processit.eu

Automation for process industries

European Roadmap for Industrial Process Automation

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An European Roadmap for Industrial Process Automation based on global trends and industrial needs. The roadmap is an inspiration for future research and project proposals in the field and contains a number of proposed actions on the road forward to the described ideal concepts.

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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 Center of innovation Excellence (CoIE) in early 2011. ProcessIT.EU is primarily focused on process automation and ICT for process industries 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 proposition:

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, PPPs and platforms, ProcessIT.EU develops and maintains this roadmap in the area of ICT and automation for process industries.

This document is the first version of the ProcessIT.EU roadmap and is slated for annual updates. 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 the 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 ideal concepts that form the direction of development proposed in this road map. Each ideal concept contains a description of the current state-of-the-art, the business potential, and a set of proposed actions to reach the ideal concept. 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). A web-based survey was also used to gather feedback from relevant industry partners in Finland and Sweden.

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 achieve projects that meet the process industries challenges where automation and ICT are increasingly important factors in the global competition.

The relevant industry sectors include the following:

- Pulp & Paper (including forestry)
- Metals
- Mining & Minerals
- Chemical
- Energy & Power
- Pharmaceutical
- Food Processing
- Infrastructure
- Mobile platforms
- Oil & gas.

2 PROCESS AUTOMATION IN THE EUROPEAN INDUSTRY

Industrial process automation is an important sector for Europe, as many European companies are world leaders in terms of systems and applications development, supply, and usage. ABB is the world leader in this area with a market share of 22 %, followed by Siemens and Schneider Electric.

The roadmap from the SPIRE consortium *(Sustainable Process Industry – European industrial competitiveness through Resource and Energy efficiency)* states that the sectors united in SPIRE represent a major portion of the manufacturing base in Europe (EU27), including more than 450,000 individual enterprises. They hire over 6.8 million employees and generate more than 1,600 billion in turnover, representing 20 % of the total European manufacturing industry, both in terms of employment and turnover. Industry accounted for more than a quarter of the total European energy usage in 2010, with a significant portion of that use occurring within the process industry.

SPIRE brings together industries that have a high dependence on resources (energy, utilities and raw materials) for their production, including cement, ceramics, chemicals, engineering, minerals and ores, non-ferrous metals, steel and water. The pulp and paper (including forestry) sector can also be added to this list – an industry that also is highly energy intensive.

According to the European study [Monitoring and control; today´s market, its evolution till 2020 and the impact of ICT on these], the major drivers for improved automation (monitoring and control) are energy efficiency, the cost of oil/gas, safety and security, the development of services and reliability. This study indicates that world market for the automation of process industries is 26,3B Euro where the European market share is 10B Euro. The annual growth rate for the European industrial process automation market is estimated at 6.9 % through 2020, and the growth rate for manufacturing (including the manufacture of mining machinery) is estimated at 6.3 %. The industry's primary challenges in the automation field consist of a) all IP and SOA architectures, b) complex systems optimisation, control and flexibility, c) availability and d) maintenance control. These areas are directly addressed in this roadmap.

The study also notes that automation services predominate over automation hardware and software. This finding indicates that engineering tools and engineering efficiency will be of utmost importance for both end users and suppliers.

Industrial process automation is very important for maintaining and further developing a competitive European process industry. The area is a global marketplace with potential for SMEs to grow by developing and commercialising innovations through corporate, university, college and institutional collaborations.

The industrial cooperation in SMIFU (Sustainable Mine and Innovation for the Future), which was led by the Rock Tech Centre (RTC, www.rocktechcentre.se), involved the mining companies LKAB, Boliden and KGHM and the suppliers ABB, Metso, Atlas-Copco, Sandvik, Outotec, ÅF and AGH is an example of the importance of cooperation in industrial process automation. SMIFU conducted a pre-project with the following objectives: a 30 % reduction in energy/ton of broken rock, a 30 % reduction in man h/ton of broken rock, no human exposure in underground excavation areas and no accidents. Similar targets are established for other process industry segments. The general conclusion is that these targets can only be reached with a high degree of easy to use and easy to implement automation solutions.

To continue further development, favourable conditions must be created and maintained to ensure that the process industry's future challenges can be turned into opportunities.

- The process industry and its suppliers are important for Europe and crucial for the Nordic countries in terms of export value, employment, investment and sustainable competitiveness.
- Refining Europe's raw materials in an efficient and environmentally friendly way is a vital European and global concern.
- Increasing globalisation brings intensified competition to the process industry and its suppliers.
- Globalisation manifests ever-increasing demands on productivity, quality, yield, recovery and new products and enhancements.

- Environmental standards and regulatory frameworks are setting new, challenging and important demands.

Emerging countries are shifting the balance of the world economy. While the US and Europe are experiencing growth problems, Asian economies in particular are rapidly expanding. This is creating new competitive conditions in the global marketplace. European companies and enterprises active in Europe must constantly reinvent themselves by applying greater knowledge, expertise, innovation, technology and product development to remain at the forefront in terms of competitiveness. This need applies not only to major companies but also to small and medium-sized businesses to ensure that they can evolve into tomorrow's large-scale corporations.

It is no exaggeration to claim that process industries have provided a foundation for the rapid rise in the standard of living. Expansion in the industry has delivered export revenues, jobs, new products and world-class research. Over the years, a constant flow of innovations have emerged and contributed to work opportunities and valuable export earnings. From this tradition, the process industry has evolved to develop new, refined products with high-tech advancements. This development has frequently been in the form of R&D collaborations between state companies and agencies and large private manufacturing companies.

All of this indicates that there is significant business potential in the activities addressed in the roadmap for stakeholders throughout the value chain (i.e., end users, machine suppliers, system/component suppliers and engineering companies), providing all with the absolute best position to exploit business opportunities.

3 METHODOLOGY

Roadmapping is a methodology that helps companies and entire industries presume future anticipated changes and illustrate market trends, environmental changes, and technology life-cycles (Naumanen, 2001). 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 (Kamtsiou et al., 2007).

This work applies a roadmapping method developed in VTT (Ventä 2004). It organises the efforts into several steps, as illustrated in Figure 1 Phases of roadmapping (Ventä 2004). 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 and 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 long-term objectives, the current state and the steps required to achieve the long-term objective are defined.

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 road map and the eventual concluding recommendations. The relevant trends are presented in chapter 4.

As for the scope of the roadmapping, the relevant general industrial needs of competence, sustainable production, and improved overall equipment efficiency (OEE) have been selected. These needs are based on the identified trends and needs from which a set of high level goals are defined; they are further transformed into more concrete actions, which are referred to as ideal concepts. These ideal concepts form the vision required to implement the roadmapping work. The ideal concepts are presented in chapter 5.

