EUROPEAN ROADMAP FOR INDUSTRIAL PROCESS AUTOMATION

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CONTENT

EXECUTIVE SUMMARY

This is an updated version of the ProcessIT.EU roadmap for industrial process automation, which was initially released in 2013 to provide guidance and input for process industry companies, providers of process industrial IT- and automation solutions, researchers as well as policy makers and bodies/initiatives that craft calls for RDI-projects.

The main objective is for European process industry to stay competitive, profitable and sustainable. Thus, to support European process industry in its industrial process automation endeavours, the ProcessIT.EU roadmap outlines three top-level needs: sustainable production, competence management and trust, security, safety and privacy. These three top-level needs intersect the following ten R&D areas:

- Productivity, efficiency, scalability and flexibility
- Sustainability through circular economy - circular economy through industrial internet
- Distributed production/modular factories and services
- Artificial Intelligence and Big Data
- Autonomous plants and remote operations
- Platform economy
- Cybersecurity
- Safety - human, machine and environment
- Competences and quality of work
- Human-Machine Interfaces and Machine-to-Machine communications,

which in turn are used as building blocks in the nine gamechangers. The gamechangers aim to influence the process industries' competitiveness, profitability and sustainability. The gamechangers are listed below:

- Modular factory for distributed and automated production
- Live virtual twins of raw-materials, process and products
- Increased information transparency between field and ERP
- Real-time data analytics
- Dynamic control and optimisation of output tolerances
- Process industry as an integrated and agile part of the energy system
- Management of critical knowledge
- Semi-autonomous automation engineering
- Integrated operational and cybersecurity management

Finally, the ProcessIT.EU roadmap provides an insight into what may need to be considered on **strategic and tactical levels**, in terms of: objectives, R&D areas, game changers and **business modelling**, to keep and develop the competitive edge and initiative.

EUROPEISKA UNIONEN
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EUROPEAN ROADMAP FOR INDUSTRIAL PROCESS AUTOMATION

1 INTRODUCTION

ProcessIT.EU was formed in 2010 and was certified by ARTEMIS as a Centre of Innovation Excellence (CoIE) in early 2011. ProcessIT.EU is primarily focused on process automation and ICT for process industries (which includes Operational Technology (OT) in process networks) and was formed by various partners, including end users, technology suppliers, academia and public authorities. The strategic idea guiding ProcessIT.EU is to accelerate growth and automation technology development through a process of project incubation by bringing together plant owners from the selected industry segments, solution providers with a focus on automation technologies, researchers from university and research organisations, and public authorities focused on developing the selected industries.

As a project incubator, *ProcessIT.EU* is innovation-driven and oriented towards identifying and implementing project activities that focus on new competitive automation technologies. ProcessIT.EU is founded on four different, mutually reinforcing value propositions:

1. Accelerate growth and technology development in Europe through increased competitiveness in related industries and research organisations.
2. Strengthen the competitiveness of process industries through innovations in ICT and automation technology.
3. Strengthen automation technology suppliers through the incubation and implementation of strong R&D projects that innovate and develop globally competitive automation solutions.
4. Support the European automation research community in further developing world-class research by providing access to highly challenging industry contexts and involvement in leading innovation projects.

To facilitate project incubation and to support and influence strategic research agendas and calls in various European initiatives, Public Private Partnerships (PPPs) and platforms, ProcessIT.EU develops and maintains this roadmap in the area of ICT and automation for process industries. A summary of some of these additional research agendas and roadmaps is given in chapter 3. This document, which is the second version of the ProcessIT.EU roadmap, is updated on a regular basis. The method used to develop this roadmap is based on a method used for several years within VTT Finland and is described in chapter 3.

This roadmap document is organised in two major chapters. In chapter 4, trends, visions and long-range goals are formulated and categorised into a set of research and development areas. In chapter 5, visions and long-range goals are concretised into a number of gamechangers that form the direction of development proposed in this road map. The gamechangers are matters that are expected to have great impact and lead to significant change. Each gamechanger contains a description, the effect on industrial competitiveness and a set of proposed actions on a timeline. There is always a close connection to the aforementioned research and development areas. In addition, the roadmap is summarised with concluding remarks and project proposals. This roadmap document has been prepared by a group of researchers and experts from Finland and Sweden, with feedback from a European reference group (members of ProcessIT.EU as well as other roadmap initiatives). Presentations, documents and more information can be found on: *www.processit.eu*

We hope that this roadmap will inspire different R&D stakeholders, so Europe can realize projects that meet the process industries' challenges where automation and ICT are increasingly important factors in the global competition. Thus, the purpose of the roadmap is to maintain and develop the European competitive edge and initiative.

The relevant industry sectors include the following:

- Pulp and Paper (including forestry)
- Metals
- Mining and Minerals
- Chemical
- Energy and Power
- Pharmaceutical
- Food Production and Processing
- Infrastructure
- Mobile platforms
- Oil and Gas

A potential new sector for the future may also be data centres.

1.1 Current developments and state of the European process industry

In recent years there has been an increasing interest in digitalisation and re-industrialisation from politicians and society. However, what does this mean for the process industry?

Regarding digitalisation for the process industry, in our view, the top (i.e., ERP-systems and other decision-making systems) and bottom (i.e., production processes and production equipment) should be electronically connected, so that information can flow in both directions and the information can be used as input to decision-making at all levels of a process industry company. Further, to get the full effect of this, the whole value -chain, including suppliers, service providers, partner and customers, etc., should be electronically connected and integrated. This will allow additional flexibility and efficiency as well as new ways of operating within the value -chain. To enable this, the increased connectivity and integration must be safe and secure. If we can do this, and many process industry companies have already achieved a lot, we can look forward to a re-industrialised European process industry which makes additional investments, employs a lot of people, has strong value-chains, and continuously develops and maintains its competitive edge and initiative.

Further, the automation systems used in the process industry need to be further enhanced in order to support the digitalisation efforts. Thus, it is important to foresee in which direction customer requirements move and what can be expected in the near future.

If the European process industry succeeds in leading the way regarding digitalisation and automation systems and if this is positioned adequately on global markets, a strong and prosperous future may be foreseen.

2 PROCESS AUTOMATION IN EUROPEAN INDUSTRY - TO KEEP AND DEVELOP THE COMPETITIVE EDGE AND INITIATIVE

As many European regions have a high labour costs and many of the process industry companies need to be located in close proximity to the main input and skilled labour, the process industry companies need to operate with high levels of automation and availability in order to be efficient, competitive, profitable and leading on the global markets. It is much better to be in the front-line and attractive for the customers than the second or third choice when discussing business and placing orders. Additional facilitating factors are gender and equality, as a higher level of automation may favour equality in the workforce (due to decreased physical requirements and improved work environment) compared to today's situation, which is rather male-dominated. An increased level of digitalisation and automation can also enhance the possibilities for outsourcing or on-demand acquisition of production capacity, as well as general engineering and development tasks, from large process industry companies to smaller ones.

Another important, and indirect, aspect for process industries is the availability of critical infrastructures which provide, for instance: electricity, water, waste management, and transportation and logistics via road/water/rail/air. These need to operate with a high availability and stability, which includes their automation systems and IT-infrastructures, and must necessarily improve and sustain their level of cybersecurity and reliability in order to allow process industry companies to operate seamlessly and smoothly.

Further, there are quite a few actors and initiatives who publish advice and strategic roadmaps or research agendas. In sections 2.2 and 2.3., there are overviews and summaries from some of the most active ones.

2.1 Top-level need groups

Below are the top-level needs for the process industry identified by the ProcessIT.EU roadmap group. The needs are divided into three main groups: sustainable production, competence management, and trust, cybersecurity, safety and privacy.

Sustainable production

- Circular economy
- Environmental security, physical security and safety
- Incentives for responsible/sustainable production and operations
- Managing profitability and investments
- Overall equipment efficiency (OEE)
- Overall cost versus quality and RDI-efforts
- Managing and improving quality
- Business models
- Accountability

Competence management

- Long-term perspective
- Invest before needed
- Experience
- Risk management
- Changing demography
- Cost level per work hour versus automation
- Retirements and need for trained and highly educated workforce
- New tools, methods and processes require continuous training and a further advanced skill set
- Knowledge management - convert tacit to formal knowledge
- Outsourcing from large companies to small companies

Trust, cybersecurity, safety and privacy

- Risk management
- Cybersecurity (including IT-/OT-/information security, etc.)
- Access to production and automation data, authentication and authorization
- Ownership of data
- Availability
- Confidentiality
- Integrity and accuracy
- Usability
- Non-repudiation (digital signatures/blockchains)
- Incident management, disaster recovery and business continuity
- Safety and liability

2.2 Summary of actions and roadmaps from related initiatives

To position the ProcessIT.EU roadmap among other related initiatives' actions and roadmaps, a number of the latter have been summarized below. There are quite a few different initiatives and bodies active in the digitalisation and technology development arena, and they each target a particular specialisation or segment. The ProcessIT.EU roadmap targets industrial process automation, i.e., industrial process IT and automation within the process industry (however, many of the issues are very similar for the manufacturing industry as well), and aim to provide guidance among top needs, R&D areas, game changers and business models that are of interest for many of the actors within the process industry. Further, it is also of great interest to develop adequate methods, processes, knowledge and skills that go hand –n-hand with technology and business to achieve a competitive edge and sustainability.

There are overlaps and different views concerning the initiatives and it is assumed that this partly depends on the perspective from which the matter is viewed as well as which objectives guide the respective initiatives. However, many of the initiatives clearly point to the fact that R&D involving technology, organisation, methods and processes is required together with competence acquisition and development.

2.2.1 Industry4.0

In Germany, an Industry4.0 standardisation roadmap was released in Jan 2016 (Industry4.0, 2016). Driven by the German push towards Industry4.0 it presents a number of areas where current standardisation is to be extended to accommodate the upcoming usage of Internet-of-Things (IoT) and Systems-of-Systems (SoS) technologies. It addresses the requirement for standards in a number of areas e.g., reference models like RAMI4.0, and reference models of the technical and organisational processes and provides clear recommendations for how such standards should organised and written.

The Industry4.0 concept has had a great impact on many other roadmaps and initiatives as well as strategic planning and policy-making in general.

2.2.2 EFFRA

The European Factories of the Future Research Association (EFFRA 2017) is an industry-driven association promoting the development of new and innovative production technologies. It is the official representative of the private side in the Factories of the Future public-private partnership, which brings together private and public resources to create an industry-led programme in research and innovation with the aim of launching hundreds of market-oriented cross-border projects throughout the European Union, to be applied in a wide range of manufacturing sectors. EFFRA was established jointly by the MANUFUTURE technology platform and key industrial associations to shape, promote and support the implementation of the 'Factories of the Future' public-private partnership. The key objective of EFFRA is to promote pre-competitive research on production technologies within the European research area by engaging in a public-private partnership with the European Union. Supported through the Horizon 2020 research programme, Factories of the Future is a European Union contractual public-private partnership of which the overall aim is to enable a more sustainable and a more competitive European industry at the centre of Europe's economy – generating growth and securing jobs. Research call topics are announced annually by the European Commission. Interested organisations form consortia and submit proposals which are then independently evaluated. A chosen project is assigned a percentage of funding from the European Union with the rest of the funding and resources coming from the members of the project consortium.

The following prioritized research and innovation domains are identified: Advanced manufacturing processes, Adaptive and smart manufacturing systems, Digital, virtual and resource-efficient factories, Collaborative and mobile enterprises, Human-centred manufacturing, and Customer-focused manufacturing. The core objective of Factories of the Future is to promote the research and innovation activities undertaken within these domains, focusing on the challenges and opportunities of: Manufacturing the products of the future, Economic sustainability of manufacturing, Social sustainability of manufacturing, Environmental sustainability of manufacturing, and Reducing resource consumption and waste generation.

2.2.3 ECS SRA

The three associations Aeneas, Artemis and EPoSS launched a joint roadmap for the Electronics, Component and System and Software industry in Dec 2017 at the EFECS event in Brussels. This roadmap addresses 5 application areas, of which one is Digital industry. Here, four grand challenges are highlighted:

- Digital platforms,
- Digital twins,
- AI machine learning,
- Condition monitoring

It has been pointed out that these technologies must be matured to a level where they can be used in industry without requiring PhD-level competence.

This is complemented by four technology areas:

- Systems and Components: Architecture, Design and Integration
- Connectivity and Interoperability
- Safety, Security and Reliability
- Computing and Storage

This addresses technology areas where enablers are required to foster innovation in Digital industry.

