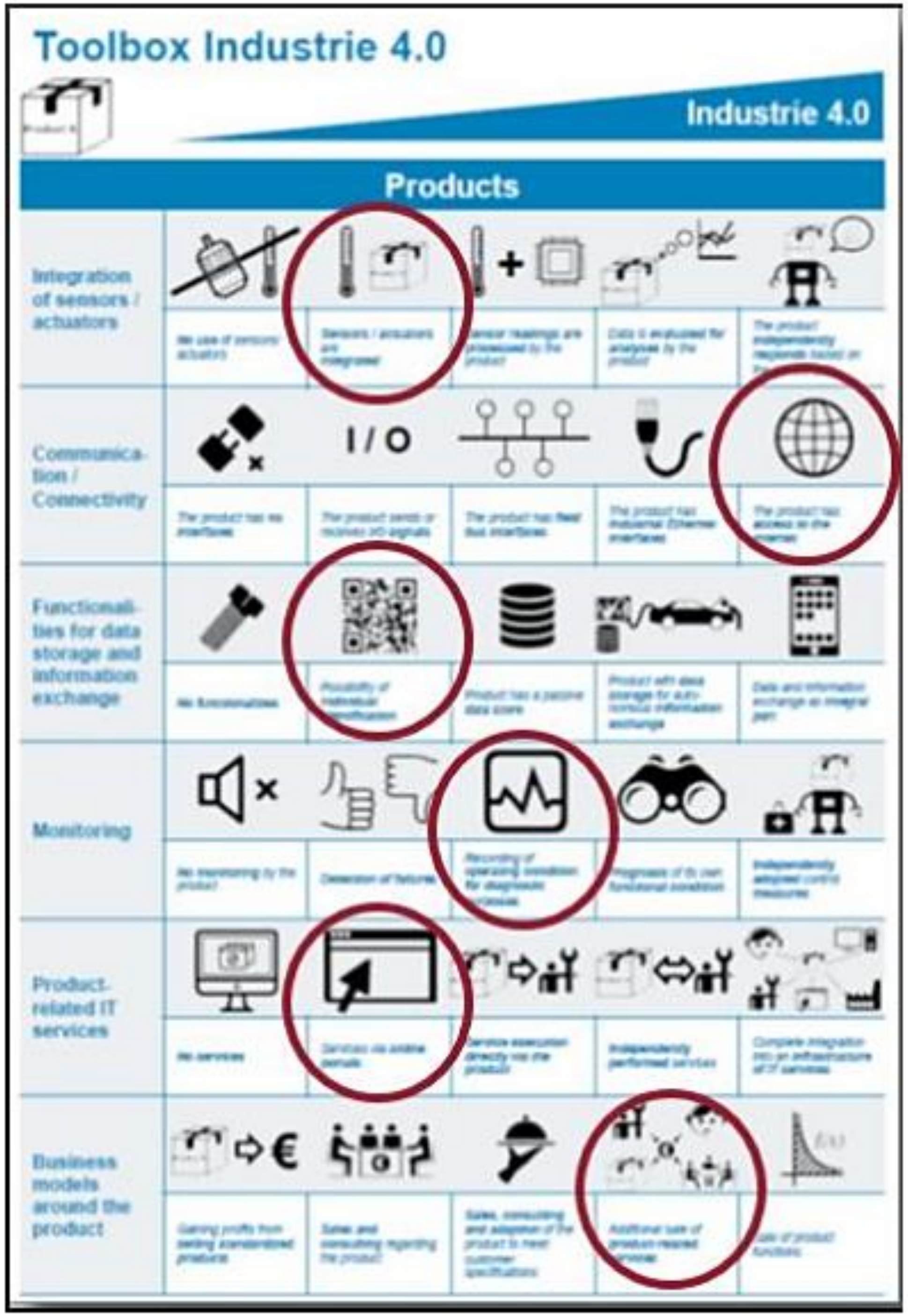






Source: VDMA

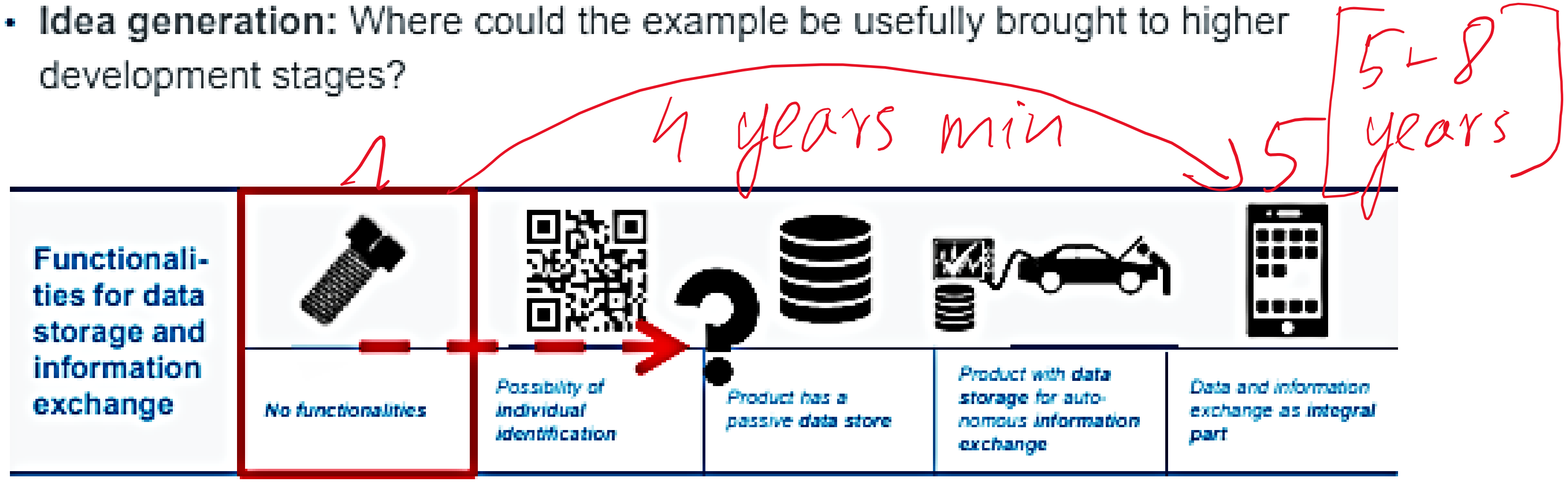
An example application of the VDMA TOOLBOX and evaluation of the company's level of digitization on the path to Industry 4.0.



Source: VDMA

Assistance in the steps of idea generation and development (product, process, individual technology, etc.)

- **Application example:** Which example from the product portfolio or production could have potentials?
- **Application levels:** Which application level(s) appear/s to be attractive for further development of the example? (rows of the toolbox)
- **Development stage:** To which development stage(s) can the example currently be assigned?
- **Idea generation:** Where could the example be usefully brought to higher development stages?



main questions ⇒ To level? Who? Finance? Time period?