Methodology

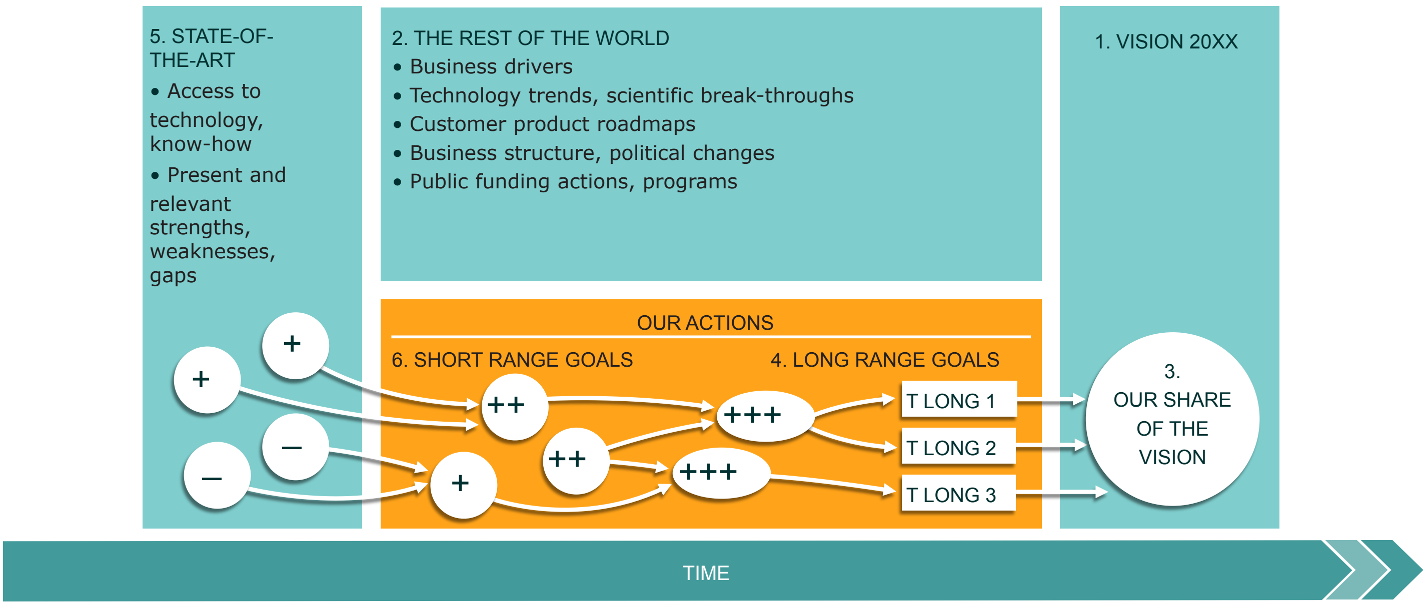

Figure 1: Phases of roadmapping (Ventä 2004).

4 IDENTIFIED RESEARCH AND DEVELOPMENT AREAS

As described in chapter 3, a well-defined description of the current business environment and trends is required to identify the development directions of the road map and the eventual concluding recommendations. The identified trends consist of global trends placed into the scope of the European process industry. An initial categorisation of top-level needs, ongoing trends, and top-level goals is shown in Figure 2.

The identified R&D areas (green horizontal arrows) support one or several of the three top level needs (brown vertical arrow): competence, sustainable production, and improved overall equipment efficiency (OEE). Based on the identified R&D areas and top level needs, a set of high-level goals are defined. In the following sections, the R&D areas and goals will be described, and in later sections, the goals will be transformed into more concrete actions, referred to as ideal concepts in chapter 5.