2.2.4 ARTEMIS

The ARTEMIS European Technology Platform (ARTEMIS 2017) was established in June 2004.One of the core tasks of the ARTEMIS ETP was to define a common Strategic Research Agenda (SRA) which acts as a reference for the Embedded Computing domain to attract investment from the stakeholders. The first version of the SRA was published in 2006. In 2007 the ARTEMIS Industry Association was founded to continue the activities of the ARTEMIS ETP and to become the legal private partner in the ARTEMIS Joint Undertaking. In 2014 the ECSEL-JU programme started with the merger of the previous ARTEMIS-JU and the ENIAC-JU and will finish in 2024. ARTEMIS Industry Association's ambition is to strengthen Europe's position in Embedded Intelligent Systems and to attain world-class leadership in this domain to support European industry. It is a multidisciplinary membership organisation with more than 170 members and associates from all over Europe. The association represents its members in ECSEL commitments (industry, SMEs, universities and research institutes) and continuously promotes the research and innovation interests of its members to the European Commission and the Public Authorities of the participating states. The ARTEMIS strategy is one coordinated, pan-European strategy in the Embedded Intelligent Systems sector in Europe. This strategy is a part of the ARTEMIS European Technology Platform and constitutes four core values: European competitiveness, Innovation, Global Impact and Improvement of day-to-day life. Three focus areas are named: Embedded & Cyber-Physical Systems, IoT and Digital Platforms.

The main focus points are:

- Build a self-sustaining Innovation Environment for European leadership in Embedded Intelligent Systems.
- Full development of the innovation potential of SMEs in Embedded Intelligent Systems.
- Address European strategic priorities in addition to the individual interests of companies and countries, upstream and downstream.
- Strengthen European industry and address societal challenges.
- Align research agendas for Embedded Intelligent Systems.

2.2.5 SPIRE

The Sustainable Process Industry through Resource and Energy Efficiency (SPIRE 2017) is a PPP driven by the European Process Industry and aligned with the strategic goals defined by the European Commission in the Europe 2020 strategy and across its various flagship initiatives such as the "Innovation Union", an "Industrial Policy for the Globalisation Era", "Resource Efficient Europe" and an "Agenda for new skills and jobs". The aim of SPIRE's goals is to help the European process industry to become competitive and sustainable, thereby leading to European growth

and jobs. SPIRE brings together cement, ceramics, chemicals, engineering, minerals and ores, non-ferrous metals, steel and water sectors, all operating from Europe. All of these sectors are highly dependent on **resources, energy, raw materials and water** in their production and striving for long-term sustainability. These industries demonstrate a clear and urgent interest in improved efficiency and competitiveness which will drive the implementation of many European policies. The sectors united in SPIRE represent a major part of the manufacturing base in Europe (EU27), including 450,000 individual enterprises with about 6.8 million employees, generating EUR 1,600 billion in turnover. As such, they represent 20% of the total European industry, both in terms of employment and turnover. The mission of A.SPIRE is to ensure the development of enabling technologies and best practices along all the stages of large-scale existing value chain productions that will contribute to a resource-efficient process industry. Some examples of cross-sectional efficiency improvements are: heat loss and the associated reduction of energy costs and of CO2 emissions through process optimisation, energy reduction in industrial processes through new energy storage systems, less production time and fewer off-spec products through sensor-enabled refractory materials, higher asset utilisation of wind and solar installations through hydrogen production, increased resource efficiency through more efficient ovens, furnaces, boilers, separators, pumps, heat exchangers and systems.

Key performance indicator areas include: New jobs & skills, Open, excellent and socially responsible RDI ecosystems, Innovation and industrial competitiveness, Sustainability and eco-efficiency

2.2.6 IoT Forum

The IoT Forum (IoT forum 2017) is a member-based organisation which aims to promote international dialogue and cooperation on the Internet of Things, organise events and conferences, and develop activities and synergies with and among its members. It supports the development of a worldwide interoperable Internet of Things, addressing technology barriers, business and societal challenges to create the conditions for a truly worldwide Internet of Things ecosystem and market. It does this by promoting international dialogue and cooperation on the Internet of Things between diverse actors from industry, research and government and across sectors.

Three work groups are active. In **Market confidence**, the objective is to collectively provide the conditions for developing the market confidence, by developing processes that members must fulfill and which: Ensure interoperability by proving conformity to a set of essential features, Avoid vendor lock-in by proving openness as conforming to some member-defined criteria, Ensure privacy, societal value and ethics by member acceptance to IoT Forum criteria, Providing a market-confidence label. In **Business Leadership**, a form of leadership is promoted where: leaders are deeply involved in customers' needs and perspectives, companies are environments with a vivid internal dialogue with internal and external stakeholders about open innovation across departments. There is more focus on societal needs than on narrow short-term company interests, and this attitude turns out to be worthwhile from a business perspective, technological innovation is an integrated part of solutions for citizens, also in areas where use of technology is not common, the company's work must make sense in a societal and global setting. In **Architecture and Interoperability**, the objective is to propose a list of Architectural Reference Model (ARM)-profiles that can be reused by architects for building their own IoT systems. Each profile will focus on specific qualities of the system e.g., (semantic) interoperability and security. Different advantages of a single profile may be proposed. Secondary objectives are definition of an ARM profile-compliant label and specification of a process leading eventually to the certification of the third-party components against specific ARM profiles. This objective will be addressed in cooperation with the "Market Confidence" work group. Maintaining an ecosystem of ARM profile-compliant open-source components for developers to reuse is a natural extension of these objectives.

2.2.7 TAMS4CPS

Trans-Atlantic Modelling and Simulation for Cyber-Physical Systems (TAMS4CPS 2017) is an EU-funded project with the mission to develop a strategic research and collaboration agenda to foster trans-Atlantic research in Modelling and Simulation for Cyber-Physical Systems. The TAMS4CPS project is a coordination and support action funded by the European Commission which ran from February 2015 to January 2017 with the overall aim to lay the foundation for EU-US collaboration in modelling and simulation in CPS. The project partners collaborate with five leading researchers in the field at top US universities to create A Strategic Research Agenda for Collaboration (SRAC), based on a comprehensive roadmapping process and endorsed by researchers in the EU and US. They will also create a set of openly available test cases for model developers which can be used for collaborative evaluation. A web-based report will also be created on the state-of-the-art in modelling and simulation for CPS to provide the context for the SRAC and to act as a baseline for future collaborative research activities. To prioritise modelling and simulation research challenges and to create a constituency which will provide a basis of future collaboration for pre-competitive research, the project partners engage industry and academic researchers and modelling and simulation users in a series of workshops and web-based meetings, utilising a consultative approach. Activities aim for a comprehensive implementation of the SRAC in a transnational context ultimately benefitting both US and EU competitiveness.

TAMS4CPS address the European priorities in CPS: Architectures principles and models for autonomous, safe and secure Cyber-Physical Systems, Systems design, modelling and virtual engineering for Cyber-Physical Systems, Real-time modelling for autonomous adaptive and cooperative Cyber-Physical Systems, MBSE applied to computing platforms and energy management for Cyber-Physical Systems. To these is added a fifth theme of Integration of socio/legal/governance models within modelling frameworks.

2.3 Other initiatives

2.3.1 Bio-based industries (BBI)

The Bio-Based Industries Joint Undertaking (BBI 2017) is a new Public-Private Partnership between the EU and the Bio-based Industries Consortium. Operating under Horizon 2020, it is driven by the Vision and Strategic Innovation and Research Agenda (SIRA)

developed by the industry.

Bio-based industries represent a significant industrial sector, especially in northern Europe. However, there are only a few ICT related topics within the calls. During year 2017 the single one is: "BBI 2017.S2 Identify opportunities for ICT to increase the efficiency of biomass supply chains for the bio-based industry".

Three focus areas are identified:

- Feedstock: foster a sustainable biomass supply with increased productivity and building new supply chains
- Bio-refineries: optimise efficient processing through R&D and demonstrate their efficiency and economic viability at large-scale demo/flagship biorefineries
- Markets, products and policies: develop markets for bio-based products and optimise policy frameworks

2.3.2 ITEA 3

ITEA (ITEA 2017) is the EUREKA Cluster programme supporting innovative, industry-driven, pre-competitive R&D projects in the area of Software-intensive Systems & Services (SiSS). Within the domain of Digital Technology, ITEA address innovation in Software, IT Services, Internal IT and Embedded Software, collectively denoted as 'Software innovation'. For Europe, an industry strong in Software Innovation is a prerequisite for maintaining global competitiveness and securing high-value jobs in digital technology and in other, more traditional industries that are dependent on digital technology.

To support the initiation and evaluation of new ITEA projects and to support the management of ongoing projects, an ITEA Living roadmap including a State-of-the-Art database with public deliverables from ITEA projects has been established. The Living Roadmap has also been extended with information about projects, societal and economic challenges and people as well as the links between them. Seven challenges are addressed: Smart mobility, Smart health, Security and safety, Smart engineering, Smart communities, Smart city and Smart industry.

2.3.3 BDVA - Big Data Value Association

The Big Data Value Association (BDVA 2017) is the private counterpart to the EU Commission to implement the BDV PPP programme. BDVA gathers large and small and medium-sized industries and enterprises as well as research organisations to support the development and deployment of the PPP work programme and to achieve the Key Performance Indicators (KPI) committed in the PPP contract. The BDV PPP activities address technology and applications development, business model discovery, ecosystem validation, skills profiling, regulatory and IPR environment and social aspects. The BDV PPP strives to achieve a comprehensive innovation ecosystem reaching and sustaining European leadership on Big Data, and for delivering maximum economic and societal benefit to European business and citizens.

The overarching general objectives of BDV PPP are:

- to foster European Big Data technology leadership for job creation and prosperity by creating a Europe-wide technology and application base and building up competence and the number of European data companies, including start-ups
- to reinforce Europe's industrial leadership and ability to compete successfully in the global data value solution market by advancing applications converted into new opportunities, so that European businesses secure a 30% market share by 2020
- to enable research and innovation work, including activities related to interoperability and
- standardisation, for the future basis of big data value creation in Europe
- to facilitate the acceleration of business ecosystems and appropriate business models with a particular focus on SMEs, enforced by Europe-wide benchmarking of usage, efficiency and benefits to provide and support successful solutions for major societal challenges in Europe, e.g., in the fields of health, energy, transport and the environment, and agriculture
- to demonstrate the value of big data for businesses and the public sector and increase acceptance by citizens, by involving them as 'prosumers' and accelerating take-up
- to support the application of EU data protection legislation and provide for effective mechanisms
- to ensure enforcement of EU data protection legislation in the cloud and for big data

3 METHODOLOGY

Roadmapping is a methodology that helps companies and entire industries anticipate future needs and changes as well as illustrate market trends, environmental changes and technology lifecycles. However, roadmapping is not a tool for predicting the future; it enables strategic planning and helps decision makers craft decisions that can achieve the most desirable outcome. This roadmap work applies a roadmapping method developed by VTT (Ventä, 2007) and has been organised with efforts into several steps (as illustrated in Figure 1). The first step is the development of a vision, i.e., the ideal situation where the end-user requirements are satisfied. Vision building consists of defining the overall vision, recognising the general trends, state-of-art, R&D areas, drivers, and how the observer's own vision is affected by them. The next step is the definition of the long-term objectives that enable the vision. After the current state has been mapped out, short- and long term objectives need to be defined together with stepping stones and game changers to use or adhere to.

To define the context for the roadmap, an overview of the areas of interest must be defined. The business environment and the relevant overall development trends must be selected for the industrial process automation domain to identify the development directions of the roadmap and the following concluding recommendations. The relevant trends and R&D areas are presented in chapters 1, 2 and 4. In order to provide a scope for the ProcessIT.EU roadmapping, the relevant general industrial needs regarding sustainable production, competence management, and trust, cybersecurity, safety and privacy, have been selected. These needs are based on the identified trends and needs from which a set of high-level goals are defined. Further, they are transformed into more concrete actions, which are referred to as game changers. These game changers help to form the vision required to implement the roadmapping work. The game changers are presented in chapter 5.In order to collect the data, or input needed to update the roadmap, a number of meetings, interviews and workshops have been conducted together with stakeholders from process- and manufacturing industries, technology and service providers, academia as well as public authorities from a number of EU-member states. Pertaining to the commercial stakeholders, all sizes from micro SME up to large global corporations have been included and participated. The data from the initial data collection was then analysed and refined during the end of 2016 and beginning of 2018 prior to a third round of evaluation among the stakeholders. After the initial data analysis, a skeleton roadmap and some initial texts were crafted and used for the evaluation. Following the evaluation, the roadmap text was written together by a number of contributors. After a final polishing, the roadmap was sent out for a final verification among the stakeholders before it was finalised and released.