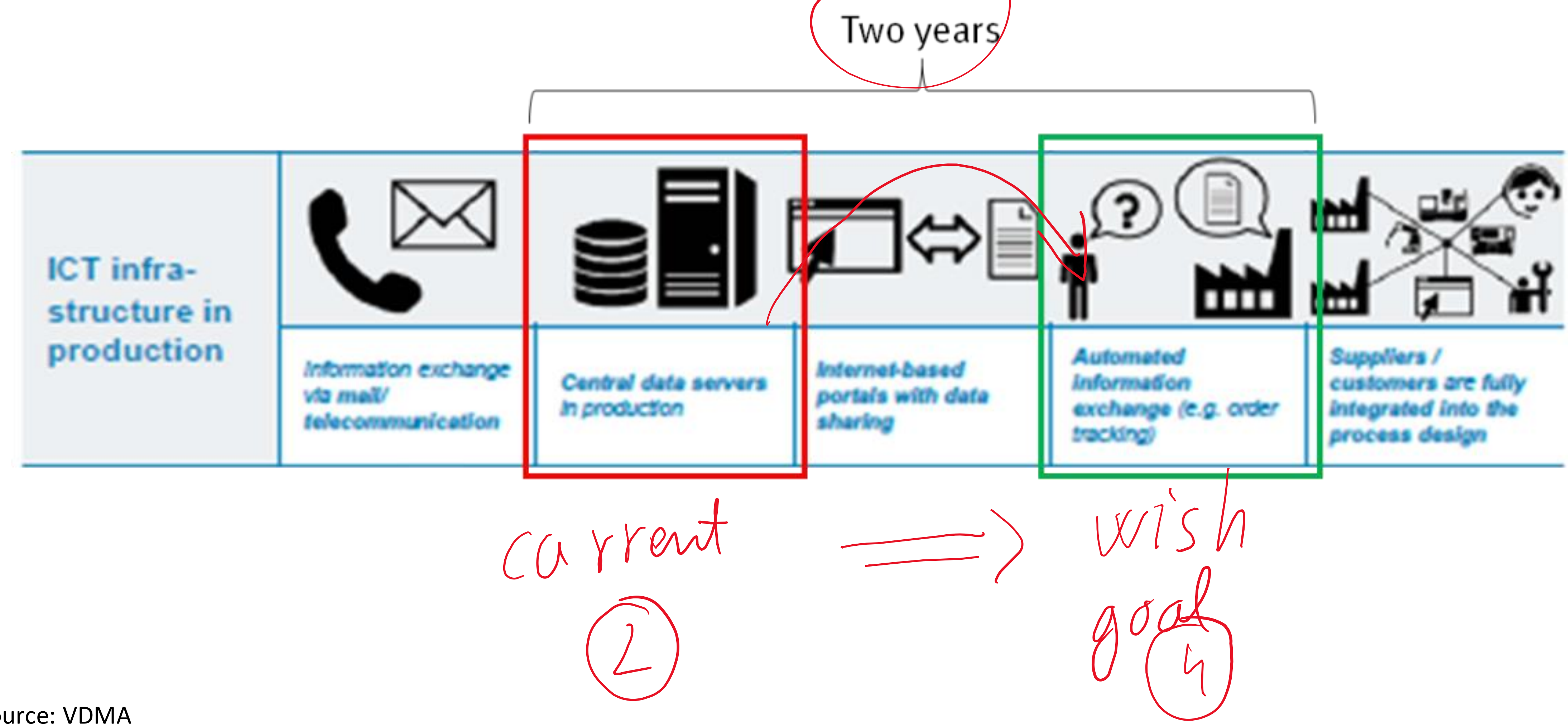
What makes sense, what does not? BE REALISTIC!!

Not every part of Industrie 4.0 can be usefully transferred to every example. Simple screws will not need functionalities for data exchange in the future. However, ideas for increasing the efficiency of screw production or the further development of business models could be quite promising.

