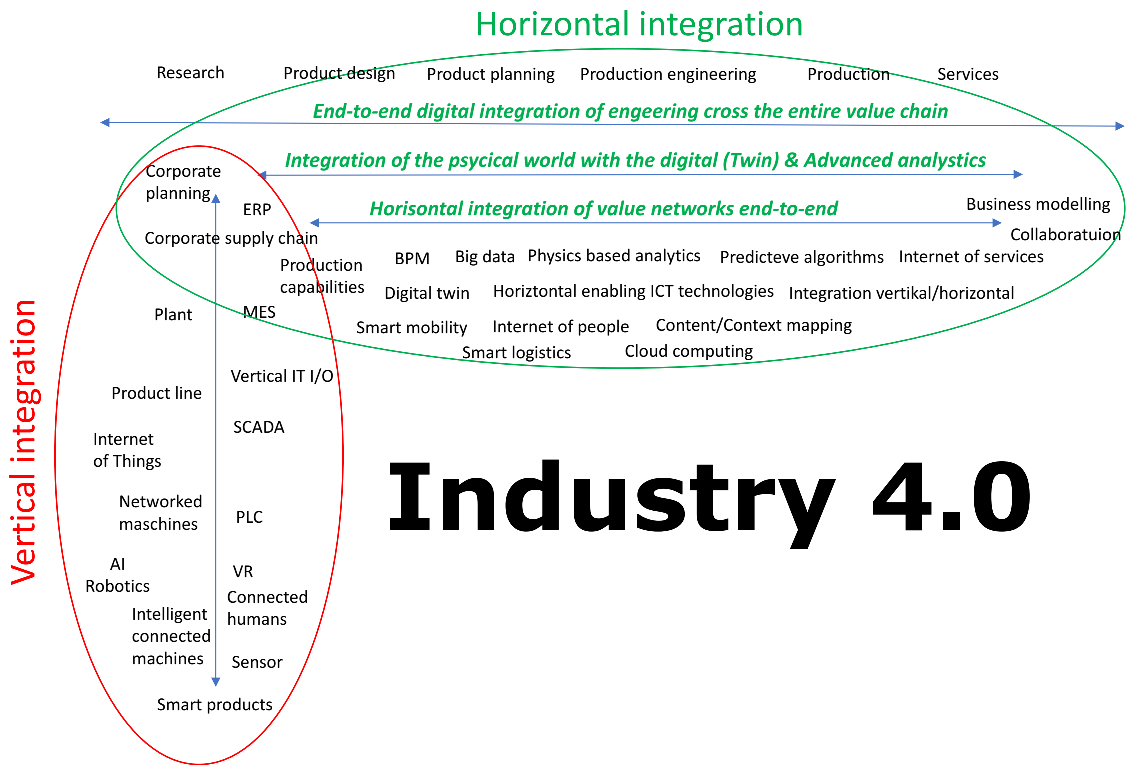
Outlining Industry 4.0



A map and a description

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1. Introduction

The first three industrial revolutions came about as a result of mechanisation, electricity and IT. Now, the introduction of the Internet of Things and Services into the manufacturing environment is driving a fourth industrial revolution.

The definition of the originators of the term Industry 4.0:

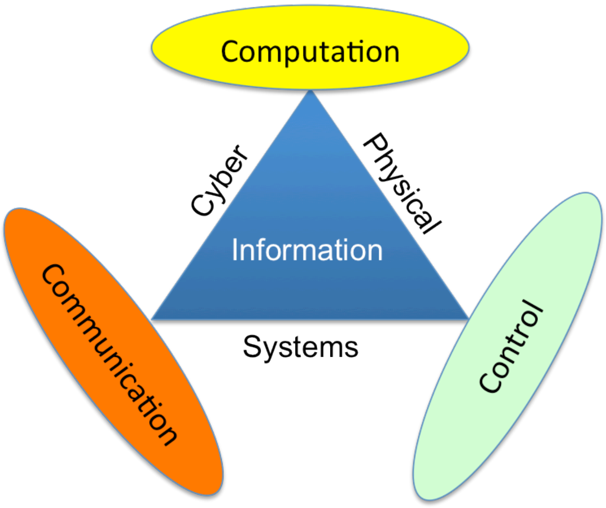
Industry 4.0 (German Industrie 4.0) describes a future scenario of industrial production that is characterized by three main aspects:

- a new level of organizing and controlling the entire value chain with the life cycle of products
- the availability of all relevant information in real time
- the creation of dynamic, real-time optimized and self-organizing cross-company value networks

There are four design principles in Industry 4.0. These principles support companies in identifying and implementing Industry 4.0 scenarios.