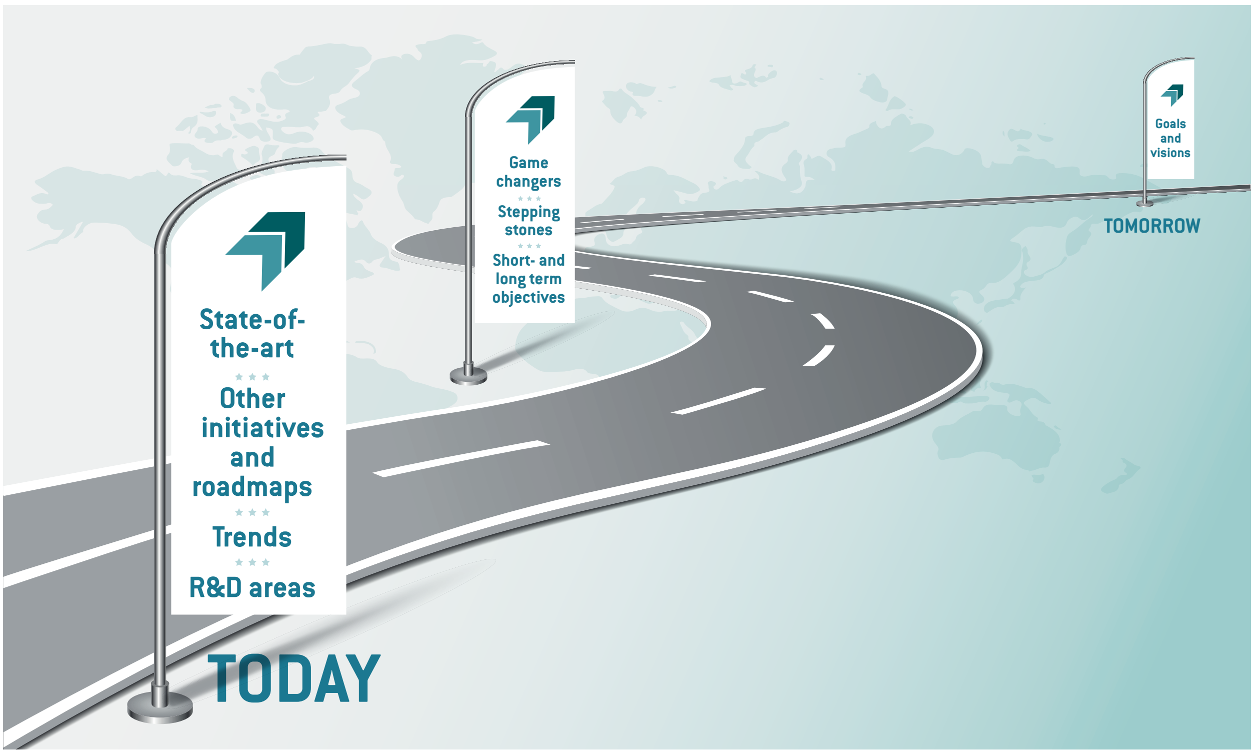

Figure 1 - Phases and timeline of roadmapping

4 IDENTIFIED RESEARCH AND DEVELOPMENT AREAS

A well-defined description of the current business environment and trends is required to identify the development directions of the roadmap and the concluding recommendations. Further, the identified trends comprise global trends in the context of the European process industry. An initial categorisation of top-level needs and industrial automation R&D areas is shown in Figure 2.

The identified ten R&D areas support one or several of the three top-level needs: sustainable production; competence management; and trust, cybersecurity, safety and privacy. In addition, based on the identified R&D areas and the top-level needs, a set of high-level goals has been defined. In the following sections, the R&D areas and goals are outlined in detail. Further, in chapter 5 and Table 1 in chapter 5, the specific R&D areas are linked to gamechangers and their effects on industrial competitiveness.

4.1 R&D areas

There are ten R&D areas, which are influenced by increasing interest and need for digitalisation and re-industrialisation within Europe's process industries. Further, cybersecurity has become its own R&D area and separated from safety, as it is in many of the other roadmaps covered in the introduction. In addition, the ability to collect, analyse and use adequate data for and from simulations or support decision-making, etc., i.e., to maximize the value extracted from the data, will be a key enabler for future competitiveness. Together with Big Data, Artificial Intelligence (AI) is an area of increasing interest in order to derive more value from the data collected and stored. Further, an increasing level of autonomy in production combined with remote operations is now evident in some process industries, and more is foreseen.

4.1.1 Productivity, efficiency, scalability and flexibility

It is of utmost high priority to continuously increase the efficiency and availability of production processes and thus the utilisation of plant equipment. The focus should be on agile and multi-use plants that can deliver both the economics of a large single stream plant, the flexibility of a batch plant as well as be part of a global production process, while, within limits, be able to make many products. This allows for production flexibility and the possibility to ramp up the production capacity for specific products on demand.
To support the above, the platforms, products and services, etc. used in the production processes will need advanced lifecycle management and collaboration functionality. Here, production-related data must be collected and used as input, and integration and interoperability must be improved. Tools for modelling, design and simulation will be necessary and later combined with tools to monitor the production process and its equipment/platforms, connectivity, productivity as well as quality of services used or provided.
Certain design steps can be replaced with design automation. Based on a survey conducted in 2017 (Lackman et al., 2017), design automation methods have been applied in sub-disciplines of plant

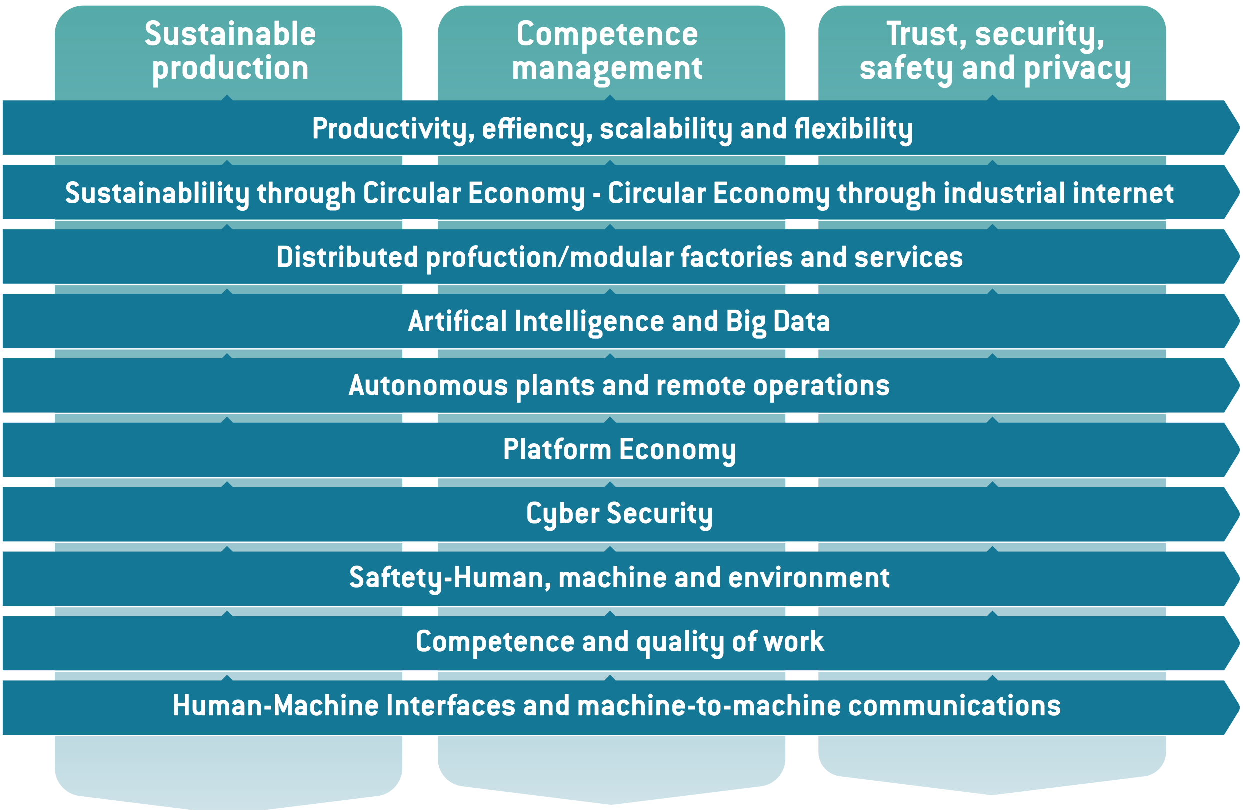

Figure 2 - Industrial top-level needs and industrial automation R&D areas

design, e.g., automated tube and pipe path design. Application to conceptual or basic plant design seems today to be missing. Further, continuous and on-line optimisation together with professional training of workers will ensure productivity and efficiency. To monitor and optimise, adequate knowledge of the production process and its equipment, etc. is required in order to be able to model it, understand which relations and dependencies are most important, as well as collect data and analyse it to provide input to decision-making and KPIs. Here, an example is maintenance and the ability to predict problems and act in a planned and proactive manner rather than react to problems that have already arisen. An issue following the growing collection and use of data is how to manage the data on a long-term basis (as well as who can use it, for what and when). The data must be preserved using a well-considered strategy to retain its usability and future value, and further some of the software used may also need to be preserved, so that old data can be used/ available in the future when needed. This matter will become increasingly complex as the amount of data collected and stored grows and external data and metadata are used, and a lot of data will in the future not be stored, but streamed (and only a few data points out of that will be stored for historical purposes).

Identified trends

- Lifecycle management and collaboration functionality
  - Sensors, ICT-infrastructures, IT/automation systems
  - Integration of planning, control scheduling and demand-side management
  - Interoperability of tools
  - Modelling tools
  - Simulators
  - Design tools
  - Monitoring tools
  - QoS tools
- Training - professional training of employees. Further, a higher level of formal training may be required for workers in production and maintenance, due to foreseen tasks as analytics (find root causes and bottlenecks as well as derive and use statistics for decisions), and use of advanced technologies and highly automated/complex systems
- Modelling
  - Automatic modelling
  - Design automation
    - Generative and evolutionary design exploration (Eichhoff and Roller, 2015)
    - Automatic Design Schemata Derivation and Design Generation (Reed and Gilles, 2016)
    - Morphogenetic engineering (Doursat et al., 2013)
  - Model based, plant-wide dynamic control
- Analytics
  - Data analytics
    - Historical data
    - Online/streaming data
    - Derived from historical/online/streaming data
    - Combining collected data with external- or metadata
  - Process analytics
  - KPIs
    - Production and process related
    - Cost/benefits of additional IT/automation investments
- Continuous on-line optimisation of efficiency and availability
  - Multivariate and multiobjective
    - Based on environment parameters
    - Based on organizational KPIs
    - Conflicting priorities
- Maintenance optimization
  - Predictive/proactive, condition-based, prescriptive
  - Reactive
  - Planned
  - Additive manufacturing of spare parts on-demand
- Digital preservation (of collected data/information and software)

Goals and visions

- Model-based design and scale-up of new processes
- Sustainable virtual factory/twin - automatic and data-driven updates of models
- Increased productivity from improved ways of working, collaboration, lifecycle management, optimisations and distributed production and services
- Zero-configuration/self-configuration and integration of automation systems
- Global access and distribution of automation services
- Efficient and long term availability/access to data and information for analytic purposes
- Decision-making based on data and facts
- User-friendly design and operation of automation systems
- Self-healing, redundant and resilient production and automation systems

4.1.2 Sustainability through Circular Economy - Circular Economy through Industrial Internet

The EU has declared that sustainability comprises three main areas that should be integrated and go hand in hand: economic, societal and environmental aspects. Apart from tardy development in the USA, environmental aspects seem to be on the rise in almost all developed countries. However, it may be hard to address the societal and environmental aspects before there is an economic foundation for doing so. However, these aspects must be addressed; otherwise, future progress may be jeopardized. For this to be realized, lifecycle analysis methods and tools have to be utilised.

There are a number of measures and actions that must be taken and planned for immediately. One of these measures is to implement better designs that make process-industry operations more agile with less environmental impact. This also includes the logistics set-up, which may involve a lot of vehicles and long-haul transports of incoming and outgoing goods, parts and raw materials. Use of, for instance, hybrid- or electric drives/motors instead of diesel or petrol motors may produce fast results.

It is necessary to monitor and control the level of emissions, waste and energy use, to be able to react to problems as well as comply with laws and regulations. By-products are an area of interest and, if possible, these should be used to create additional income and create less waste that must be managed or disposed of. Thus, the sustainability thinking should be part of the original and continuous design of process industries and the surrounding logistics and supply-chains, to optimise the operations and production capacity in a sustainable manner. This will require complex systems simulations

and optimisation, and the necessary models need to be built and maintained.

There are new or emerging business models that are more sustainable than the common ones, i.e.: products, services, products with services, solutions etc. Looking at the new or emerging ones, e.g., Product-Service Systems (PSS), Industrial Product-Service Systems (IPS2) and functional provision, where the contracts often are result-, performance- or availability-based, the provider assumes more responsibility and risks but can on the other hand charge more and be harder to imitate and compete with. These examples of new or emerging business models have sustainability aspects built in already from start.