Source: VDMA

An example of planning the next steps in one category

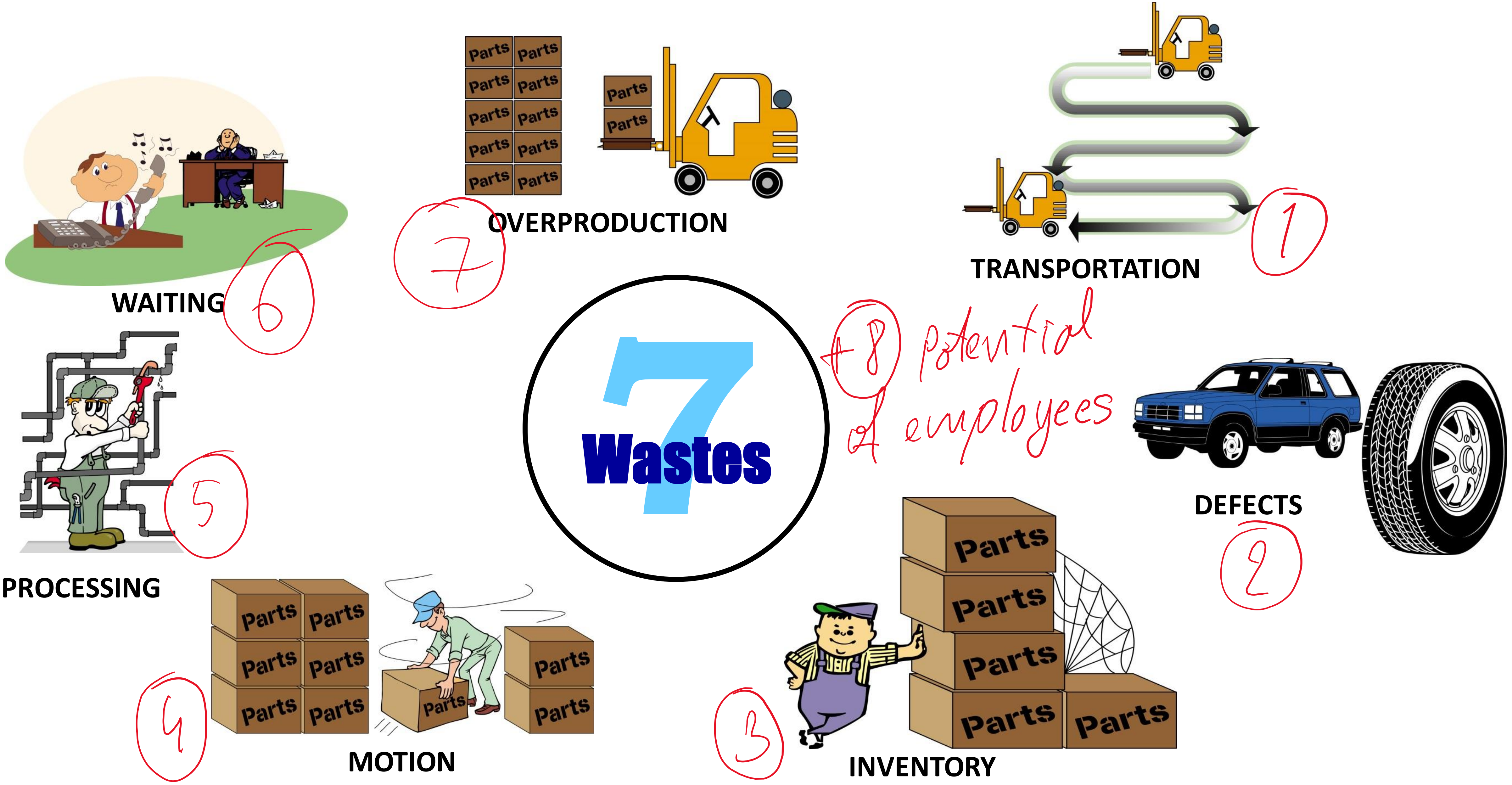
https://www.pac.gr/bcm/uploads/guideline-industrie-4-0-vdma.pdf