- <u>Interoperability</u>: The ability of machines, devices, sensors, and people to connect and communicate with each other via the Internet of Things (IoT) or the Internet of People (IoP)
- <u>Information transparency:</u> The ability of information systems to create a virtual copy of the physical world by enriching digital plant models with sensor data. This requires the aggregation of raw sensor data to higher-value context information.
- <u>Technical assistance:</u> First, the ability of assistance systems to support humans by aggregating and visualizing information comprehensibly for making informed decisions and solving urgent problems on short notice. Second, the ability of cyber physical systems to physically support humans by conducting a range of tasks that are unpleasant, too exhausting, or unsafe for their human co-workers.
- <u>Decentralized decisions:</u> The ability of cyber physical systems to make decisions on their own and to perform their tasks as autonomously as possible. Only in the case of exceptions, interferences, or conflicting goals, are tasks delegated to a higher level.

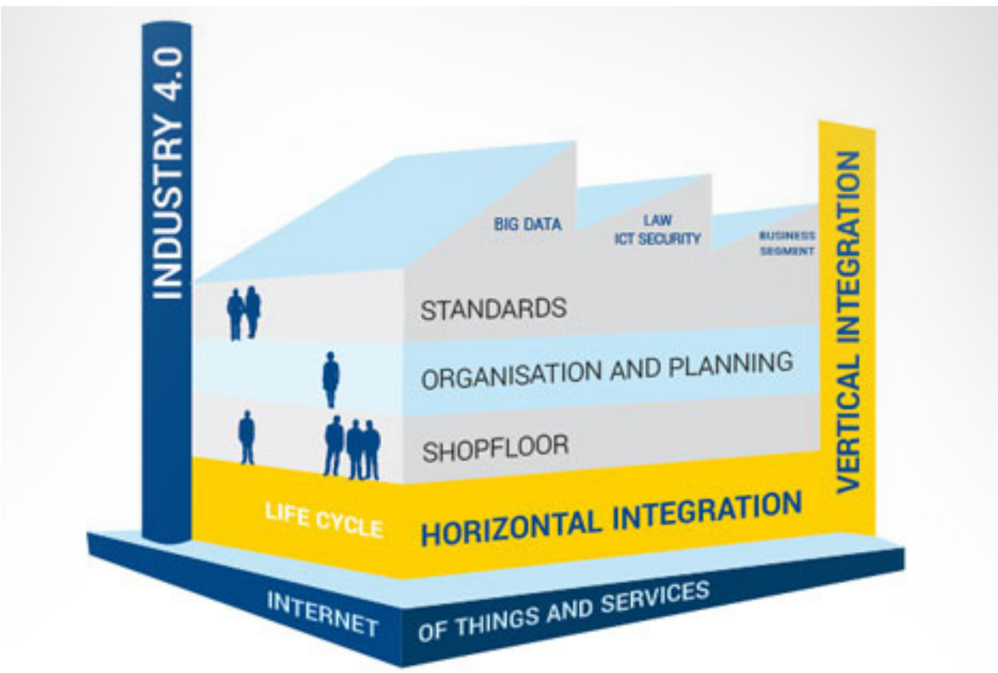
In the future, businesses will establish global networks that incorporate their machinery, warehousing systems and production facilities in the shape of **Cyber-Physical Systems (CPS)**. Now a global term originating from Germany that has spearheaded the development, structuring and organising of Industry 4.0 (Industrie 4.0).