Identified trends

- Key performance indices (KPIs) related to the environmental performance of process (even online)
- Lifecycle analysis, simulations/optimisation and management - it is a customer and societal demand
- Circular-economy – increased utilisation of side and waste-streams as raw materials
- Seasonal supply of raw materials and energy
- Agile operation
- Electrical drives/motors
- Monitoring and control
  - Legislation
    - Waste
    - Energy
- Design
- Complex system optimisation
  - Energy efficiency
  - Minimise emissions (CO_2, NO_x, etc.)
  - Ability to use/cope with bi-products and produce less waste
- New or emerging business models

Goals and visions

- Stable societies and viable economic development of areas with process industries - quality of life, new types of jobs
- Long-term environmental planning and care in areas with process industries
- Optimised logistics set-ups
  - Extended lifecycle analysis and management
  - Low emissions and waste/disposal output from production processes
  - Re-use of energy and optimized energy- and raw materials consumption
  - Move towards renewable energy sources and less use of fossil energy
  - Less environmental handprint (i.e., during operations and logistics, etc.) and footprint (when building and setting it up) from process industries
- Look to use more sustainable business models such as result-, performance- or availability-oriented ones both in the production process as well as in what is delivered to customers
- In the long term, economic, societal and environmental aspects do not conflict

4.1.3 Distributed production, modular factories and services

The transformation of raw materials into valuable products or other offers is a distributed production process that involves several different entities that are managed by many different plant owners. It is foreseen that the distribution of the production process will continue to increase in the future. To facilitate this, distributed production resources and external services will be needed. Further, this requires standardized technical interfaces between the main production resources and the distributed ones in order for them to work together and interoperate. In addition, standardized business interfaces allow fast and efficient negotiations and contract set-ups, via an automated broker (using, e.g., Smart Contracts via blockchain technology (Smart contracts, 2017) or brokers like AirBnB, etc.) with distributed production resources. Prior to changing the production, it is desirable to simulate and optimize the new scenario (comprising multiple production units, customer demand and support system network) in order to avoid creating performance issues/ bottlenecks, logistic- or quality problems. Distributed production, or multi-stakeholder operation, which will be a natural step with global production, needs continuous optimisation and control to be efficient. Thus, the level of automation needs to be increased with focus on: interoperability, management and mining/analysis of big data generated and collected, to improve the competitiveness of production plants and processes.

Global provision of products, related services and knowledge, etc. requires changes to the traditional business environment and business models used. Connectivity and the Internet will be a prerequisite for emerging services such as: personalized and targeted B2B-marketing, broker services, automated contracts (smart contracts), use of distributed production resources, and maintaining global industrial process automation solutions. Companies that are successful in capturing and distributing process knowledge as well as ensuring a high level of personnel competence will secure their competitiveness in the global marketplace. Further enablers for global and distributed production are data and information security and reliable exchange/distribution of data and information necessary among the parties involved in the production process and related activities.

European companies are building new production units primarily in developing countries due to market proximity, low raw material cost and reduced labour costs compared to Europe (although some European companies are bringing home production in order to increase flexibility, get faster delivery and improved control). At the same time, as the complete production process is further distributed, management (including, e.g., production planning and process control) is still focused on individual production entities rather than on the interconnections between production entities or sets of production entities. Combining a globally distributed production process with an increasingly volatile market demand will introduce new requirements on the agility, optimisation ability and security of production entities, and the orchestration of sets of production entities, to maintain a high OEE. Thus, industrial process automation will play an important role in this future development. Below are the identified trends regarding distributed production and services

Identified trends

- Increased automation of logistics. Possibilities for new or emerging actors (having a platform advantage) within logistics of intermediate products from plant to plant, optimised/adaptive logistics, optimisation of material flows

- Processing of raw materials will be done closer to the source, e.g., separating bark and wood on-site in the forest
- Standardized technical interfaces enabling interoperability and use of distributed production resources and services
- Standardized business interfaces enabling:
  - Automated negotiation and contract/order management
  - Broker service for fast acquirement of accredited/certified:
    - Services
    - Production capacity
- Simulation of extended/distributed production processes
- Multi-stakeholder operation
- Global optimisation and control
- Data and information security
- Data and information distribution
  - Connectivity
  - Timely sharing of commonly needed information/data among partners in the value chain

Goals and visions

- Increased agility, security and flexibility of production processes
- Orchestration and portfolio management to control and optimise what and where to produce in the most efficient manner
- Enabling new tool chains with integration of legacy tools, IoT tools, SoS tools, ML tools, etc. fostering engineering simplicity/efficiency
- Achieving a dynamic combination of competencies and continuous knowledge of entities
- Communication for value creation from globally networked operations involving business management, global supply chain management, analysis of data, product-service linkage and management of distributed production assets
- Communication, virtualization and simulations are key technologies for achieving a well-functioning distributed production process
- Automatic detection of dynamically evolving production system structures. Utilisation of these structures in automatic modelling, decision support, control and optimisation

4.1.4 Artificial Intelligence and Big Data

A growing volume of data (e.g., via IoT) and advancements on machine learning (ML) has made Artificial Intelligence (AI) useful in a wide range of applications (Russel, 2016). AI/ML is a broad concept which most often is behind the term "Smart". Further, ML and AI techniques will require substantial amounts of data to learn from.

AI will provide decisions or decision support based on models, training data and continuous adaptation to real time data. Further, AI will also enable the management of interactions and answer questions as well as interact in support situations based on data and past gained knowledge. A challenge for AI and Big Data is the adaption of this technology such that an automation engineering process for time-varying processes that are common in process industries. This calls for further RDI investments.

Identified trends

The Internet abounds with articles regarding trends in the AI area. Below, a few are summarised from the process industry perspective:

- AI will impact almost every industry, with targeted, not general-purpose, AI systems. The AI systems will be able to use both structured as well as unstructured (big) data from multiple sources and formats.
- Service business around AI will emerge as the next big opportunity, also having room for SMEs. This will be enabled partly by better, easier-to-use tools.
- Interesting use cases/technologies for process industry are support situations, queries, predictive maintenance, sensor data analysis, prevention against cybersecurity threats, sensor data fusion, decision support, robotic process automation.
- Human-machine interaction will become richer.
- AI will be used in process design and, later, for re-designs and optimizations of the designs.

AI implementations will be focused on incremental improvements in the short term; the long term is expected to see transformative changes.

Goals and visions

- Fast and improved decision support (both for humans and machines)
- Decisions based on data/big data as well as data from multiple sources
- ML and AI to support monitoring and automated decision-making within cybersecurity, production processes, predictive maintenance, etc. to speed up corrections or responses to issues
- Improved learning by AI-systems and adaptation to industrial needs
- Engineering processes and tools simplifying the adaptation, usage and evolution of AI/ML technology to process industries.

4.1.5 Autonomous plants and remote operations

The production processes within process industries will acquire more autonomous parts as a result of development in extreme or hazardous conditions, or process industries located in remote/distant areas - where much can be gained from an increasing autonomy combined with remote operations. The objective is to save costs as well as to improve safety and availability/OEE. Production areas that are remote (where there normally are no workers) or hazardous (where people should not be or cannot be present) can to a large extent be operated remotely with autonomous equipment and vehicles, etc. supported by skilled people. This enables a skilled worker to support 10-20 production processes simultaneously instead of one, and to take control when and where necessary to rectify or adjust a process. As an example, autonomous energy production facilities remotely operated from other plants or offices have been around for years. Thus, successful autonomous operation requires technologies such as predictive maintenance, ML and AI, augmented and virtual reality, drones as well as simulation.

Identified trends

- Increasing level of autonomy and autonomous parts/equipment in production processes
- Advanced robotics
- Remote operations - distant and hazardous areas
- Requirement for supporting technologies and methods
- Connectivity added to remote and production sites with low connectivity properties (e.g., underground hard rock mines, metal production) - WLAN and 5G
- Skilled and multitasking workers - easier to find when operating remotely
- Situational awareness [example Tampere inland harbour] - improved process- and operator view

Goals and visions

- Autonomous production processes
- Standard autonomous production equipment, e.g., machines, vehicles and robotics, available on the market
- Safety and security as well as cybersecurity
- Standard products or solutions offering high bandwidth communications for industrial contexts with low connectivity properties
- Fewer work-related injuries and improved work safety
- Higher work performance/efficiency per unit of worked time - economic benefit
- Autonomous operation will change, not only plant, but the whole value-chain operation including logistics

4.1.6 Platform Economy

There are new and emerging powerful and quickly growing platforms that have a large impact on the global economy. Examples in the B2C-space are AirBnB, Alibaba, Uber and Spotify, and in the B2B-space Google, Amazon, Microsoft, IBM, Siemens and ABB all have platform offerings in terms of cloud services, automation, IoT, industrial internet, etc. In order to make efficient use of platforms and create new value, interoperability, APIs, standards, common practice, etc. are important for lowering engineering efforts in terms of system integration and sharing of data. If they attract enough users, the platforms will benefit from the network effect (cf., Shapiro and Varian, 1998). Existing systems need to be able to work together, as all legacy systems cannot be replaced all at once. In order for many actors and stakeholders to jointly use platforms, the platforms must necessarily be scalable, prepared for global use (legal matters, etc.), cybersecured and the data pertaining to different value chains kept apart (and sensitive data protected). New and emerging business models will be used, and new customers without a legacy may be more likely to try more complex business models (see chapter 6). New platforms will continue to emerge and grow, and it is up to process industries to select the ones that are beneficial and suitable.

The big questions in the platform economy are: who owns the data, who can use it and for what. Currently, the providers try to get ownership of the data in order to be able to create additional value from it. The process industry and the actors and stakeholders should carefully consider giving away the data that are generated in their own organizations and value chains. Further, as data from one company are added to a platform, and then another company increases the value of that data, some kind of value sharing mechanism/incentive is necessary so that the first company gets some benefit as well. Incentives to participate in value sharing are needed and should be taken into account in the platform design. However, incentives used within consumer products are not applicable in the process industry space.

To stay profitable and competitive, a high availability and OEE together with reasonable market prices for the production output are important factors. An increase in availability or OEE by 1-2% or only tenths of a per cent can make a big difference. This requires highly reliable, robust and maintainable hardware and software platforms which can efficiently integrate components into systems. Further, marketing and sales platforms are also of interest. In addition, these platforms should enable quicker integration into value chain systems or eco-systems with faster testing and implementation cycles.

Identified trends

- Faster and flexible system implementations based upon platforms
- B2B-platforms will emerge in greater number concerning, for instance: process design, process operation, value- and supply chain integration
- Increased use of IoT-platforms - to efficiently facilitate integration and maintenance of IoT-devices
- Enhanced connectivity - connectivity is an enabler and adding WLAN or 5G networks in industrial settings will provide high bandwidth communications
- Platform interoperability - vendor neutral
- Data value related sharing mechanisms/incentives or business models - all contributors to data with increasing value added should be rewarded
- Arrowhead framework - open source (Delsing, 2017)
- Open specification/interfaces/API - enables companies to join value chains or eco-systems

Goals and visions

- Cost efficiency
- Benefit from network effect (Parker et al., 2016)
- Higher availability and OEE for production processes and related equipment as well as systems
- Improved maintainability
- Stable and scalable IoT-, industrial internet- and cloud platforms
- Improved cybersecurity
- Standards for interoperability - enable efficient integrations and interactions between stakeholders

4.1.7 Cybersecurity

The term cybersecurity has many facets, and the most important ones for process industry are a combination of physical- and perimeter security, site/asset monitoring, anti-sabotage measures and IT/information/automation systems security. The cybersecurity threats and measures will have inferences on functionality in physical planning and IT/automation systems, and cybersecurity will need greater attention and efforts due to the increasing number and sophistication of cyberattacks and intrusion attempts. Examples of attacks are denial-of-service attacks, hostile encryption of data or information, as well as disruption of production process and equipment. Further, the increased use of IoT-devices, often with an inadequate level of basic security features, will require that these are properly secured prior to being used to prevent them from being used as entry points for intrusions (or being used to attack others via botnet attacks). In addition, numerous (IoT-) devices installed at plants may each have different operating systems and different security software or configurations, etc. Keeping these up-to-date with respect to cybersecurity is a challenge. An adequate level, i.e., not too little and not too much, of reliance on IT/automation poses challenges. The multitude of operating systems and other software poses a challenge on an organizational level, since knowledge and competence must be ascertained for every piece of software and reliable routines for updates, either manual or automated, have to be in place,. Thus, the cybersecurity spanning both IT/automation systems requires planned and integrated cybersecurity-, operational- as well as safety management.

Ensuring the availability of operations and data or information is key in order to be able to deliver to customers on time. Thus, IT/information/automation systems need to be stress-tested in order to withstand common problems such as erroneous input, overloads and DDOS-attacks. On the organisational level as well as the IT/information/automation system level, a well-developed business continuity planning is required to sustain the desired level of availability. Further, sensitive data must be protected by upholding its confidentiality and integrity (i.e., no undetected/unauthorized changes) and the access to assets and IT/automation systems should be guarded by strong authentication and authorization schemes. This will allow trusted sharing of data inside an organisation as well as between organisations when collaborating.

In most production processes which have been active for many years there are a mix of automation systems, devices and equipment from different vendors and of varying generations. This puts a requirement on how to manage their lifecycles (e.g., controlled and planned upgrades and patching) while they are integrated with other systems that contribute to managing the production process.