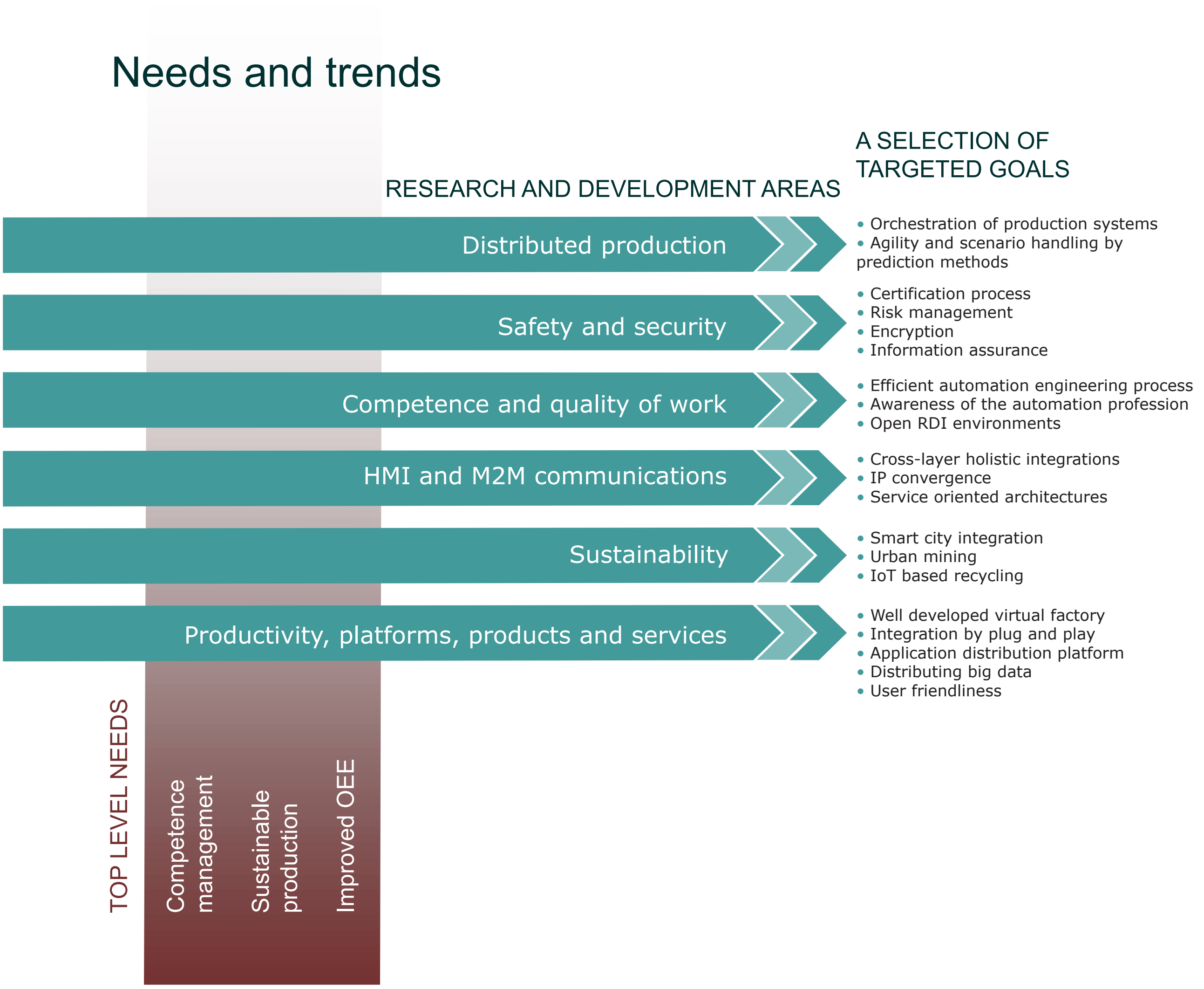

Figure 2: Industrial top level needs, industrial automation R&D areas and a selection of targeted goals.

4.1 Productivity, Platforms, Products, and Services

Continuously increasing the production efficiency and utilisation of plant equipment is a high priority for the European process industry. The focus must be on agile plants that can deliver both the economics of a large single stream plant and the flexibility of a batch plant while, within limits, be able to make almost any product required. It is clear that the way forward is to continuously update existing plants by using efficient yet low capital-intensive investments. Increasing the level of automation by focusing on system interoperability and managing (data mining) enormous amounts of data will improve the competitiveness of production plants. For example, the efficient increase of plant uptime requires maintenance systems that are able to collect the correct information and to interoperate with other relevant systems.

The product and service business will grow even further on the global market, where much of the new investments in terms of green field projects are ongoing. For example, European SME companies must have the ability to reach outside their domestic boundaries and provide products and services using efficient and reliable methods all over the world. This requires changes to the traditional business environment in which the Internet is predicted to play an increasingly important role by providing a framework for marketing, distributing, and maintaining industrial process automation solutions, much like the frameworks and platforms observed in the consumer sector (e.g., mobile phone echo systems).

Companies that internally capture and distribute process knowledge and ensure a high level of personnel competence will secure their competitiveness in the global marketplace.

Below are the identified trends for production efficiency and platforms, products and services.

4.1.1 Identified Trends

- Growth without new heavy investments. Low capital-intensive technologies.
- Increased integration of production and business operations. Optimisation through cross-layer integration.
- Produce to order and not to stock (e.g., Vendor Managed Inventory, VIM). Mass customisation and tailor-made products. Dynamic disturbance management in the production planning. Shorter product life cycles.
- Process industry as part of the smart energy system.
- Increased competition for raw materials.
- Increased availability and uptime. Integrated production and asset management.
- Improved plant management and control during abnormal operations.
- Rapid technology adaptation (e.g., spare parts, new technology introduction).
- Fast degeneration of performance for advanced process automation solutions.
- Increased focus on the life cycle for managing the automation system.
- Higher demands for Return on Investment (ROI).

4.1.2 Goals & Visions

- Well-developed virtual factory.
- Increased productivity from improved ways of working.
- Zero-configuration and integration of automation systems.
- Global access and distribution of automation services.
- Efficient data to information transition.
- User-friendly design and operation of automation systems.

4.2 Efficient Resource Usage

Consumers are increasingly motivated to purchase goods that conform to production criteria that are environmentally friendly and fulfil ethical principles while still being affordable. In addition, there is an overall societal pressure on suppliers to use resources efficiently to achieve sustainable production.

A long-term transition away from fossil fuel supplies towards fully renewable energy sources is required to obtain long-term sustainability. To reach this long-term goal, process optimisation

and improved system efficiency are vital components, as is increased agility in large scale energy systems. A closer integration of process industries and urban society can support the development of sustainable cities through higher resource utilisation and increased overall energy efficiency.

4.2.1 Identified Trends

- Increased energy cost.
- More restrictive environmental legislation.
- Increased competition for raw materials.
  - New products use same sources of raw materials (e.g., pulp and paper vs. electricity and heat production).
  - Protection of forests and other natural resources.
  - Competition of food vs. other commodities production.
  - Progress in recycling of used materials.
- Implementation of cap & trade systems.
- New exhaust cleaning technology.
- Greater awareness of the ethical, business and societal context of research.
  - Sustainable and ethical production, packaging and distribution.
  - Processes, products and tools that improve health, well-being and longevity.

4.2.2 Goals & Visions

- Zero waste and environmentally neutral plant.
- Zero-waste and environmentally neutral plant.
- Improved production efficiency by means of new technology and plant-wide optimisation.
- Extending the use of forest-based biomass in the process industry.
- Increased production agility, enabling process industries to further integrate with society.
- Urban mining and systemised recycling.
- Minimising water usage, e.g., closed water systems in production plants.
- Virtualisation of the production chain as a tool to improve energy usage.

4.3 Human-Machine Interface and Machine to Machine Communication

As the degree of automation in process industries increases, the requirement of communication within and across system boundaries also increases. Improving system functionality and enabling the integration of traditionally separated systems will require future proofing standards that have the ability to evolve over time to maintain compatibility with upcoming technical equipment.

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. Machine to machine communications (M2M) using Internet of Things (IoT) principles will form the

Cyber-Physical Systems (CPS) of tomorrow; these systems are predicted to enable new automation paradigms and improve plant operations in terms of increased OEE. Important development areas to archive M2M communications in the process industry are, for example, robust and energy efficient wireless technologies combined with technologies for energy harvesting to minimise installation costs. The implementation and development of service-oriented architectures (SOA), 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 while keeping manual configuration to a minimum.

The human-machine interface (HMI) development must continue to improve the possibilities for efficient plant operations. Visualisation, virtualisation, and simulations of a plant and its automation system will be introduced into daily operations where e.g., combined with mobile equipment will improve maintenance work. It is also foreseen that the development of HMI will continue to gain inspiration from the consumer computer game industry and social media.

4.3.1 Identified Trends

- Scope of automation is extending to enterprise systems, forming a System-of-Systems architecture.
- Production becomes more geographically distributed, requiring advanced communication solutions.
- Service-oriented architecture technology moves from enterprise-level to field-level devices.
- Industrial expression of interest in Internet of Things technology.
- Need for open standard.

4.3.2 Goals & Visions

- Higher degree of IP-enabled devices to support cross-vendor and cross-level communication.
- IP-based (soft) real-time services.
- Adoption of Internet of Things technology in automation and maintenance systems.
- Service Oriented Architecture in lightweight Internet of Things devices.
- M2M communication to enable machine learning in process automation.
- Global real-time access to all devices at the field and automation levels.
- Collaborative automation using networked services.
- Automation system HMI inspired by the consumer game industry and social media.
- Access to user-friendly simulation models.