In the manufacturing environment, these Cyber-Physical Systems comprise smart machines, storage systems and production facilities capable of autonomously exchanging information, triggering actions and controlling each other independently.

This facilitates fundamental improvements to the industrial processes involved in manufacturing, engineering, material usage and supply chain and life cycle management.

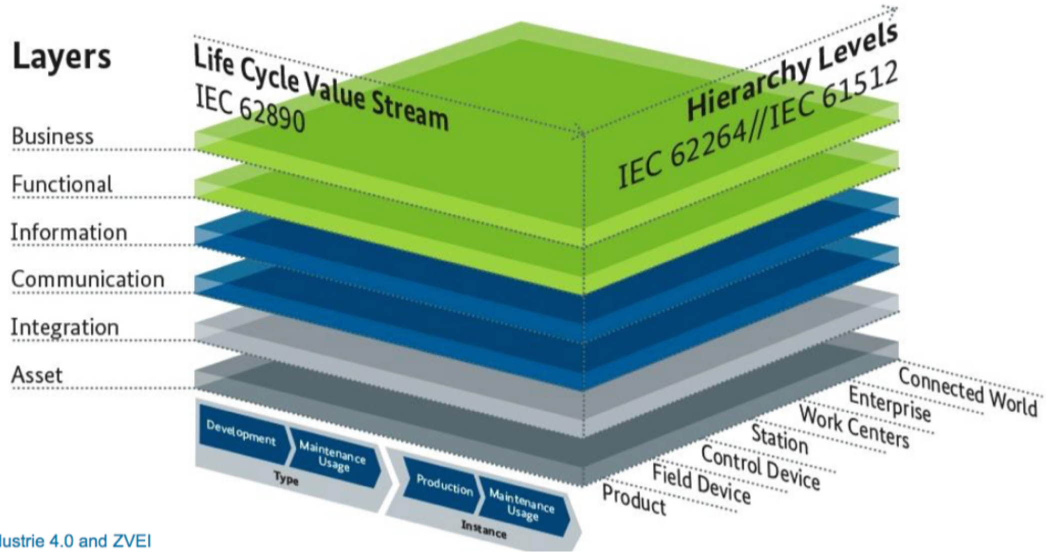
The smart factories that are already beginning to appear employ a completely new approach to production. Smart products are uniquely identifiable, may be located at all times and know their own history, current status and alternative routes to achieving their target state. The embedded manufacturing systems are *vertically networked* with business processes within factories and enterprises and *horizontally connected* to dispersed value networks that can be managed in real time – from the moment an order is placed right through to outbound logistics. In addition, they both enable and require end-to-end engineering across the entire value chain.



Industry 4.0 holds huge potential. Smart factories allow individual customer requirements to be met and mean that even one-off items can be manufactured profitably. In Industry 4.0, dynamic business and engineering processes enable last-minute changes to production and deliver the ability to respond flexibly to disruptions and failures on behalf of suppliers, for example. End-to- end transparency is provided over the manufacturing process, facilitating optimised decision-making. Industry 4.0 will also result in new ways of creating value and novel business models.

Global competition in the manufacturing engineering sector is becoming fiercer and fiercer and many countries have recognised the trend to deploy the Internet of Things and Services in manufacturing industry. Almost all developed countries have now a national program for develop its industry towards Industry 4.0.

An Industry 4.0 reference architecture (RAMI 4.0) has been developed:



Graphics © Plattform Industrie 4.0 and ZVEI

The **characteristic features of Industry 4.0** are:

- **Horizontal integration through value networks**
- **End-to-end digital integration of engineering across the entire value chain**
- **Vertical integration and networked manufacturing systems**