If personal information, and in particular sensitive personal information, is stored, processed or communicated within the production system and its related systems, the personal privacy must be upheld according to the EU General Data Protection Directive (GDPR), which will enter into effect during May 2018. The GDPR is an update of the existing directive and clarifies that actions may need to be taken, requires explicit data ownership and responsibilities, and suggests that new roles are required within organizations. This goes hand in hand with a potential use of cloud services or distributed systems involving third parties, which requires an analysis of the cybersecurity of the third party to avoid introducing weaknesses or impairing the availability/business continuity of the production process. To facilitate most of the above, the methodologies for general and system security analysis need to be kept updated and they must also embrace the new legal/regulatory requirements such as the GDPR.

Identified trends

- Integration of cybersecurity-, operational- and safety management
- Cybersecurity interferences on functionality, e.g., current IoT-devices are risky
- Physical- and perimeter security should be better integrated with cybersecurity
- Software-defined perimeter security - for the IT/automation infrastructure and production process
- Availability of operations and ensured availability of data/information
  - Stress testing
  - Incident management
  - Disaster recovery
    - Use of simulation to plan recovery actions in advance
    - Use of simulation for training purposes
  - Business continuity planning
- Access management, authentication and authorization, confidentiality and data integrity,
- Data sharing inside a stakeholder as well as in collaborating situations between stakeholders
- Mixed generations of automation systems, devices and equipment
  - Legacy system integration
  - Upgrades (must be made in a controlled and tested manner to not disrupt the production process)
  - Generations (a lot of the devices and equipment are used 20-30 years prior to being replaced)
- Privacy and personal data, GDPR-compliant systems and information management, data ownership and new roles required
- Cloud services and distributed systems; reliance on third parties/vendors
- System security analysis methodologies
- Cyber threat modeling and simulation

Goals and visions

- Cybersecurity standards for IoT-devices
- The cybersecurity aspects should be integrated in design and simulation models to enable risk evaluations throughout the lifecycle of the production system and its evolution
- Cybersecurity-related tacit knowledge is systematically captured and converted to explicit knowledge among the employees
- Cyber threat modeling and attack simulations of complex IT systems can greatly assist identifying structural vulnerabilities and threats in the risks assessment work of an information security management system. This allows managing risk based on “hard” quantitative data rather than qualitative assessments which is becoming increasingly difficult with large interconnected systems.
- High level of cybersecurity within production plants and production processes in terms of availability, integrity, confidentiality, authentication and authorization, and privacy
  - Secure communication in between systems using strong encryption
  - Network segmentation
  - Secure operations using intrusion detection and prevention systems
  - Integrated approach between standardisation, innovation and research to enable new secure solutions
  - Information assurance that verifies the information consistency
- Robust and resilient production systems
- Third party/vendor cybersecurity level - ensured/verified cybersecurity level
- Security-thinking along the whole lifecycle of IT/automation systems as well as cloud services and distributed systems
- Employee and management cybersecurity awareness
- Legal and regulatory compliance
- Secure/Smart contracts

4.1.8 Safety - Human, machine and environment

Although safety within the European process industry is generally very good, compared to that in other non-European countries, accidents and incidents that may have been prevented still occur every year. The process industry, together with national and European regulatory bodies, continuously strives to minimize the number of accidents and incidents and improve the safety level. Human exposure to hazardous environments in the process industries can be reduced through, for instance, remotely managed operations, better monitoring systems and an increased automation level, thus limiting the risks and preventing accidents involving employees. Physical security measures together with enhanced perimeter security, for ensuring the safety of employees and assets, should be integrated and combined with cybersecurity to guarantee safety.

A higher degree of automation will increase system safety, as less manual work and fewer employees are required to do manual work in potentially dangerous areas. Automation and remote operation are two technical methods used to support the development towards increased operational safety. Further, another way to increase safety is to employ localisation of workers, vehicles and moving equipment, combined with additional sensors, proximity detection, context awareness/information and safety inferences to warn/notify of danger or even stop equipment when possible. An additional important safety-related aspect is the availability and timely presentation of critical information to the proper personnel. Wearable and handheld devices as well as emerging HMIs can contribute to appropriate presentation of safety information at different organisational levels. The advance of collaborative robot and mobile machinery/equipment will place even higher requirements on adequate operational safety.

It is necessary to continue safety development to sustain a profitable and socially accepted process industry in Europe. Many European process-industry facilities were built more than 30 years ago and the number of greenfield projects has declined in recent decades. A majority of these process industries are considered "old", and as their processes and equipment age, the risk of breakdowns and faults increases, thus affecting machine safety. To maintain the safe operation of an aging process-industry facility, for instance, predictive- and condition-based maintenance are key technologies for ensuring safety together with high availability and OEE. Thus, safety analysis, including both normal and extreme conditions, should be based on models and use appropriate methods and simulations. When designing new process-industry facilities, operational safety should be considered at an early engineering and modelling stage while it is relatively easy to prevent possible safety risks through re-design. Ergonomics is also an important area, as poor ergonomics will lead to injuries and long-term health issues. It is also important to keep in mind that there are different kinds of ergonomics that may affect younger and older workers differently, where, for instance, digital stress (poor HMI, inadequate safety or information systems, privacy issues, etc.) is as important as the physical ergonomics.

In order to uphold a high level of safety, some areas (including the IT/automation systems involved), in which extreme danger, explosives or toxic substances are involved can benefit from certification combined with applicable laws and regulations. Thoroughly performed verifications of the current safety measures and processes combined with risk evaluations of new functions are of great importance in reducing the risk of non-predicted safety issues and errors.

Identified trends

- Safety interferences on functionality
- Localisation of personnel, machines and vehicles
- Situation aware safety
  - Sensing of safety issues
  - Proximity detection
  - Online human risk evaluation
  - Map generation (2D/3D)
- Increased and intrinsically safe collaboration between humans, robots and any machinery
- Sensemaking - adequate safety information should be presented to the workers/operators as well as how to take action if needed
- Safety analysis methodologies concerning extreme conditions
  - Model-based analysis
- Ergonomics
  - Related to older workers
  - Digital stress on workers
- Certification for certain areas
  - Explosives
  - Toxic substances
  - Traceability and measurements
- Verification of safety logics

Goals and visions

- Safe workplace - physical- and perimeter security combined with cybersecurity
- Eliminate human exposure to dangerous areas through increased remote operation and automation
- Timely access to context-driven critical/safety information for the personnel in the factory. Further, the information must make sense and be understood quickly
- Wearable technology and well-developed user interfaces to ensure that personnel react on the information they receive
- The safety aspects must be integrated in the simulation models to enable risk evaluation in the conceptual design, design phase and during operation
- Safety-related tacit knowledge among personnel is systematically captured and converted to explicit knowledge among the employees - used in training and safety education as cases
- Well-developed predictive condition monitoring systems detect machine degradation before it causes an increased risk
- Zero-configuration devices will reduce implementation and configuration errors
- Integrated approach between standardisation, innovation and research to enable new safe solutions
- Safety and security classification of new technologies such as IoT-devices

4.1.9 Competence and quality of work

On a strategic level, the European automation and industrial IT industry depends on the ability to attract competent personnel and maintain their competence over time. The workplaces also need to be attractive and the work content interesting to entice young and well educated professionals. New and further complex business models, new innovations and technology, increased integration of systems, and an evolving legislation are some of the factors that drive the need for management of and development of competence in companies. To facilitate this, creativity and innovation processes need to be connected to the competence area and there must be structured continuous professional education as well as transfer of knowledge from one to many (which includes transforming tacit knowledge/know-how and experience to formal knowledge - or passing it on to a new generation of workers) and the retention thereof. Building cross-sector competencies (e.g., designing automatic controls combined with human machine interfaces and new sensor systems or designing automation systems combined with knowledge of legislation) will be crucial for successful development. To be able to rapidly scale up and scale down, companies will use outsourcing and insourcing of parts of

the workforce, services and R&D capabilities. However, it is clear that collaboration in mobilising R&D resources and developing open innovation environments will be necessary to secure competence in a lean and competitive way. The current tools and methods, which support knowledge management in general and tacit knowledge management in particular, are early or emerging versions and need to be further developed. In the literature an ever-growing gap between practical engineering (design) and academia has been identified. Academia seems to produce ever more complex methods, tools, etc. which are then used in (simple) case studies in order to get a publication, but never taken into actual use. This gap needs to be closed.

New emerging automation paradigms involve an increasing distribution, cloud-based software and automation systems, interoperability, standards and cybersecurity, at the same time as the workers need improved ergonomics and HMI. Further, there is a clear political and legal position that gender, equality and disabled-worker issues must also be considered when outlining and planning production facilities.

Virtual factories and processes will be used for modelling, simulations and optimization as well as to educate operators and other personnel. However, several issues must still be addressed before a streamlined educational framework for using virtual factories and processes is widely implemented. For instance, the virtual factories and processes need to become easier to model and keep updated/maintained, and they must also be integrated into into training environments. Further, for this to work, means of generating process and factory models automatically and model deduction are necessary (Ersal et al., 2008). Presented below are the identified trends for competence and quality of work.

Identified trends

- Creativity and innovation processes
- Continuous professional education (e.g., MOOC, personalized education), knowledge transfer and retention
- Workers' experience
- Emerging sensor systems, for instance, optical measurement/monitoring technologies
- New automation paradigms
- Ergonomics
- Human-Machine Interface (HMI)
- Gender, disabled workers, enabling (disabled) workers
- "Experimentation culture" to enhance innovation ("fail fast")
- Gamification (links to AI via e.g., reinforcement learning) and VR applied to training, maintenance and operations
- Crowd-sourcing

Goals and visions

- Augmented workers, implants and robotic parts
- Increased collaboration between companies and universities in order to mobilise necessary R&D resources
- Creation of open research-, development-, and creative innovation environments
- Efficient automation engineering and collaboration characterised by model-based engineering, simulations, reusability, and requirement management
- Increased attraction to and knowledge of the automation profession
- Structured knowledge management supported by adequate systems
- Context-driven user-centric information based on big data
- Coordinate industrial process automation activities on the national agendas within EU
- Influence the legislation on the national and EU level
- New designs of plants and production processes with higher automation levels and fewer but increasingly skilled workers

4.1.10 Human-Machine Interfaces and Machine-to-Machine communications

The automation level is increasing in the process industries and requires communication within and across the involved systems' boundaries. Standards and proofing mechanisms are needed for the additional system functionality and integration of traditionally separated systems, in order to maintain compatibility and interoperability with emerging and future technical equipment and systems. Thus, the human-machine interfaces (HMI) and machine-to-machine (M2M) communications need to be improved as well. Future automation systems will also require communication capabilities across organisational levels and between geographically distributed sites. Internet compatibility and open standards are expected to be key elements in the expansion of large-scale automation systems.

Novel HMI and M2M communications based on the Internet of Things (IoT) principles and new business models, including additional soft parts, will form the Cyber-Physical Systems (CPS) of tomorrow. Further, these CPS are predicted to enable new automation paradigms and improve plant operations in terms of increased OEE and improved production process stability, robustness and availability. Important development areas to achieve HMI and M2M communications in the process industry are, for example, advanced visualisation of collected/analysed data, robust and energy efficient wireless technologies combined with centralised lifecycle management functions to minimise time and costs for installation, (re)configurations, operation and replacement. The implementation and development of service-oriented architectures (SOA) and cloud services, covering the complete scope of field-level devices to large-scale enterprise systems, will also be required to achieve evolvable industrial automation systems and practically utilise the benefits of M2M. The HMI development must continue to improve the

visualisation means and possibilities for efficient plant operations. Thus, visualisation, virtualisation and simulations of a plant and its automation system will be introduced into daily operations and, e.g., combined with mobile equipment, which will enable efficient maintenance work. In addition, inspiration will be retrieved from other areas such as mobile apps, the gaming industry and social media.

Identified trends

- Augmented reality (as well as virtual reality) will be used to support a number of tasks such as:
  - Modelling/simulation of equipment behaviour or processes, etc. before making changes or additions
  - Pre-test action in simulation prior to real-world introduction
  - To enhance remote help/support by entering into the actual help/support case environment and show what should be done and how to do it, and also be able to run simulations prior to making changes in configurations or set-ups
- Enhanced visualization of data and analytic results will be required to support decision making. Thus, an increased understanding of the following is necessary:
  - Data modelling
  - Analytic methods
  - Semantics
- Knowledge on semantics will enhance the understanding and usefulness of data, and various contexts may need the data to be:
  - Human readable
  - Machine readable
- The data collected and analyzed must be adequately visualised and presented in various interfaces, depending on whether a human or a machine will use the analytic outcome for decision support.
- Various interfaces and data from sensors can be used to create an awareness of the situation or context around a machine or humans in a production environment. The awareness can support safety, efficiency and quality improvements.
- International and industry standards will be more commonly utilized in order to extract the necessary information.