4.4 Competence and Quality of Work

The continued success of the European automation and industrial IT industry is very much dependent on the ability to attract competent personnel and maintain their competence over time. Technology integration, the rapid introduction of new technology, and increasingly complex legislation are some of the factors that drive the need for competence. Building cross-sector competencies (e.g., designing automatic controls combined with human machine interfaces or designing automation systems combined with knowledge of legislation) will be crucial for successful development.

The levels of outsourcing and insourcing services, products, and research will continue to vary over time. 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. Capturing and transferring tacit knowledge is one of many key elements when introducing new staff to the industry (e.g., process operators and maintenance technicians). However, the tools and methods that support knowledge management in general (and tacit knowledge management in particular) are still in the research phase.

There is a clear trend in utilising virtual factories to educate operators and other personnel. However, many open issues remain before a streamlined educational framework for using virtual factories and processes is widely implemented. There must be a special focus on developing the tools to become more user-friendly and pedagogic. Updating and maintaining the virtual factories, managing education plans on an individual level and improving access to the training environment are some of the factors that still limit the potential of virtual factories.

Presented below are the identified trends for competence and quality of work.

4.4.1 Identified Trends

- Sound working conditions and worker safety is becoming a competitive advantage.
- Increased complex regulations on the environment and safety of workers.
- Urbanisation affecting the on-site competence availability.
- Increased complexity of development requires the involvement of different competencies, thereby extending the value chain.
- Reduction in R&D budgets at process industries.

4.4.2 Goals & Visions

- Collaboration for mobilisation of R&D resources, e.g., between company sites and universities.
- Creation of open research, development, and innovation environments.

- Requirement management to secure the interface between client and recipient.
- Efficient automation engineering and collaboration characterised by model-based engineering, reusability, and requirement management.
- Increased knowledge of the automation profession.
- Context-driven, user-centric information based on big data.
- Coordinate industrial process automation activities on the national agendas within EU.
- Influence the legislation design on the national and EU level.

4.5 Safety and Security

Safety in the European process industry is generally very good compared to that in other non-European countries; however, unnecessary accidents and incidents still occur. Reducing these numbers is a consistent goal for the industry, European public attitudes, and national and European regulations.

By supporting the possibilities for remote process operation, the human exposure to hazardous environments in the industries can be reduced, thus limiting the risks of accidents involving employees. A higher degree of automation will (in most cases) also increase system safety, as 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.

Another important safety-related aspect is the availability and presentation of critical information to the proper personnel. Handheld devices and other emerging HMIs can contribute to improving the information presentation possibilities at different organisational levels.

The implementation and continuous improvement of automation solutions have increased the industry competitiveness on a global scale by reducing production costs, quality variations, and required manpower while increasing personnel safety. Continuing this development is necessary to obtain a profitable and socially accepted process industry in Europe. Today, however, many companies recognise that a low availability of specific process knowledge makes their operations fragile. Therefore, the process of transferring and distributing tacit knowledge to explicit formal information is a challenge for many European process industries

Because many European process industries were constructed more than 30 years ago and the number of green field projects has declined over the last decades, a majority of these process industries are considered "old." As their machinery ages, the risk of breakdowns and faults increases, thus affecting the machine safety. To maintain a safe and secure operation of an aging process industry, conditioned-based maintenance is a key technology for ensuring success.

When designing new process industries, 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.

It is foreseen that intrusion attempts will increase as automation systems continue to become part of globally connected enterprise systems. Non-authorised access to information may not only potentially affect a company's competitiveness, but it may also create a safety risk for the production process.

To maximise uptime and agility while simultaneously maintaining safe operations requires secure communication and secure information assurance. If the information integrity in the automation systems cannot be secured, the effects can be devastating. Faulty, tampered or disrupted information can introduce small errors at one end of the process that can propagate through the process and result in serious production faults and safety issues. It is thus highly important that intrusion detection, data validation and information encryption are applied to critical sections of the system.

Flexible system architectures are often desirable from a production efficiency perspective; however, increased flexibility may introduce undetermined safety and security issues. Thoroughly performed risk evaluations of new functions and flexibility are of great importance in reducing the risk of non-predicted errors.

4.5.1 Identified Trends

- The right information at the right time is critical for safety. When it is a question of human, mechanical or external safety, getting the right information at the right time is a key issue in avoiding risks.
- Experienced personnel with much tacit knowledge retire. Limited possibilities to capture and transfer their knowledge to less experienced personnel.
- Aging factories highlight the importance of maintenance, repair and renovation to keep up with newer production plants in e.g. Asia and South America.
- Increased regulation complexity. More advanced automation and measurement systems are required to fulfil the requirements.
- More information will be accessible using Internet protocols.
  – Well established security profiles available.

4.5.2 Goals & Visions

- Remove the human exposure to dangerous areas through increased remote operation and automation.
- Address context-driven critical information to the personnel in the factory.
- Well-developed user interfaces to ensure that personnel react on the information they receive.
- The safety and security aspects must be integrated in the simulation models to enable risk evaluation in a design phase and during operation.
- Safety- and security-related tacit knowledge among personnel are systematically captured and converted to explicit knowledge among the employees.
- Well-developed predictive condition monitoring systems detect machine degradation before they cause an increased security risk.
- Zero-configuration devices will reduce implementation and configuration errors.
- Integrated approach between standardisation, innovation and research to enable new safe and secure solutions.
- Safety classification of new technologies such as IoT devices.
- Secure communication systems with strong encryption of crucial information.
- Secure operations using intrusion detection and prevention systems.
- Information assurance that verifies the information consistency.

4.6 Distributed Production Process

Today's transformation of raw materials into valuable products is a distributed production process that involves several different entities that are managed by several different plant owners. It is foreseen that the distribution of the production process will continue to expand in the future. European companies are building new production units primarily in developing countries due to market closeness, low raw material cost, and reduced employment costs compared to Europe.

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 marked demand (as observed over the last few years) will introduce new requirements on the agility of production entities (and the orchestration of sets of production entities) to maintain a high OEE. Industrial process automation will play an important role in this future development.

4.6.1 Identified Trends

- Increased offshoring of production.
- Design anywhere, produce anywhere.
- Advances in information communication enable worldwide automation solutions.
- Expansion in transportation sector provides efficient trading conditions.
- Increasingly volatile market demand combined with fierce competition.
- Mass customisation.