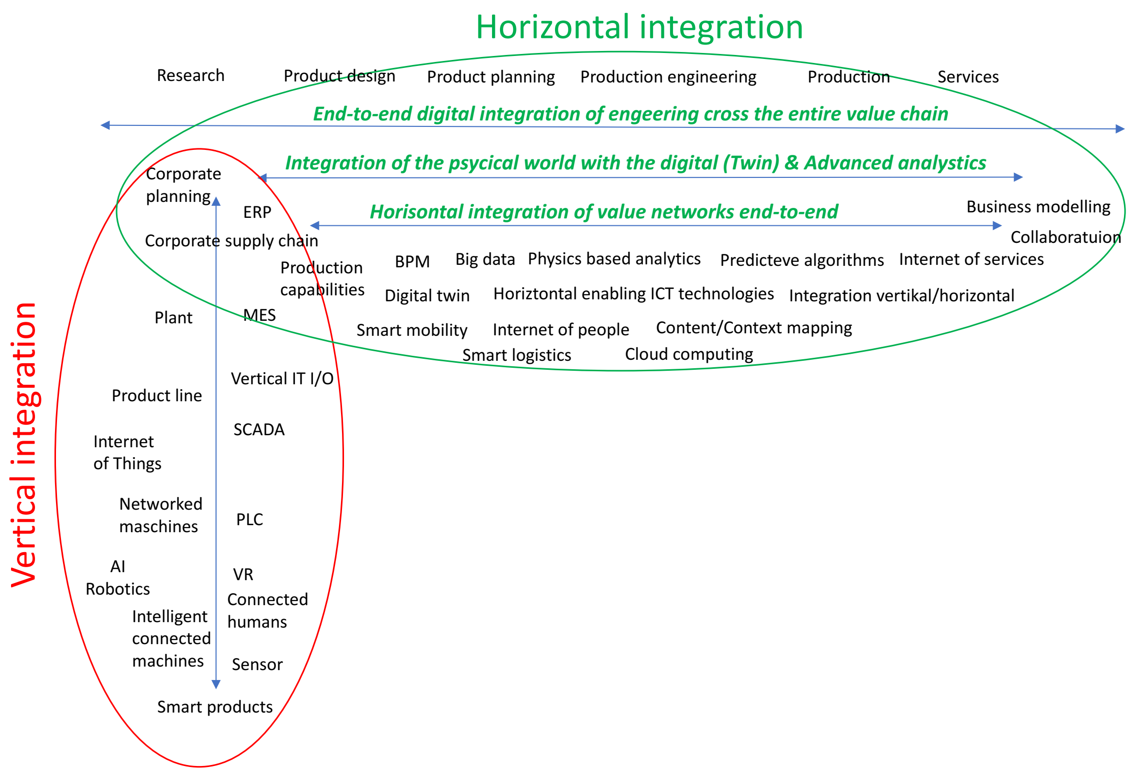
In the fields of production and automation engineering and IT, **horizontal integration** refers to the integration of the various systems used in the different stages of the manufacturing and business planning processes that involve an exchange of materials, energy and information both within a company (e.g. inbound logistics, production, outbound logistics, marketing) and between several different companies (value networks). The goal of this integration is to deliver an end-to-end solution.

In the fields of production and automation engineering and IT, **vertical integration** refers to the integration of the various components and systems at cross the different hierarchical levels (e.g. the actuator and sensor, machines and machine control, production management, manufacturing and execution up to corporate planning levels) in order to connect to an end-to-end solution. Vertical integration

The vertical integration includes the human operator, human-machine interfaces as well as smart products.

The **end-to-end digital integration of engineering of across the entire value chain** is the extension of the horizontal integration of the supply chain (SCM) to become the integration of the entire product life cycle management (PLM) value chain.

In the following chapters will each features of Industry 4.0 be further discussed. The illustration below summarizes this paper:



2. Vertical integration and networked manufacturing systems

In short one could say that the vertical integration is to connect the physical product being manufactured all the way up to the business ERP and processes level. This for retrieving data (bottom-up) and to distribute data (top-down). The vertical integration is done in real-time and not batch oriented or with delays.

To describe the domain, we walk through the different hierarchical levels involved starting on the shop floor/machine level with the product being manufactured and continue "upwards".