Source: VDMA

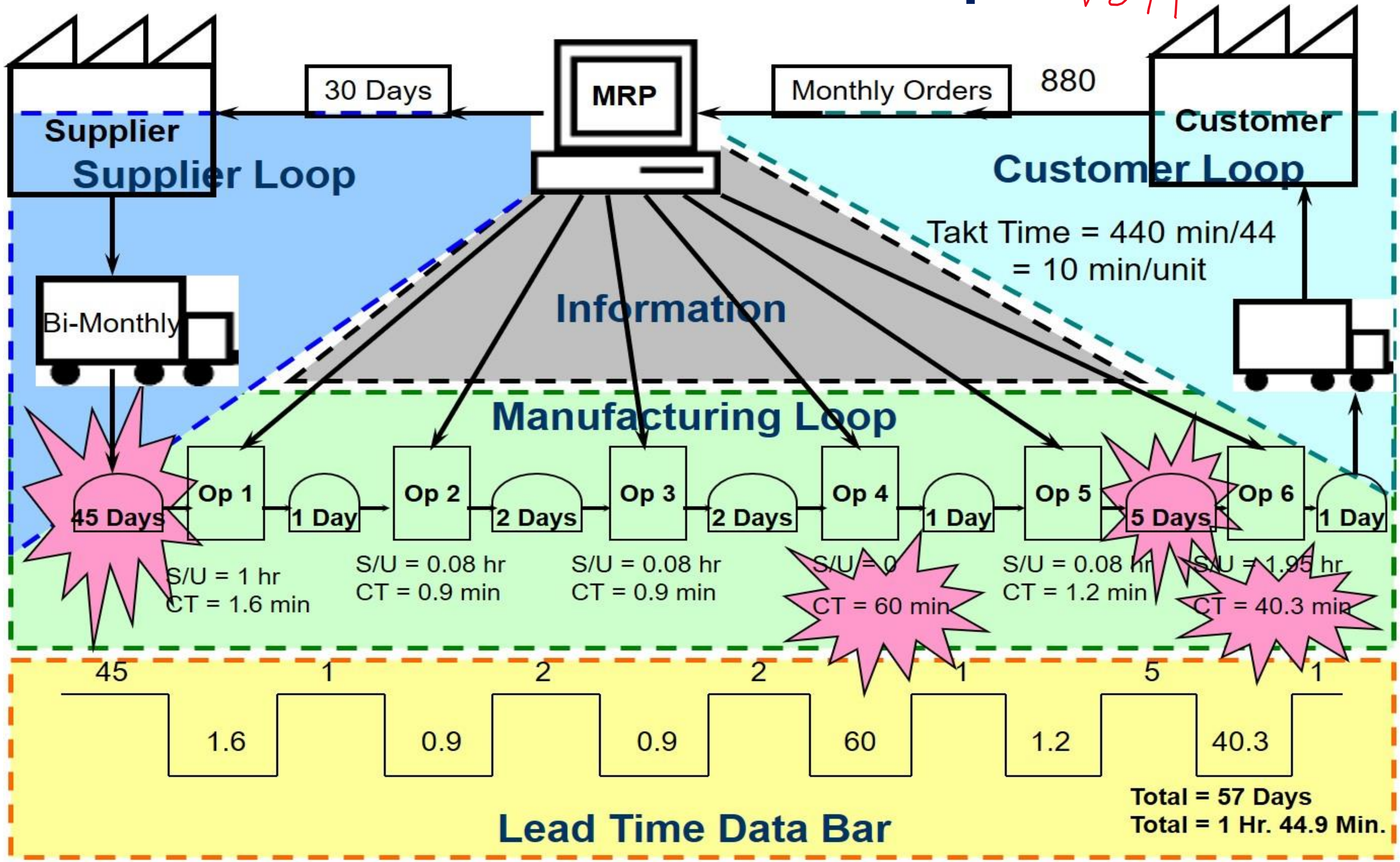
Bottom-up approach in implementing I 4.0 solutions

Elimination of wastes – use of I 4.0



Elements of Value Stream Maps

VSM



Main steps of VSM

1. Numerous workshops with employees from all areas of the company
2. Studying the state in production (Gemba Walk)
3. Value Stream Map - Current State
4. Development of the ideal state (Develop Ideal State Map)
5. Development of the future state (for a period of 3 months) (Develop Future State Map - 3 months out)
6. Development of the future state (Develop Future State Plan)
7. Management report presentation (Management Report Out)

Virtualization of processes and systems, visualization of production

Planning
Processes
Logistics

monitoring !!
alarming

Virtualization of manufacturing processes and systems

1. Digital factory – digitization of processes and systems – a prerequisite for virtualization
2. Virtual factory
3. Virtualization of manufacturing processes with mathematical and simulation models
   - of the product
   - Individual elements of the factory
   - Production cells and lines
   - Entire factories
   - Business processes

4. Virtualization of manufacturing processes and systems with digital twins, as cyber-physical systems (Digital twins, CPS)
   - of the product
   - Individual elements of the factory
   - Production cells and lines
   - Entire factories
   - Business processes

Vizualization of manufacturing processes, planning

1. Visualization is one of the most important conditions (from a psychological perspective of humans) for the acceptance of digitalization, digital twins, etc.

2. Some known software tools include PREACTOR, SCADA, My Scada, PLM - TEAM Center.

3. Pure visualization programs include MS Power Bi, among many others.