4.6.2 Goals & Visions

- Increased agility and flexibility of production processes.
- Orchestration and portfolio management to control and optimise what and where to produce.
- Achieving a dynamic combination of competencies and continuous knowledge of entities.
- Communication for value creation from globally networked operations involving global supply chain management, product-service linkage and management of distributed production assets.
- Communication and virtualisation are key technologies for achieving a well-functioning distributed production process.

5 A SELECTION OF PRIORITIZED IDEAL CONCEPTS

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 can be made resulting in identified "white areas" that require further development. In this roadmap, we have chosen to express white areas as ideal concepts. An ideal concept is characterised by the following:

- A vision statement.
- Inspired by specific industrial trend(s).
- A demonstrator of how technology and methods can respond to needs.
- Reachable by 2020.
- An inspiration to new RD&I projects.

The following ideal concepts are developed:

1. Instant Access to a Virtual Dynamic Factory.
2. Increased Information Transparency between Field Devices and ERP.
3. Real-time Sensing & Networking in Challenging Environments.
4. Process Industry as an Agile Part of the Energy System.
5. Management of Critical Knowledge to Support Maintenance Decision Making.
6. Automation Service and Function Development Process.
7. Open Simulator Platform.
8. Automation System for Distributed Production.
9. Balancing of System Security and Production Flexibility.

In Figure 3, Ideal concept estimated level of impact on research and development areas. Figure 3 it is shown how each of the nine ideal concepts contribute to research and development areas defined in chapter 1.

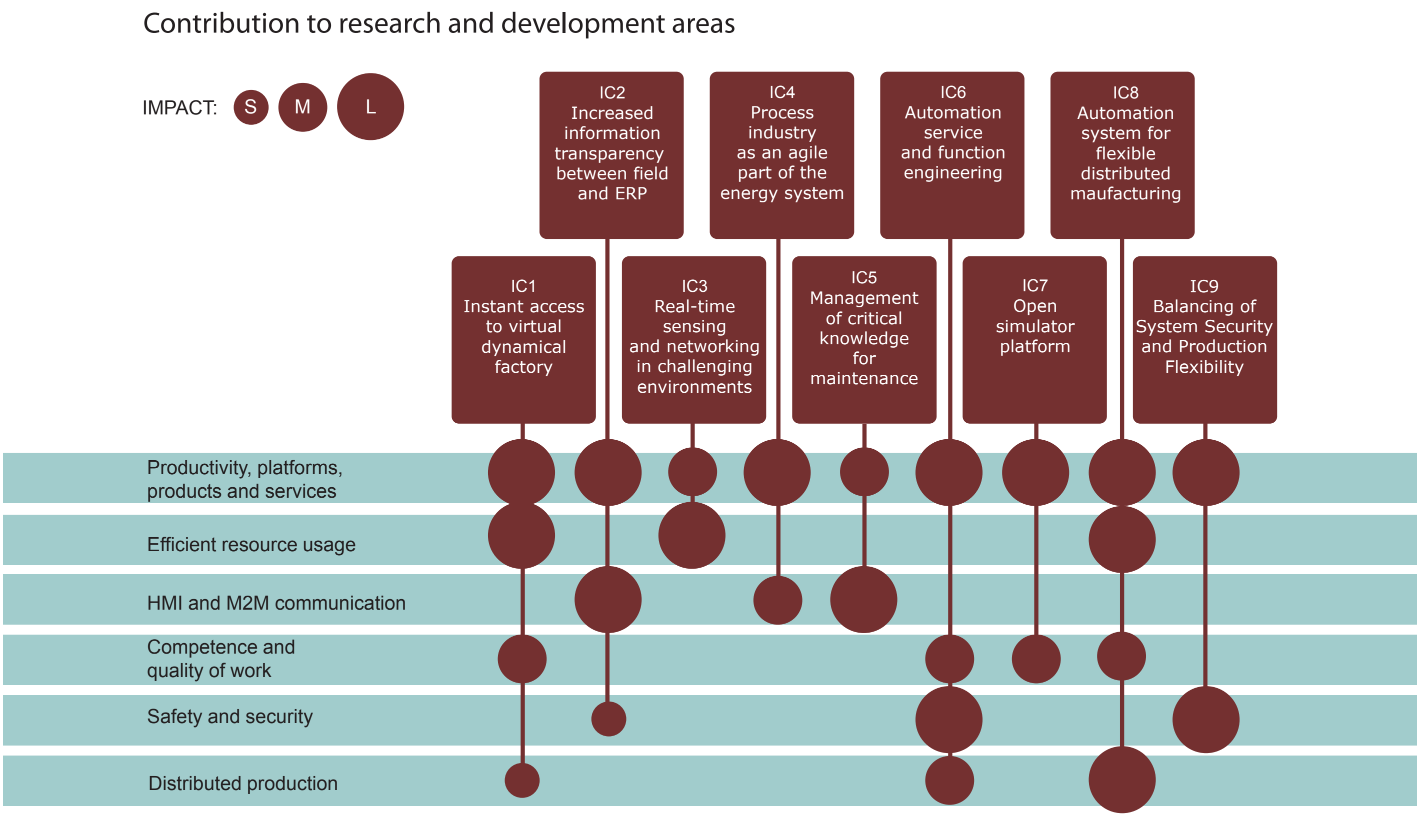

Figure 3: Ideal concept estimated level of impact on research and development areas.

5.1 Instant Access to Virtual Dynamic Factory

5.1.1 Vision

To have instant, organisation-wide, and inter-organisation access to a virtual real-time plant to provide the right service to the right people at the right time.

5.1.2 Description of Ideal Concept

In today's industry, many varieties of virtual dynamic factories (simulators) are in use. These simulators can be roughly divided into two categories: offline or online executed simulators. Offline simulators are not connected to plant operations in real time, although these simulators are intensively used, e.g., when preparing and executing plant or control system modifications (or when performing operator training). Typically, the maintenance of offline simulators suffers during idle time periods. This results in a high threshold for start-up because adaptation to a current process status and re-verification of their performance is required. Online simulators, conversely, are connected to real-time plant operations because they are simultaneously executed with the actual production process. The maintenance of parameter variations is often handled (semi-) automatically, whereas structural modifications are handled manually. When the simulator is online and in use, maintenance is more continuous compared to when the simulator is offline. Online simulators are often restricted to linear simulations used for e.g. MPC or other optimisation algorithms. There are typically no mechanisms in place that allow an online simulator to run in an offline mode or vice versa.

There is enormous potential in achieving a platform for a virtual dynamic factory that has instant and cross-organisational access capabilities, i.e., enabling fast transitions between the real and virtual representations of software (e.g., a control system) and a plant and that can be run in either online or offline conditions. Managing the virtual dual of factories or processes is as crucial for competitiveness as managing or operating an actual building.