- **Connectivity to Smart products**: with memory and embedded intelligence coordinate and control its own production. Smart products can communicate with smart machines at the workstation, with humans at the workstation but as well via the internet of things with all levels in the vertical integration. Or a combination of them all.
- At the workstation, **intelligent connected machines** using provided data and/or local sensor input to perform production operations. Intelligent machines include advanced robotics as well as artificial intelligence (AI) enabled equipment.
- At the workstation **connected humans** perform or overlook production operations, possible in cooperation with intelligent machines. Example of this is human – robot multi-sensor interaction. Augmented reality is another example how human perform computer aided production operations.
- Before, during and after the production operation, **relevant data is provided, captured and communicated in time.**
- **Networked manufacturing systems:** Machines are networked on work station level, as well as networked to an optimised production line or unit. Production lines are networked to plant level. This includes a wide range of operations including physical actions to the product, measuring, corrections, mounting and assembly just mentioning some steps. By networked means one machine feeds its operation result directly to another machine. The lowest networking level is a pure physical handover while more advanced include peer-to-peer communication of data.
- Humans, machines or networks of machines reports status, results, supply needs etc to product planning, warehouse supply, production management and maintenance and so on. Likewise need instructions and support. A wide range of processes and support systems are in use today and not unusual is to have different systems for different purposes, like for inventory, resource planning and maintenance scheduling. A successful vertical integration brings together all these for specific purposes designed systems. Here follow three examples of different hierarchical levels:
  - A **programmable logic controller** (**PLC**), or **programmable controller** is an industrial digital computer for the control of manufacturing processes, such as assembly lines, or robotic devices and ease of programming and process fault diagnosis. PLCs can range from small "building brick" devices with tens of inputs and outputs (I/O), in a housing integral with the processor, to large

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rack-mounted modular devices with a count of thousands of I/O, and which are often networked to other PLC and SCADA systems.
    - **Supervisory control and data acquisition**(**SCADA**) is a control system for process supervisory management and uses e.g. PLC's to interface with the process plant or machinery. The operator interfaces which enable monitoring and the issuing of process commands, such as controller set point changes, are handled through the SCADA computer system. However, the real-time control logic or controller calculations are performed by networked modules which connect to the field sensors and actuators.
    - **Manufacturing execution systems** (**MES**) are computerized systems used in manufacturing, to track and document the transformation of raw materials to finished goods. MES provides information that helps manufacturing decision makers understand how current conditions on the plant floor can be optimized to improve production output. MES works in real time to enable the control of multiple elements of the production process (e.g. inputs, personnel, machines and support services). MES act both as a system in the vertical integration and as a system for plant wide horizontal integration.
- Optimization and decision making must be on several levels. The vertical integration feed data up to levels with more end-to-end accumulated data (requirements, availabilities, analysis and predictions) and that provide back instruction for optimisation. The vertical integration reaches **all up to the corporate planning level**, e.g to the Enterprise Resource Planning system, ERP.

2.1. Subject matter examples, vertical integration

The vertical integration covers several subject matter disciplines, examples are:

- Intelligent machines: connected/sensors, controls & SW app's
- Equipment knowledges; vertical integration enabling technologies
- Smart products: with memory and embedded intelligence coordinate and control its own production
- Vertical IT integration: Various IT system of different hierarchal levels (sensor-control-prod.mgmt-inventory-execution-planning)
- Smart and connected machines and products
- Internet of things & local communication
- Augmented reality
- Multi-sensor interaction: human – robot
- Hype technologies: e.g. AI

3. Horizontal integration through value networks

Much of what Industry 4.0 stands for relates to the horizontal integration. Already on shop floor level or plant level information and data is gathered, compared with requirements, analysis and decision making done and instruction and data is dispatched to right receivers. This is also done on the entire corporate supply chain level to optimize supply capabilities with market needs. The horizontal integration is through value chain networks on different levels; plant level, production (e.g. multi-production units), entire corporate supply chain and to enlarged communities of partners opening up for new business models and new value network participants.

The horizontal integration can be seen from three aspects; The integration end-to-end as such, the integration of the physical world with the digital, and advanced analytics then possible given the two first mentioned.