Goals and visions

- Interoperable IP-enabled devices to support cross-vendor and cross-level communication
- IP-based (soft) real-time services
- Adoption of IoT technology and HMI in automation and maintenance systems
- SOA within lightweight IoT devices
- Well-defined M2M communication standards to enable machine learning in process automation to support e.g., simulation and optimization for decision support
- Global real-time access to all devices at the field and automation levels
- Collaborative automation based on networked/cloud services
- Game-industry-inspired HMIs within automation systems
- Access to user-friendly simulation models

5 PROCESS INDUSTRY - GAMECHANGERS FOR COMPETITIVENESS

In the previous sections, high-level goals and global trends were identified and discussed. Together with the current state-of-the-art, a gap analysis has identified "gamechangers", i.e., matters that will have great impact and lead to significant change. The following gamechangers have been selected and will be further described below:

#	Gamechanger	Effect on industrial competitiveness	Associated R&D areas
1	Modular factory for distributed and automated production	Scalability and expansion	• Productivity, efficiency, scalability and flexibility • Distributed production/modular factories and services • Autonomous plants and remote operations • Artificial Intelligence and Big Data • Autonomous plants and remote operations • Platform Economy
2	Live virtual twins of raw-materials, process and products	Improved process design and more efficient operations through an integrated multi-simulator platform	• Productivity, efficiency, scalability and flexibility • Artificial Intelligence and Big Data • Autonomous plants and remote operations • Human-Machine Interfaces and Machine-to-Machine communications • Cybersecurity
3	Increased information transparency between field and ERP	Improved information flows and use of the information	• Productivity, efficiency, scalability and flexibility • Distributed production/modular factories and services • Autonomous plants and remote operations • Platform Economy • Cybersecurity • Human-Machine Interfaces and Machine-to-Machine communications
4	Real-time data analytics	Real-time production optimisation /efficiency	• Productivity, efficiency, scalability and flexibility • Artificial Intelligence and Big Data • Autonomous plants and remote operations • Safety - Human, machine and environment • Human-Machine Interfaces and Machine-to-Machine communications
5	Dynamic control and optimisation of output tolerances	Continuous quality control	• Productivity, efficiency, scalability and flexibility • Sustainability through Circular Economy - Circular Economy through industrial internet • Artificial Intelligence and Big Data • Autonomous plants and remote operations • Human-Machine Interfaces and Machine-to-Machine communications

#	Gamechanger	Effect on industrial competitiveness	Associated R&D areas
6	Process industry as an integrated and agile part of the energy system	Energy demand response, new value stream possibilities and sustainable production	• Productivity, efficiency, scalability and flexibility • Sustainability through Circular Economy - Circular Economy through industrial internet • Distributed production/modular factories and services • Cybersecurity • Safety - Human, machine and environment • Human-Machine Interfaces and Machine-to-Machine communications • Autonomous plants and remote operations • Artificial Intelligence and Big Data
7	Management of critical knowledge	Ability to adapt to new technology as well as have impact on it	• Competence and quality of work • Artificial Intelligence and Big Data • Cybersecurity
8	Semi-autonomous automation engineering	Digitalisation of value-chains (enabled by lower engineering cost)	• Distributed production/modular factories and services • Artificial Intelligence and Big Data • Autonomous plants and remote operations • Cybersecurity • Safety - Human, machine and environment • Human-Machine Interfaces and Machine-to-Machine communications
9	Integrated operational and cybersecurity management	Minimized downtime, improved cybersecurity, increased availability, higher quality and operational culture	• Cybersecurity • Productivity, efficiency, scalability and flexibility • Artificial Intelligence and Big Data • Autonomous plants and remote operations • Safety - Human, machine and environment • Human-Machine Interfaces and Machine-to-Machine communications

Table 1 - Gamechangers and their effect on industrial competitiveness as well as their relation to the R&D areas

Table 1 visualises the gamechangers and their impact on, as well as relation to, the R&D areas. Further, in Table 1 outlines how each of the nine game changers may have an effect on industrial competitiveness as well as their relations to the R&D areas (see chapter 4).

5.1 Gamechangers

A total of nine gamechangers have been found during the work on the roadmap (see Table 1) and these are described below in additional detail. Further, the gamechangers' effect on industrial competitiveness as well as associated R&D areas will be outlined below. The R&D areas will be put on a timeline to indicate when in time they need to be addressed in order to stay in the game and thus remain competitive. The timeline is organized in such a manner that **short term** corresponds to 1-4 years, **medium term** to 4-6 years and **long term** to 7-10 years - when the R&D area supporting the effect should be realized (i.e., have been addressed).

5.1.1 Modular factory for distributed and automated production

The modularization of factories allows a higher level of customization (or variation of output) through use of modules that can be reorganized or replaced. In this aspect, process- and manufacturing industries differ a bit, where the process industry commonly does not often reorganize the production lines but rather reconfigures production lines and equipment when producing various products (or product qualities). Manufacturing industries with a need to produce a variety of different products using the same production equipment will benefit a lot from increased modularization. Further, modularization increases flexibility, scalability and expansion opportunities in factories and improves the ability to use distributed production resources. It is also desirable to achieve highly automated production with a high level of remote operations/management. In addition, it is necessary to increase the OEE and production resource utilization (i.e., have production orders when production is available in order to make full use of production resources) by making production resources available to others when own orders are completed, or a higher profit can be made by letting others use the own production resources (as long as delivery times to "own" customers are met).

In order to be able to reap benefits from modular factories and automated production, it is necessary to be able to quickly build models for what needs to be produced next - and simulate and optimize that prior to doing it in reality (see 5.1.2). This will help to prevent unnecessary problems, bottlenecks and slow production flows.

Effect on industrial competitiveness

Scalability and expansion - to be able to change production volume faster and to be able to quickly scale up or add new production lines when wanted. The new production lines may be in the own factories or set up by using someone else's distributed production equipment/resources. Further, increasing the OEE and production resource utilization is also desired.

Associated R&D areas and timeline

- Short term
  - Artificial Intelligence and Big Data
  - Cyber Security
- Medium term
  - Productivity, efficiency, scalability and flexibility
  - Distributed production/modular factories and services
  - Platform Economy
- Long term
  - Autonomous plants and remote operations

5.1.2 Live virtual twins of raw materials, process and products

A virtual twin is a digital replica of a product or process, with all necessary design and operational data. A live virtual twin extends the latter with possibilities to simulate the process dynamically. This requires a model of the artefact, equipment, or process, etc., and it is necessary to generate the model as automatically as possible from existing information (e.g., design documents, CAD files, process information, etc.) as it is very time-consuming and tedious to do this manually. Furthermore, the models need to be kept updated, preferably automatically, based on new process measurements and changes to design data. This live virtual twin will be used, e.g., for problem-finding, simulations, optimization, predictive and condition-based maintenance, and control as a prediction. It is important to remember that different simulations and optimization may require a purpose-made model - and thus it is not possible to have one generic model (or virtual twin) for all purposes. In order to be able to timely, e.g., simulate and optimize a complex reality, the model has to be simplified but at the same time not lose too much accuracy and precision.

Effect on industrial competitiveness

Improved process design and more efficient operations through an integrated multi-simulator platform - an integrated multi-simulator platform enables t changes to equipment, processes or configurations, etc. to be tested before actually being implemented in order to determine whether or not this can actually be done. It will further be possible to, based on simulations, optimize processes or equipment. Further, if models for maintenance are assembled too, predictive and condition-based maintenance for, e.g., production equipment can be enabled and used as well.

Associated R&D areas and timeline

- Short term
  - Artificial Intelligence and Big Data
  - Human-Machine Interfaces and Machine-to-Machine communications
    - Cybersecurity
- Medium term
  - Productivity, efficiency, scalability and flexibility
- Long term
  - Autonomous plants and remote operations

5.1.3 Increased information transparency between field and ERP

In order to be able to use data generated in production processes together with data residing in other systems such as MES, CMMS and ERP, there needs to be a transparency and flow of data and information in between these levels and systems. Further, the format of various data also needs to be translated or transformed into something that can be used in M2M, data analytic algorithms and decision-making support - and in a form in which results or outcome can be understood by humans. Conversely, the decisions made need to be translated or transformed into what the recipient systems or automation systems need in order to execute the decisions made.

The transparency requires a number of measures, for instance, applying the Industrial Internet paradigm, information translation, interoperability between various systems and levels of systems,

fast/efficient integrations of various systems and use of standards. Further, transparency will require information and data models, ontologies, use of both stored and streaming data, and cybersecurity to keep the data secure while stored, processed or communicated. In addition, the Industrial Internet and automation systems will to a greater degree be based on IoT in the future (i.e., the number of sensors, etc. will grow).

Effect on industrial competitiveness

Improved information flows and use of the information - this is a necessity in order to make use of the information and data generated at various levels in a production system or factories. Many decisions need data from a number of different levels, systems such as MES, CMMS and ERP, and automation systems, in order to get what is required to make decisions based upon facts. The decisions then need to be efficiently transformed into commands, etc. and executed on the right level, system or automation system. This will create efficiency, possibility to steer/control the production processes, enable prediction and condition-based maintenance, and thus improve competitiveness.

Associated R&D areas and timeline

- Short term
  - Productivity, efficiency, scalability and flexibility
  - Platform Economy
  - Cyber Security
  - Human-Machine Interfaces and Machine-to-Machine communications
  - Autonomous plants and remote operations
- Medium term
  - Distributed production/modular factories and services
  - Autonomous plants and remote operations
- Long term
  - -

5.1.4 Real-time data analytics

Data analytics in real-time is needed when controlling processes or machines with situational awareness, a lot of changes need to be accounted for, and adjustments as well as adaptations are required within milliseconds. The current situation is that this must be managed within the machine or a local automation system (and SCADA systems) with low communications latency (in order to respond in a few milliseconds). The development of faster networks, faster wireless networks as well as faster mobile networks (e.g., 5G) in combination with (local) cloud services and edge computing, allows for an interesting change, in that more and more of the real-time analytics and, in particular, that which is not directly involved with the core functions of, e.g., a machine, can be put into local clouds, edge computing, etc. The benefits from this will be scalability, cost effectiveness, easier maintenance and a better overall computing architecture. There is also a decision as to which data analytics to keep locally or centrally, and there are distributed needs to be considered and weighed against the benefits and drawbacks.

Other types of applications for real-time data analytics are: predictive- and condition-based maintenance (i.e., in critical areas where failures or breakdowns can develop fast); swift decisions on either graceful degradations or emergency shutdowns; reorganization decisions if there are problems with the equipment part of a production process, and reconfiguration of process parameters in order to make adjustments if the output quality is not within specifications. Further, when combining control/measurement of input quality, process parameters, predictive maintenance and output quality (i.e., continuous quality control) in real-time or close to real-time, depending on the process throughput, much faster decisions can be made compared to when quality control is done at the end of the process. Thus, if something goes wrong, only a few output(s) are produced, instead of a whole batch in worst case prior to discovery.

As mentioned earlier, big questions with respect to future data analytics are who owns the data, who can use it (or sell it), what can it be used for, when can it be used and for how long, and that needs to be agreed upon among the stakeholders and preferably stated in an agreement. The new EU GDPR also needs to be considered if the data can be linked to individuals or sensitive personal data is part of the data collected and processed/analysed.

Effect on industrial competitiveness

Real-time production optimisation/efficiency allows for faster detection of problems or issues in areas where swift decisions are required. Further, if real-time data analytics is implemented as a combination of predictive maintenance, process control and continuous quality control, the production can be optimised in terms of less energy used, less scrap and discarded output, higher and even quality, and higher production process availability, etc. In addition, this creates trust in the production processes and allows the company to accept orders that stretch capacity and might otherwise have been waived, and it can improve the OEE and profitability significantly.

Associated R&D areas and timeline

- Short term
  - Productivity, efficiency, scalability and flexibility
  - Artificial Intelligence and Big Data
  - Safety - Human, machine and environment
  - Human-Machine Interfaces and Machine-to-Machine communications
- Medium term
  - Autonomous plants and remote operations
- Long term
  - -

5.1.5 Dynamic control and optimisation of output tolerances

To dynamically control and optimise the tolerances of the output from production processes requires data or measurements about the input (i.e., if there are variances or issues), so that process parameters can be adjusted to still produce output within stipulated tolerances. Further, if process parameters look acceptable and predictive maintenance monitoring indicates that there are arising issues, it may be possible to resolve the impending issue by reconfiguring process parameters to compensate. If the output is monitored/measured after one or more process step(s) there will be immediate indications if the output is outside of expected/

acceptable tolerances. The faulty output can then be removed from the production process to prevent it from accidentally ending up in a customer shipment. If a certain percentage or two of (consecutive) outputs are outside of tolerances, it is an indication that the process parameters need to be checked and reconfigured or that there is a need to maintain the production equipment (or perhaps gracefully degrade the operations to last the current batch). In case it is not possible to continue and produce acceptable output, a decision needs to be made as to whether to reorganise and produce something else that is still possible or to stop production in order to prevent production of bad output.

The integration of input measurement/data, process parameter monitoring, predictive maintenance and continuous quality control of the output, enables dynamic control and optimisation of output tolerances. However, there are many variables affecting this and if it is possible to run fast simulations (or linked simulations if needed), this will provide guidance as to whether to reconfigure process parameters, make equipment adjustments, gracefully degrade the production rate, or reorganise, etc.