The envisioned platform would provide features such as the following:

- True representation of the virtual digital factory over the entire life cycle.
- Real-time access to operator training with actual plant status.
- Safe and fast evaluation of new ways of running the plant.
- Evaluate and understand advanced control applications.
- Model-based reasoning at several ISA-95 levels.
- Process prediction and backtracking for e.g. support services.
- Soft sensors using model-based state-of-the-art estimation techniques.
- Safety analysis from providing up-to-date definitions of plant interconnections.
- Model-based offline and online optimisation (set-point, controller parameters and structure).

In general, the platform would support different virtual views of the process (e.g., dynamics, statics and statistical properties).

Instant Access to Virtual Dynamic Factory

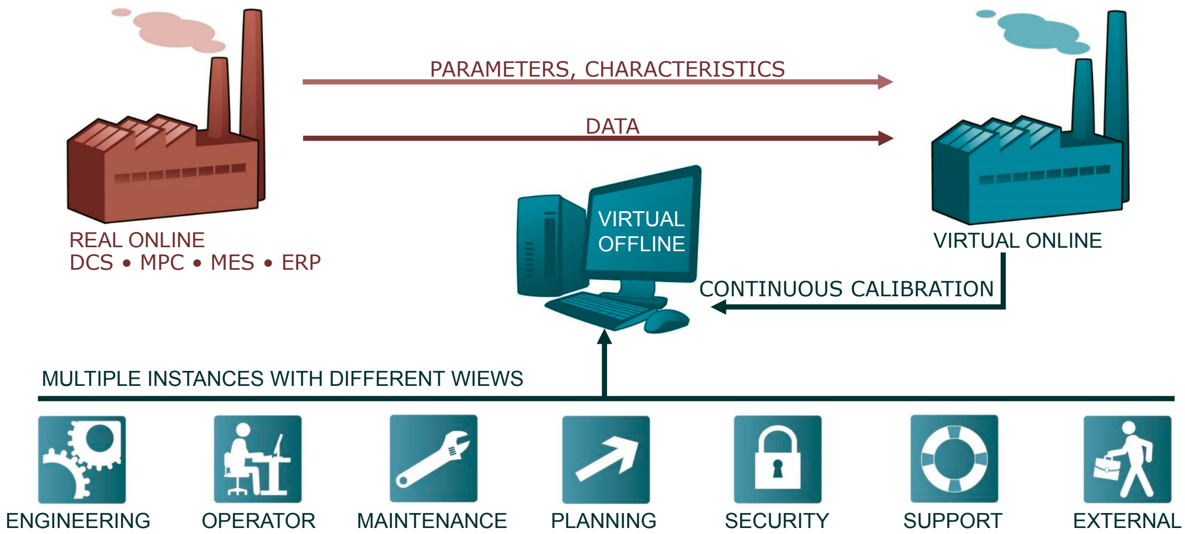

Figure 4: Principal concept of instant-access virtual dynamic factory. A virtual factory is continuously estimated online, and when required, an update is sent to virtual'. The computation and storage node must support multi-virtualisation and backtracking. The key principle is to allow a smooth transition from online model(s) to offline model(s) to support the different views (i.e., not comparable to typical online model-based controllers found in the industry).

5.1.2.1 Trends Supported by the Ideal Concept

- Growth without new heavy investments, low capital-intensive technologies: Improving operations by using a virtual dynamic factory is clearly a low capital-intensive technology with a foreseen low IRR.
- Increased integration of production and business operations, optimisation through cross-layer integration: Performed by the combination of information transparency, zero-configuration units and virtual models that create prediction possibilities for plant operations.
- Produce to order and not to stock (e.g., Vendor Managed Inventory, VIM). Mass customisation and tailor-made products. Dynamic disturbance management in the production planning. Shorter product life-cycles: Product changes are challenging for many process industries and typically result in large quantities of waste production. A virtual dynamic factory can enable efficient and flexible production by providing operator training and scenario handling and prediction.
- Process industry as part of the smart energy system: Understanding the high level of system integration is enabled by a virtual dynamic factory.
- Increased availability and uptime. Integrated production and asset management: Scheduling and planning maintenance using buffer management requires a model-based approach.
- Rapid technology adaptation (e.g., spare parts, new technology introduction): Typically requires new control strategies and plant operations that must be verified using a model-based framework.
- Increased complex regulations for the environment and worker safety: Using a model-based development process is the only way to prove system safety (e.g., building a safety argument).

- **Urbanisation affecting the on-site competence availability:** Remote competence centres for automation systems require data access and models (e.g., efficient backtracking of faults).
- **Increased complexity at development requires involvement from different competencies, thereby extending the value chain:** It is foreseen that the exchange and usage of virtual dynamic factories will be as natural as geometric data (e.g., CAD drawings) for securing the quality of the development process.
- **Experienced personnel with tacit knowledge will retire. Limited possibilities to capture their knowledge and transfer it to less experienced personnel:** The training of personnel and the designing of personal education plans will require using a virtual factory.
- **Increased production offshoring. Design anywhere, produce anywhere. Increasingly volatile market demand combined with fierce competition:** Requires model-based tools to have efficient production and process planning.

5.1.2.2 Visions and Long-Range Goals supported by the Ideal Concept

- **Well-developed virtual factory:** Strong focus for improving the life-cycle management of virtual factories.
- **Increased productivity from improved way of working:** Reduce the gap between real and virtual, thereby enabling the use of the virtual domain as part of everyday engineering.
- **Global access and distribution of automation services:** Simulation-based services such as remote maintenance, asset management.
- **Efficient data to information transition:** Generating information from data often requires a model-based approach.
- **User-friendly design and operation of automation systems:** Universal access to operator training and model-based reasoning. Model-based reasoning at all organisation levels.
- **Improved production efficiency by means of new technology and plant-wide optimisation:** Combining recent developments in optimisation theory with a model-based approach will enable plant-wide optimisation.
- **Collaborative automation using networked services:** Services that require models due to their prediction possibilities. Models are online in real time.
- **Automation system HMI inspired by the consumer game industry and social media. Access to user-friendly simulation models:** Virtualisation is a key technology.
- **Efficient automation engineering and collaboration characterised by model-based engineering, reusability, and requirement management. Collaboration for mobilisation of R&D resources, e.g., between company sites and universities.** Well-maintained models are necessary for an efficient collaboration.
- **The safety and security aspects must be integrated in the simulation models to enable risk evaluation in a design phase and during operation:** Real-time safety evaluation.
- **Well-developed predictive condition monitoring systems that detect machine degradation before they cause an increased security risk:** Prediction by model.