3.1. Horizontal integration of value networks end-to-end

All from the different domains within a plant, within the corporate production capabilities, within the entire supply chain, within the entire business of the corporate and within the wide eco-system need on each level be integrated.

It starts with the horizontal integration of business processes. The horizontal integration impact the design, operations and improvement of the processes for production development. This imply a focus on design and operations of the Production Systems where the product is realized. The production systems comprise components like premises, humans, machines, equipment and software/ICT implying the need for a holistic end-to-end process view when designing and operating the end-to-end production value chain.

This means in practical terms the integration of the various IT system in different stages in manufacturing, in the business planning processes that involve exchange of anything company wide, and in the next level of enlarged communities value networks.

The horizontal integration includes ensuring that the vertical integration in assets used in the horizontal integration domain, work from a horizontal integration purpose.

The integration provides **a real-time end-to-end seamless and transparent “infrastructure” for information flow.**

Horizontal integration enabling technologies is central knowledge in this. It also encompasses areas of smart mobility, smart logistics and Internet of people that cater for connected people and optimised decision making. It also includes Internet of services and the change in business models and eco-system it brings. It responds to “On demand” production.

3.2. The integration of the physical world with the digital

The concept of the digital twin to the physical asset is fundamental in Industry 4.0. The digital twin must at each and every moment in time be a true relevant twin to the physical real world asset. An asset can be a product being manufactured, a machine, a material, a measurement or any other object in the real world. As the analytics and decisions will be made on the digital data, in almost-real time, it is imperative that the digital twin data is of enough quality and accuracy.

Digital twin refers to a digital replica of physical assets (physical twin), processes and systems that can be used for various purposes. The digital representation provides both the elements and the dynamics of how the physical twin operates and lives throughout its life cycle.

Digital twins integrate with data to create living digital simulation that update and change as their physical counterparts change. A digital twin continuously learns and updates itself from multiple sources to represent its near real-time status, working condition or position. This learning system, learns from itself, using data that conveys various aspects of its operating condition, from human experts, such as engineers, from other similar machines, from other similar fleets of machines, and from the larger systems and environment in which it may be a part of. A digital twin also integrates historical data from past machine usage to factor into its digital model.

In Industry 4.0, digital twins are being used to optimize the operation and maintenance of physical assets, systems and manufacturing processes.

3.3. Advanced analytics

With the vertical integration providing real-time data from the product being produced and from the shop floor, the horizontal integration providing seamless end-to-end understanding and a digital twin replication of the physical world, then data can be assembled for analysis and optimised decisions.

The amount of data available becomes significant and this known as Big data. Management of Big data becomes key. Advanced analytics extract the right relevant data from Big data, provide physics based analytics and through predictive algorithm guide both operative steering of individual production operations, tactical production planning as well as drive automation.

Big data challenges include capturing data, data storage, data analysis, search, sharing, transfer, visualization, querying, updating, information privacy, security and data source.

To sum it up, there are 6 C's in Big data and analytics with respect to the Industry 4.0 environment. They are:

- Connection data quality, which pertains to sensors and networks
- Cloud computing
- Cyber, which involves model, memory and security

- Content/Context mapping or filtering
- Community, or sharing and collaboration between and among stakeholders
- Customization

3.4. Subject matter examples, horizontal integration

- End-to-end digital integration of value chain
- Horizontal integration of value networks end-to-end
- Integrate the physical world into the digital i.e. build, maintain and update a digital twin for all relevant assets
- Horizontal integration enabling technologies
- Advanced analytics: Big Data, Physics based analytics, predictive algorithm, automation
- Digital end-to-end engineering across the entire value chain of both products and manufacturing systems
- Horizontal integration of: Various IT system in different stages in manufacturing + business planning processes that involve exchange of anything companywide + value network
- Internet of people: Connecting people, optimised decision making
- Internet of Services: New business models and new eco-systems
- Smart mobility & Smart Logistics
- On demand production, Kanban, etc.

4. End-to-end digital integration of engineering across the entire value chain

The vertical integration connects physical product and product making level with all hierarchal levels up to overall business management system and processes. The horizontal integration connects all vertical integrated manufacturing systems and networks to an end-to-end solution allowing optimised analytics, predictions, management and communications over the entire manufacturing and supply chain.