If it is possible to correct production output outside of tolerances with post operations, the measurement data should be sent to that production step in order to speed up the processing (no need for new measurements) and ensure that the right post operation(s) are conducted. If measurements after the post operations still indicate the output is outside of expected tolerances, a decision needs to be taken as to whether to scrap/recycle or perform additional post operations.

Effect on industrial competitiveness

Continuous quality control, the use and integration of continuous quality control quality, i.e., on-line measurements in production processes where appropriate, with monitoring of machines/equipment, will produce a significant effect on the bottom-line result, as it will, if working well, render: even quality level of output produced, less energy/materials used, higher availability of machines/equipment and production processes, trust (know when adequate output can be produced and stretch the limits when necessary), improved OEE, etc.

Associated R&D areas and timeline

- Short term
  - Artificial Intelligence and Big Data
  - Productivity, efficiency, scalability and flexibility
  - Human-Machine Interfaces and Machine-to-Machine communications
- Medium term
  - Sustainability through Circular Economy - Circular Economy through industrial internet
- Long term
  - Autonomous plants and remote operations

5.1.6 Process industry as an integrated and agile part of the energy system

Process industries often consume a lot of energy and, often, a lot of energy is also produced or released during the production processes (e.g., ventilation or cooling). Some process industries re-use the energy they produce or distribute the redundant energy to district heating or the power grid, and may in the future also store it in large batteries or other types of efficient energy storage in order to sell it or use themselves when energy prices are high. Thus, the process industries (and manufacturing industries) will be both a consumer and producer of different types of energy, and will need to be well integrated into the surrounding energy system and its subsystems. The process industries, and here we do not include the energy producers and distributors, will thus assist in balancing the energy system and its fluctuating supply and demand situations.

If we adopt a larger view of the energy system, it can also include optimization and management of water, waste, electricity, other types of energy (excess heat/ventilation air, process heat, biogas/fuel), wind and solar energy produced on-site, and cooling. Thus, it is important for process industries to look into what commonly is referred to as “side streams” (e.g., excess energy, chemicals, gases, fibres, etc.) or residual material that is not currently processed or needed and find out what can be reused, recycled, further refined (by themselves or via customer or partners), sold or traded in order to achieve a sustainable production and energy system and create additional revenue. Some process industries also add wind turbines and solar cells where appropriate in order to secure the availability of electricity for production. Finally, some process industries, such as pulp and paper mills and steel mills, heat nearby cities or greenhouses and keep harbours ice-free during winter. In order to achieve this, critical energy infrastructures must be available and not too hard or rigid to integrate into.

Foreseen is that traditional process industries, such as mining, pulp and paper, and steelmaking, will get further integrated and work in symbiosis with energy producers/distributors and plan the energy consumption in line with the expected availability and price of electricity. In addition, weather forecasts will be used to plan the energy production and consumption as well as potential storage of electricity in storage such as batteries. This may require common/jointly used automation and information/planning systems.

An increased integration of actors in an agile energy system will require a high level of cybersecurity and safety in combination with big data analytics and AI for decision-making support. As complexity rises with more actors, additional sources of energy, energy storage, etc. simulations and optimisations will also be necessary to support decision-making processes in order to guide the automation systems and keep the balance in the energy systems.

Effect on industrial competitiveness

Energy demand response, new value-stream possibilities and sustainable production - the process industries will assist in balancing the supply and demand in overall energy systems. The future storage systems for energy will have a great impact on whether process industries can also assist in stabilising, e.g., the electric grid by using large batteries, etc. in the event of power plant problems or within a region having a high share of variable renewable energy (solar, wind). The services provided, as well as energy produced sold or traded, will provide revenue and contribute to a further stable energy system and circular economy.

Associated R&D areas and timeline

- Short term
  - Productivity, efficiency, scalability and flexibility
  - Cyber Security
  - Sustainability through Circular Economy - Circular Economy through industrial internet
  - Safety - Human, machine and environment
  - Human-Machine Interfaces and Machine-to-Machine communications
- Medium term
  - Distributed production/modular factories and services
  - Autonomous plants and remote operations
- Long term
  - Artificial Intelligence and Big Data

5.1.7 Management of critical knowledge

Knowledge, particularly critical knowledge, must be secured, documented and transferred timely among employees and others who need it. Thus, critical tacit knowledge (know-how) needs to be managed (prioritised and quality controlled), documented (i.e., transferred to explicit knowledge (formal)) and made available in a secure manner to those who need it and should have access to it. One or more knowledge management systems should be integrated into the work processes, both to capture the knowledge but also to serve as a repository that can be looked into when knowledge is required. The knowledge should also be indexed and searchable, and new knowledge easy to add and link to from, for instance, service routine descriptions, etc.

Some of the future critical knowledge will have to do with how AI, data analytics, simulation and optimization can be used together with the ordinary work routines in order to find anomalies and root causes to problems in automation systems, machines/equipment, maintenance and production processes. Thus, if workers do not possess these skills, professional training will be necessary or additional highly skilled workers/engineers hired. The improved decision-making based on data, analytics and AI, etc. should also be formalised and managed properly.

The critical knowledge can further be used to improve or create new services to complement the existing customer offers. To protect critical knowledge, employees need to be aware of what to protect (and not), and also customer or partner agreements should protect the critical knowledge/intellectual property rights and manage these in order to stay competitive and profitable. Further, the data and information generated and needed to perform these additional services should also be safeguarded and kept securely to streamline future repetition of the tasks and processes.

Effect on industrial competitiveness

Ability to adapt to new technology as well as have impact on it - in order to stay competitive, critical knowledge must be used and developed and new technology adopted and work processes adapted/improved to use new technology. Further, the work processes should have a feedback loop to the design of new technology in order to facilitate new features and rectify features that were poorly designed or not appropriate from the start. Critical knowledge must therefore be securely managed and adequately used for optimisation and continuous improvements.

Associated R&D areas and timeline

- Short term
  - Competence and quality of work
  - Cyber Security
- Medium term
  - Artificial Intelligence and Big Data
- Long term
  - -

5.1.8 Semi-autonomous automation engineering

The success of today's automation is well proven. Current automation systems are built for a pre-defined purpose, thus allowing for design time engineering decisions on system architecture and implementation solutions. Current market developments point to the demand for more customer-tailored products to be produced using existing production facilities. This puts a growing demand on production, ecosystem flexibility and evolvability. This is a major driver for the digitalisation of production ecosystems. Here IoT and SoS technology is projected to provide the market breakthrough for digitalisation.

A parallel development is a more fine-grained automation enabled by low cost IoT solutions. Most industrial automation systems hold a limited number of I/Os (Input/Output points). A majority of automation systems have fewer than 1.000 I/Os. Today the largest automation systems ever built comprise 100-200.000 I/Os. There are only a handful of theseglobally. So why do we not see more such large automation systems? One obvious answer is that the cost of such systems is hard to justify based on return on investment. A major reason for this is the high engineering costs for implementing large complex automation systems.

Thus we have two major market development trends:

- Digitalisation integration multi-stakeholder ecosystems enabling production optimisation
- Exploitation of fine-grade automation

For a widespread implementation and usage of the above digitalisation and automation perspectives industrial capacity for digitalisation engineering enabling efficient deployment, operation, maintenance and evolution of such system is a prerequisite.

A smooth interoperability between new IoT and legacy automation technologies can significantly reduce application engineering cost, as much as 50-75% according to Lindström et al. (2018). Thus, new engineering tools for legacy- and IoT/SoS technology integrations are needed. This opens the perspective for real-world large-scale digitalisation and automation where ecosystem stakeholders can interact under dynamically changing conditions.

The direction of enabling IoT and SoS technology towards a greater degree of autonomy is obvious. This is one of the major directions for reducing engineering and maintenance cost for evolution of legacy automation solutions and integration with the emerging IoT/SoS-based digitalisation and automation paradigm and associated solutions. The further projection is that self-adjustment, self-repair and self-X should be possible to some degree for IoTs and limited SoSs. Further, integration of nano-procurement and nano-payments in production and value-chains are necessary in future multi-actor scenarios.

For integration of legacy tools, access to data in IoT and SoS technology is essential. These large-scale digitalisation solutions will require a new set of tools and a much more integrated tool chain supporting efficient and partly machine-managed engineering of digitalisation and automation evolution.

Effect on industrial competitiveness

The obvious effect on industrial competitiveness is better efficiency regarding a number of aspects for production/manufacturing in terms of production efficiency, energy efficiency and environmental footprint. A main contributor to this is reduced cost of digitalisation/ automation engineering.

Associated R&D areas and timeline

- Short term
  - Distributed production/modular factories and services
  - Artificial Intelligence and Big Data
  - Cyber Security
  - Safety - Human, machine and environment
  - Human-Machine Interfaces and Machine-to-Machine communications
- Medium term
  - Autonomous plants and remote operations
- Long term
  - -

5.1.9 Integrated operational- and cybersecurity management

It is paramount that operational management is flexible, efficient and secured against malicious actors seeking to disturb, hinder, destroy or make unauthorised changes, etc. in IT and automation systems, as the consequences can otherwise threaten both production and personal security/safety. Further, the environmental consequences can be very large and severe if, for example, a chemical plant, oil or energy production facility is disrupted and emissions/spills occur. The operational management should be integrated with the cybersecurity management such that trust is created at the same time as little or no additional complexity is added. However, if cybersecurity measures such as strong authentication are missing, these must be implemented, which will affect the operators and users. However, a lot of cybersecurity measures should not be noticeable to users if adequately set up, configured and maintained. The lifecycle functionality of cybersecurity management systems should also reinforce and supplement the lifecycle functionality of IT/information/automation systems used in the operational management.

The expected increase in the number of IoT devices will be a challenge for both operational and cybersecurity management, and it is expected ithat the use of standardised IoT devices with adequate cybersecurity and improved management functionality will gradually replace IoT devices lacking these features. It must be possible to efficiently update and manage large numbers of IoT devices and lifecycle management functionality, such as pre-configured set-ups/plug-and-play, minimal cybersecurity baseline, reporting on battery level and sensor functionality, etc., should be part of the IoT frameworks used.

The operational management needs and changes should be aligned with efficient ways to set up/configure/reconfigure e.g., authentication levels required, access rights/authorisation, logging, network segmentations, system/network monitoring, intrusion detection, etc., as the maintenance of a dynamic cybersecurity will otherwise fail. Online monitoring and anomaly detection could be handled by AI and machine learning algorithms to enable swift detection and action in response to attacks; alternatively, the AI can report to a human, who will then take action. To keep the cybersecurity level up to date with operational changes, the cybersecurity level should be tested and analysed regularly as well as when operational changes have been made.

Effect on industrial competitiveness

Minimized downtime, improved cybersecurity, increased availability, higher quality and operational culture - the effects of a well-integrated operational- and cybersecurity management are multiple. It will lead to greater trust, minimized downtime/increased availability and higher quality of production output as well as services. The integration should also promote an operational culture aligned with the cybersecurity culture- in order to avoid future problems and open up cybersecurity flaws or issues.

Associated R&D areas and timeline

- Short term
  - Cybersecurity
  - Productivity, efficiency, scalability and flexibility
  - Artificial Intelligence and Big Data
  - Safety - Human, machine and environment
  - Human-Machine Interfaces and Machine-to-Machine communications
- Medium term
  - Autonomous plants and remote operations
- Long term
  - Artificial Intelligence and Big Data

6 NEW AND EMERGING BUSINESS MODELS ENABLED BY DIGITALISATION SERVICES AND TECHNOLOGIES

6.1 Introduction

A business model represents a cognitive schema that explicates how a company or industrial actor creates, delivers and captures value through the exploitation of business opportunities. Traditional business models have been transaction-oriented, where the provider would offer a physical product or service or a basic combination of product and services. However, such industrial norms are being challenged within process industry, where providers and customers are increasingly providing/procuring advanced product-service combinations, such as pay-per-service models or outcome-based results. These new business model innovations offer the potential to create and commercialize technologies and deliver added customer value. Thus, today we are witnessing a trend towards increasing servitization or integration of products with services into more advanced and complex business models.

The reason for providing complex offers to customers, and moving from simple to more advanced underlying business models, is to give the customers what they need/want. As some customers may be used to buying products and services only, they also need to become aware about the benefits and drawbacks of procuring and using additionally complex offers. However, three reasons motivate why providers and sometime customers are interested in new advanced product-service based business models. Firstly, this has the potential to offer higher profit margins and more stable income. For example, through advanced services a steady flow of revenue can be secured, even during economic downturns, by locking customers into long-term service agreements. Secondly, adding service components to physical products offers strategic benefits in the form of increased inimitability and creating offer differentiation due to customization of product-service offerings to meet diverse customer needs. Finally, recent studies suggest that advanced product-service business models can increase the market attractiveness of the product component, leading to increased sales growth.

On a general level these business models are often discussed under the labels of Product-Service Systems/Industrial Product-Service Systems (PSS/IPS2).