5.1.3 State-of-the-art Analysis

The online commissioning of simulation models is a well-known technology in the process industry and has been used for controller synthesis-like model predictive controls and for various model-based diagnostic approaches. However, these models are not meant or designed for offline operations. Tracking simulators that can continuously match the model and the actual process are only at the research stage, and few articles can be found since 2006. Tracking simulators enable operators to predict future responses to an applied action and are designed to function in both offline and online modes.

Today, there are no actual frameworks or methods that allow smooth model transitions between offline and online modes to generate representations suitable for a variety of users.

Previously mentioned advances, however, must be considered a first step in realising such a framework, i.e., this ideal concept. Virtualisation must continue to develop such that the virtual factory is a trusted representation of an actual factory that provides services in a user-friendly and organization wide way.

Numerical optimisation is frequently applied in research projects, but due to the lack of adequate virtual plants, numerical optimisation is often restricted to model-based supervisory controls such as MPC or LQ control. New findings in large-scale numerical optimisation, combined with the life-cycle management of virtual plants, can enable further optimisation applications in the process industry.

5.1.4 Proposed Actions

Below is a set of required actions for the introduction of instant-access virtual factories into present production.

- Studies of numerically robust parameter and state update mechanisms for complex dynamic models (parameters are not constant!).
- Mechanisms that allow for the fast and robust virtualisation of the control system and its pairing with the virtual factory. Strive for a seamless transition between the virtual and physical representations.
- Computational issues regarding the large number of simultaneous instances of a virtual factory. Selection of computing architecture, computer clusters, distributed networks and cloud computing.
- Storage and access (i.e., data management) of necessary data to enable backtracking.
- Platform for all purposes and multi-technology simulators with integration of computations, simulations and engineering data.
- Platform to support several functional views, e.g., dynamic, topological, steady-state.
- Develop business opportunities by creating a portfolio of applications that utilise the concept. Target all hierarchical levels in the ISA-95 pyramid.
- Strategies for exchanging virtual representations as a natural part of achieving collaborative automation.
- Describing legacy systems (e.g., old HW).
- Standard and concept for HW components containing models as a service.

5.1.5 Business Potential

The business potential for generating services and applications based on this concept is high, though it is difficult to foresee the direction of development enabled by the concept. However, the strong trend of educating operators combined with the need to capture and distribute tacit knowledge will most likely drive the first application and service area for introducing and implementing this concept in the industry. This approach is also supportive of the emerging need to educate personnel for various green field projects outside Europe. Some of the most promising business potentials are:

- Real-time access to training, preferably in a consumer-oriented game-inspired environment.
- Model-based reasoning at several ISA-95 levels by providing prediction and back-tracking possibilities.
- Usage of soft-sensors where actual sensing is impossible.
- Providing first-line rather than back-office simulation services, i.e., new methodologies for different ways of working – simulations is part of every day engineering.
- Enabling agile production with efficient support due to prediction possibilities.
- Enabling remote service providers (global) through optimisation, structural analysis, and problem solving services that require a virtual factory.
- Meeting the challenges of fast process adaptation due to mass customisation, rapid technology adaptation and plant redesign.

5.2 Increased Information Transparency between Field Devices and Enterprise-wide Systems

To enable full interoperability and configurability with zero-configuration characteristics between computational devices from different organisational levels using open network and communication technologies.

5.2.1 Description of Ideal Concept

This concept targets full cross-domain interoperability between traditionally separated systems, Figure 5. To support the development of a dynamic system-of-systems architectural approach, seamless communication between field devices and high level systems (such as enterprise resource planning (ERP) systems) is required. Field-level embedded devices that are directly accessible from high-level systems in a non-predefined way can create possibilities for dynamically reconfiguring and orchestrating advanced processes, which will support agile production and rapid re-design.

To achieve system-wide interoperability, semantics and ontology are important long-term research factors for overcoming the interoperability and compatibility issues often found in today's systems.

Incompatibility limits the full potential and capacity of installed computerised systems. It also significantly increases installation and maintenance cost because specialists from many sub-contractors often need to be involved.

By adopting well-established network protocols, in particular the TCP/IP-suite, the possibility of increased interoperability and protocol convergence emerges, resulting in improved interoperability between vendors. For example, a Siemens device can directly exchange information with ABB or Honeywell actuators, or be directly accessible through SAP's ERP system.

This ideal concept also promotes the principles of Service-Oriented Architecture (SOA), where sensors, actuators and process functions can be expressed as services either within a local network or globally across the Internet. Services can be created, reconfigured and removed as needed using the principles of loosely coupled services. Because the principle of SOA conforms well to the TCP/IP protocol suite, the technology will support communication between plants geographically located on different sites by using the Internet. This is a prerequisite for flexible distributed production, which will be further presented in Section 5.8: Distributed Production.

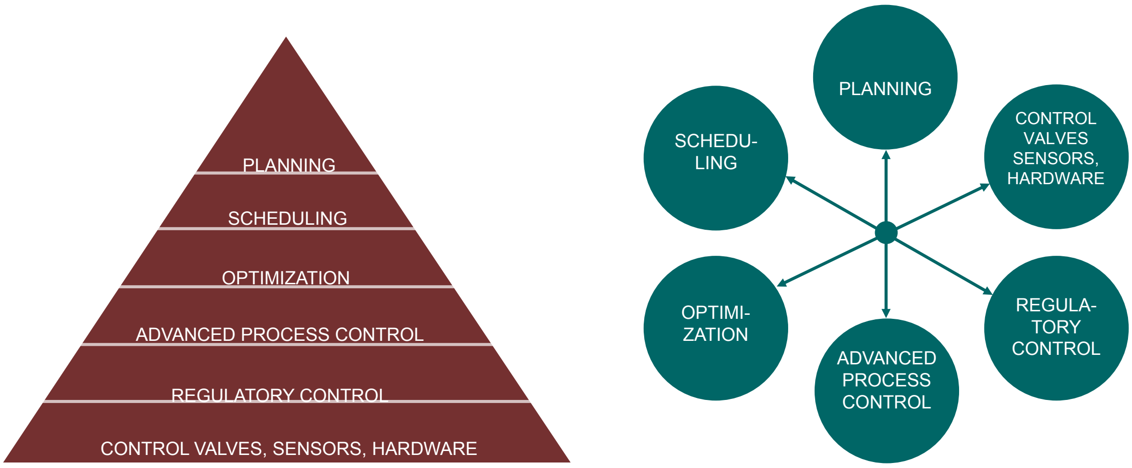

Figure 5: Left: The traditional hierarchical (e.g., ISA-95) structure. Each level in the structure can only be accessed from the neighbouring levels. Right: Cross-function interoperability enables access to information and data from traditionally separated systems using common data exchange protocols. Real-time systems with special time-critical functionality may have independent communication channels to meet the requirements, as indicated in the figure by the dashed line.