Having above in place pave the way for of an end-to-end digital integration of engineering across the entire value chain. This is to seamless connect Research, Product design and development, Product planning, Production engineering, Production and Services. One challenge will be that a holistic systems approach is required that spans the different technical disciplines involved. This will require new engineering competencies.

Today's value chains – from customer requirements to product architectures and production – have often arisen over a period of many years and tend to be relatively static. IT support systems exchange information via a variety of interfaces, but can seldom use this information with regard to specific individual cases. **There is no global overview from the perspective of the product that is being manufactured**. As a result, customers cannot freely select all of their product's functions and features, even though technically it would be possible to allow them to do so.

The model-based development (enabled through CPS) allows the deployment of an end-to-end, modelled, digital methodology that covers every aspect from customer requirements to product architecture and manufacture of the finished product. This enables all the interdependencies to be identified and depicted in an **end-to-end engineering tool chain**. The manufacturing system is developed in parallel based on the same paradigms, meaning that it always keeps pace with product development. As a result, it becomes feasible to manufacture individual products.

The end-to-end digital integration of engineering across the entire value chain is the extension of the horizontal integration of the supply chain (SCM) to become the integration of the entire product life cycle management (PLM) value chain.

5. Other general areas of importance

If Industry 4.0 is to be successfully implemented, research and development activities will need to be accompanied by:

- **Standardisation** and reference architecture: Industry 4.0 will involve networking and integration of several different companies through value networks. This collaborative partnership will only be possible if a single set of common standards is developed.
- **Managing complex systems:** Products and manufacturing systems are becoming more and more complex. Appropriate planning and explanatory models can provide a basis for managing this growing complexity. Engineers should therefore be equipped with the methods and tools required to develop such models.
- A comprehensive **broadband infrastructure** for industry: Reliable, comprehensive and high-quality communication networks are a key requirement for Industry 4.0.
- **Safety and security:** Safety and security, physical as for information and digital systems, are both critical to the success of smart manufacturing systems.
- **Work organisation and design**: In smart factories, the role of employees will change significantly. Increasingly real-time oriented control will transform work content, work processes and the working environment.
- **Training and continuing professional development**: Industry 4.0 will radically transform workers' job and competence profiles. It will therefore be necessary to implement appropriate training strategies and to organise work in a way that fosters learning, enabling lifelong learning
- **Regulatory framework:** Whilst the new manufacturing processes and horizontal business networks found in Industry 4.0 will need to comply with the law, existing legislation will also need to be adapted to take account of new innovations.
- **Resource efficiency:** Quite apart from the high costs, manufacturing industry's consumption of large amounts of raw materials and energy also poses a number of threats to the environment and security of supply. Industry 4.0 will deliver gains in resource productivity and efficiency. It will be necessary to calculate the trade-offs between the additional resources that will need to be invested in smart factories and the potential savings generated.

6. References

Reference Architectural Model Industrie 4.0 (RAMI 4.0), Plattform Industrie 4.0 2017
Industrie 4.0 – Technical Assets, Basic terminology concepts, life cycles and administration models, Zvei 2016
Recommendations for implementing the strategic initiative INDUSTRIE 4.0, Final report of the Industrie 4.0 Working Group, Acatech 2013
"Digital twin to enable asset optimization". Smart Industry. 2017.
"What Are Digital Twins and Why Will They Be Integral To The Internet Of Things?". ARC. 2017.
Rethinking the Factory, Arup 2016
Hermann, Pentek, Otto, 2016: Design Principles for Industrie 4.0 Scenarios, 2016
Jürgen Jasperneite:Was hinter Begriffen wie Industrie 4.0 steckt in Computer & Automation, December 2012.
Heiner Lasi, Hans-Georg Kemper, Peter Fettke, Thomas Feld, Michael Hoffmann: Industry 4.0. In: Business & Information Systems Engineering 4 (6)

Plus, a number of articles in magazines and media.