Below is a summary of different PSS business model categories that can underpin customer offers (see Figure 3). Concrete examples can be:

- Product-oriented business models (e.g., product with additional maintenance services)
- Use-oriented business models (e.g., product leasing where ownership is retained by provider)
- Result-oriented business models (e.g., pay per service unit where the supplier is responsible for delivering the result).

Which of the below business model(s) to use as a provider depends on the own organisation's (or provider consortium's) abilities, competencies/skills, risk aversion, market trust, investment capacity, etc. as well as how to position the offer on the market in order to meet the targeted process industry needs and requirements.

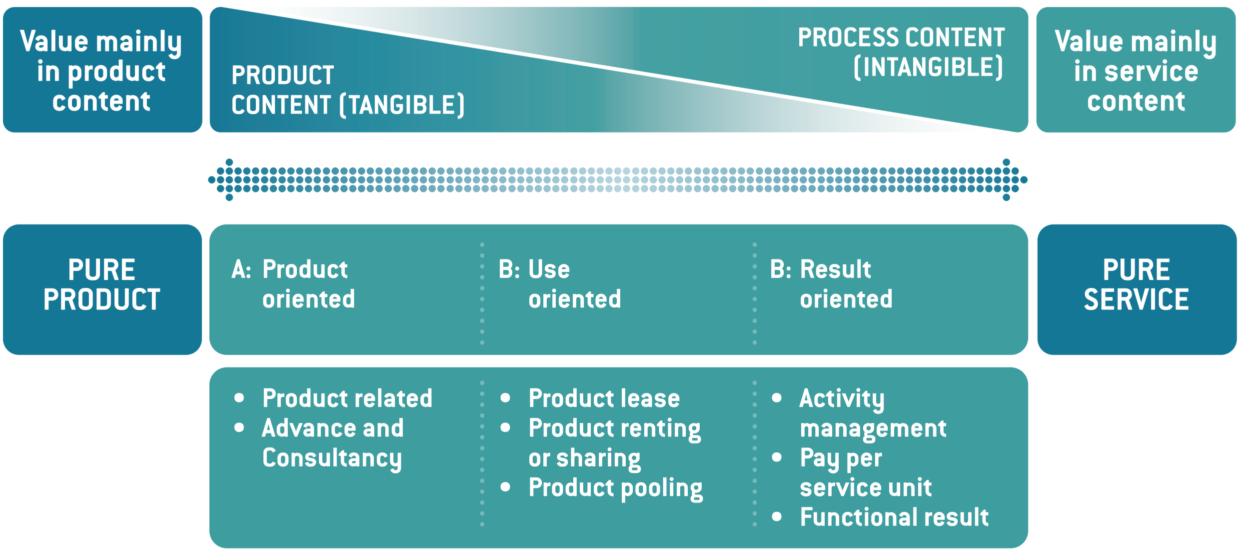

Figure 3 - Different types of PSS business models (based on Tukker, 2004)

6.2 What is different?

Especially, new Product-Service System (PSS) business models introduce change in a number of different areas with respect to how value is created, delivered and captured within process industries:

- Firstly, more advanced business models such as PSS/IPS2 can be offered with different customer contract parameters compared to products, which commonly have, for instance, a 2-year warranty, and these parameters can be embodied as increased productivity/ efficiency, result- or availability-based, or sharing of risk/profit, etc. This means that the provider side needs to assume a greater responsibility and risk - and should thus be compensated for that with increased revenue, as the customer experiences fewer problems and issues. Another change can also be whether the ownership of the hardware, spare parts, software or licenses, etc. used/needed is kept by the provider side and not transferred to the customer. In this scenario leasing can also be an option to manage the level of required capital expenses versus operational expenses.
- Secondly, a distinguishing factor of more advanced and outcome-based PSS such as pay per service is that they represent a 'promise' of outcome. This means that the design and delivery of the solution (i.e., required product and service activities) that delivers that outcome can be altered in novel ways. This allows for significant openness in the way the outcome is defined, designed and delivered in order to foster innovation and to create potential for revised value creation and capture for both firm and customer. For instance, the provider is free to use new technology so that certain service activities can be automated, and to invite new partners that are better placed to deliver certain activities or redesign the roles and responsibilities of existing partners in the interests of increased efficiency and value creation. For example, the provider can focus on introducing innovative digital technologies such as increased use of simulations/optimisation/ big data and AI for decision-making support, predictive analytics to enable smart maintenance and increased resource utilisation. The complex offerings are often customized offers and configured/ adapted for the customer's specific conditions and requirements. Thirdly, PSS requires changes in the approach to delivering value over an extended duration where provider and customer co-create value in interaction. PSS business models can thus enable continuous improvement of solutions over an extended duration rather than for each purchase of a product. It is more demanding to develop, operate and maintain the complex offerings, as they may comprise integrated hardware, software, services/support system and must be managed over the long term. Further, this can require that new design and development processes/methods need to be learnt and used in order to get an optimal "output" to offer to customers. With increased responsibility and capability (through technology and use of operational/monitoring data), these new business models will create the incentives for the provider to develop PSS with increased productivity and efficiency (e.g., avoiding sub-optimization on separate components) which in turn will lead to improved competitiveness and less environmental impact.
- Finally, from a customer perspective, it will be different to procure a function, a specified level of availability or productivity, compared to specifying what components and hardware/software specifications a product should have. Thus, an understanding of the new or emerging business models and how offers based upon these can be embodied will be required. It will be important to understand the own processes, the functionality and results wanted by the users, and how to set up the contractual parameters and responsibilities among the parties involved. For example, instead of buying a excavator to buy X tonnes of dirt moved per day, what is purchased is a production increase of 5% compared to today, or 99.8% availability of a machine during normal production schedules.

6.3 Industrial impact and effects

Novel PSS business models will have impact and effects on both the provider and customer sides. Below, a few of the most important effects from provider and customer perspectives areoutlined:

- Risk management - additional risks and responsibilities are transferred to the provider side (such as uptime grantees) and thus the provider is able to charge premium price for offerings.
- New revenue models- how value is captured during the relationship between provider and customer changes. New revenue models have been proposed in this direction, such as risk and revenue sharing, subscription-based model,etc.
- Capitalization on digitalization - sensors, interconnected machines or equipment and analytics open up new ways to create, deliver and capture value. It is evident that the information layer is becoming a central part of future offerings and business model innovation.
- Provider side consortiums - it may be necessary to form provider consortiums in order to provide large/complex offerings (underpinned by a PSS business model), as no actor alone can have all competencies/skills, abilities, customer and partner networks, IT/automation infrastructures, etc. required.
- Customer knowledge on business models - the customers need to learn more about new and emerging business models underpinning the new offers in order to optimise the use and benefits from these as well as understand how to procure them (e.g., evaluate).
- Increased focus on win-win relationship - moving from transactional to relational oriented relationships provides new ways of thinking about how alignment of incentives can be achieved. Innovative approaches to business model promote such win-win relationships. In addition, this requires a further enhanced dialogue and transparency between the provider and customer sides in order to reach long-term relationships and agreements where both sides are content and profitable.
- Customization and higher value generation - customers do not want just a product or service, but rather customized solutions that are designed for addressing their unique needs. This means that both the customer and provider need to co-create value throughout the relationship.

In the longer term the following industry effects can be envisioned as:

- Sustainable industry effects ensuring the triple bottom line of economic, social and environmental sustainability are critical to the transition to a circular economy, which, if successful, has been predicted to increase European resource productivity by up to 3 per cent annually and GDP growth by as much as 7 percentage points (i.e., EUR1.8 trillion) relative to the current development scenario.
- Relationships based on interactions, having a long-term focus, and continuous innovation will lead to an improved ability of industry actors to involve providers/customers in co-creating sustainable solutions based on digital technologies. Indeed, adopting sustainable business models would strengthen relationships within industrial ecosystems where providers and customers work jointly towards identifying opportunities for improving operations.
- Ecosystem transformation towards common goals. For example, there will be an increased need to understand risk management, procurement governance, partner management, contract development and IPR. As the ecosystem around these actors expands, other European companies can adopt sustainable business models through benchmarking.

7 SUMMARY, CONCLUSIONS AND FUTURE DIRECTIONS

7.1 Summary

The ProcessIT.EU roadmap for industrial process automation contributes to the European process- and manufacturing industries by providing input on what is possible and necessary within IT and automation. The roadmap should be seen as input for strategic decision-making in order to stay competitive, profitable and sustainable over time. On a tactical level, the roadmap can be seen as a checklist and source of ideas for R&D planning and activities. Further, the roadmap is also intended as input to policy makers and the bodies which craft public calls for RDI proposals targeting industrial process automation, automation of production/manufacturing, and matters related to the future process industry.

The roadmap outlines **three top level needs**: sustainable production, competence management and trust, security, safety and privacy. These three top-level needs intersect the **ten R&D areas** (see Figure 2 earlier):

- Productivity, efficiency, scalability and flexibility
- Sustainability through circular economy - circular economy through industrial internet
- Distributed production/modular factories and services
- Artificial Intelligence and Big Data
- Autonomous plants and remote operations
- Platform economy
- Cybersecurity
- Safety - human, machine and environment
- Competences and quality of work
- Human-Machine Interfaces and Machine-to-Machine communications

Some of these R&D areas are a must or important and support the others, i.e., artificial intelligence and big data, cybersecurity, safety and competencies and quality of work. Regarding the others, productivity, efficiency, scalability and flexibility, there is probably also a requirement to be sustainable and circular. A growing trend is distributed and autonomous production in various forms, as well as remote operations, which can allow production closer to the raw materials and allow personnel to a large extent work from a safe place where they want to be or live. The platform economy, together with advanced technology and sophisticated use of it, will change how IT and automation providers act and help their customers. Thus, is it possible to state that any of the ten R&D areas are more important than the others? In some cases, yes. However, in most cases the R&D areas together contribute to meeting the three top-level needs. This becomes obvious when scrutinizing **the nine gamechangers** and their effect on industrial competitiveness and profitability. The nine gamechangers are:

- Modular factory for distributed and automated production
- Live virtual twins of raw-materials, process and products
- Increased information transparency between field and ERP
- Real-time data analytics
- Dynamic control and optimisation of output tolerances
- Process industry as an integrated and agile part of the energy system
- Management of critical knowledge
- Semi-autonomous automation engineering
- Integrated operational and cybersecurity management

In order to achieve and address the gamechangers, it is necessary to use the building blocks, i.e., the R&D areas, and push these building blocks far enough so that they can together be used to support a gamechanger. The gamechangers will become a matter of great importance and many of these also comprise most of today's hot topics such as cybersecurity, artificial intelligence and big data etc. As society and technology continue to develop, new game changers will appear, as will novel R&D areas.

For anyone with strategic or tactical responsibility within a corporation a reasonable question is how much resources does this require compared to the potential benefit? Another question is which gamechangers need the least or most resources to achieve the impacts wanted? Answering these two questions requires an analysis of the current state as well as the desired future state of business and technology. Subsequently, it is possible to map out the start points (in terms of when in time as well as the level of change, e.g., using TRL (Technology Readiness Level)), and the end points (when in time and level of change reached). This can provide a strategic map for planning of investments as well as the business development and R&D work required.

Traditionally, mainly products and services have been used in the process industry. However, solutions are used as well. Future-wise, it is expected that new and emerging business models will be used both to attract new business and to remain competitive. This goes for both the process industry companies, which traditionally have provided mainly products, as well as for the IT- and automation providers to the process industries. Here, new thinking in terms of, for instance, result-, productivity- or availability-based contracts are foreseen to grow. Thus, new or emerging business models, with a larger content of integrated services, monitoring, transfer of risk from customer to provider, etc., such as PSS, Industrial PSS (Meier et al., 2008) and Functional Products (Lindström et al., 2013) are expected to be used.

7.2 Conclusion

The requirement for change and adoption is a never-ending story. However, the pace of the change has increased over the last two decades, as has competition from countries outside of EU with lower labour cost, good know-how, high-technology production processes and abundant capacity for production. Thus, the European process industry needs to stay ahead on strategic and tactical levels and innovate ion a regular basis to stay competitive, profitable and sustainable.

7.3 Future Directions

The future of process industries, and closely related industries such as manufacturing and logistics, etc., will become smarter, faster and leaner through use of improved processes and methods, use of new and better technology, a higher level of automation and adoption of new or emerging business models. This will require corporations to focus on continuous improvements as well as insightful planning and actions on strategic and tactical levels.

The ProcessIT.EU roadmap for industrial process automation will continue to be updated to reflect new requirements, legal matters, ideas, trends, technology and business models.

8 MAIN SOURCES OF INFORMATION AND REFERENCES

Main sources of printed information

Related roadmaps:

- Industry4.0
- EFFRA FoF
- ECSEL MASRIA
- SPIRE
- IoT Forum
- TAMS4CPS

EU GDPR - http://ec.europa.eu/justice/data-protection/reform/index_en.htm

The ProcessIT.EU team also collected information during a number of international workshops conducted during 2014-2016, forming the initial structure for the R&D areas and the outline of the whole roadmap.

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