5.2.1.1 Trends Supported by the Ideal Concept

There is a tremendous amount of research presently focused on emerging network technologies; however, relatively little consideration is given to the needs of process industries.

To capture the most important technological trends (and adapt them for usage in process-automation environment), the industry must take action and influence the development of future standards and technologies at an early stage through involvement in relevant R&D projects and standardisation organizations.

Some trends of significant importance for future network and information architectures within process automation include the following:

- **Increased usage of IP-protocols:** Using internet-compatible communication methods in a larger context to reduce the complexity and diversity of today's system solutions.
- **Need for open standards:** Promote open standards to reach a higher grade of compliance between vendors and technology suppliers.
- **Service oriented architecture technology moves from enterprise-level to field-level devices:** By expressing the functionally of devices as fundamental services, higher level services can be assembled by underlying services in a system-of-systems fashion. This methodology simplifies the reconfiguration and orchestration of large-scale complex systems.
- **Cross-layer optimisation:** Holistic information exchange between operation levels enables improved model verification and production prediction.
- **Increased integration of production and business operations:** With more seamless integration and interaction between business operation and production, facilities will reduce management.
- **Increased availability and uptime:** To reach higher overall equipment efficiency, the importance of keeping facilities operational at all times is increasing.
- **Improved management during abnormal operations:** Operational protocols in the case of abnormal operation are also a part of increased OEE.
- **Fast degeneration of performance for advanced process automation:** The fast development of new vendor-dependant automation systems causes a fast degeneration of new investments.
- **Increased focus on the life-cycle for managing the automation system:**
- **Rapid technology adaptation (e.g., spare parts, new technology introduction):** To meet the accelerated technology development, systems of tomorrow must be open and reconfigurable to meet the requirements of future systems with improved, new and still unknown functionality.
- **Scope of automation is extending to enterprise systems. A System-of-Systems architecture is formed.** By designing systems with a holistic/transparent approach, high-level automation systems can be designed using services from different organisational levels (subsystems) to orchestrate large-scale automation.
- **Industrial expression of interest in Internet of Things technology:** The Internet of Things can be considered an enabling technology for increased global connectivity within automation systems.

5.2.1.2 Visions and Long-Range Goals supported by the Ideal Concept

- **Meet the challenges of fast process adaptation due to mass customisation, rapid technology adaptation and plant redesign.** With SOA in place throughout the process systems, more rapid reconfiguration will be possible.
- **Compliance with standards.** The semantics and ontology of future generation automation systems must support cross-vendor and cross-domain communication.
- **"Sufficiently" open architecture.** To support the development and implementation of future (and possibly third-party) functionality in the automation systems, the systems must be sufficiently open.

- **Improved information targeting. The right information, to the right person, at the right time, in the right format.** Communicate the correct processed information instead of the raw data.
- **IP-based real-time data and services. Enabling technology to integrate and network businesses.** Real-time on IP-networks are limited to soft real-time with flexible applications. Using IP-based systems to the extent possible enables the use of global services, even in embedded soft real-time applications.
- **Fully interoperable systems, both vertical and horizontally.** Full interoperability between devices and services at the shop-floor, automation and resource planning levels.
- **Increase awareness of the automation profession.** Promoting communication technologies found outside the world of process automation will broaden the source of technical personnel.

5.2.2 State-of-the-art Analysis

Today's process industry is, to a large extent, limited to closed proprietary solutions operating at different levels in the ISA-95 structure, which limits system dynamics and reduces the ability to freely choose system devices based on function and price.
It is also common to see several parallel, non-compatible systems operating at one level in the ISA-95, thus requiring a need for additional mediators and converters. Different types of non-interoperability cause industries to invest in several parallel systems at a high cost. This cost can be significantly reduced if vertical and horizontal systems integration can be achieved.

There is a great deal of research currently focused on Service Oriented Architecture (SOA) and how it can be used to remove the structural barriers in the ISA-95 structure, thus enabling new system functionalities through software installation and orchestration. The development and maturity of SOA systems and technologies varies between the levels of the ISA-95 structure. In top-level management systems, SOA is frequently used, but further down in the ISA95-structure, it is far less common and is almost non-existent at the field-level. These differences can primarily be explained by tradition and the limited bandwidth and computational power of many field devices.

Wireless field systems are widely available today, but they mostly act as static-cable replacements and do not offer the full potential of the SOA concept (nor do they support the functionality of loosely coupled devices or services).

5.2.3 Proposed Actions

As mentioned above, SOA is available on powerful/resource-rich devices utilising high bandwidth connections usually found in the upper levels of a wide-scope automation system. Traditional proprietary fieldbus solutions still dominate the resource-constrained devices typically found at the shop-floor level. In this ideal concept, we promote the expansion of Service-Oriented Architecture towards light-weight embedded devices to replace traditional fieldbus solutions.

The list below states some actions necessary for reaching these visions and long-range goals:

- Focus research on how field devices should integrate with high-level systems to address the target of seamless integration and transparent systems, including data compression, distributing computation and decision support, service descriptions and semantics.
- Develop and integrate Services-Oriented Architecture at the field level and learn how to benefit from those on ERP level. Integrate advanced properties and functions at field-level directly with ERP/MES. Lower-level systems and devices must be able to send service descriptions to ERP.
- Identify relevant ongoing projects and development in other business field. What are they doing, and what could be useful for process automation?
- Identify specific process industry needs in detail.
- Implement a systems engineering approach to build architectures and applications.
- Automation in the cloud through loosely coupled sensors and systems.

5.2.4 Business Potential

The business potential for benefitting from improved networking technical solutions is expected to grow. Increased transparency between system levels enables fast reconfiguration and increases system flexibility.

- Reduced cost for maintaining parallel systems; different vendors/protocols often require the involvement of several subcontractors.
- Possible system redundancy reduces downtime.
- Interoperability, i.e., not being bound to a single vendor (avoid vendor lock-in).
- Reduction of data-conversion tools.
- Reconfiguration of system functionality.
- Wireless system removes (or reduces) the need for cables and connectors.
- Installation of new sensors is cheaper (installation and configuration).
- IP convergence will increase the number of available programmers, thus enhancing the ecosystem of developers.

5.3 Real-time Sensing & Networking in Challenging Environments

5.3.1 Vision

Real-time measurement of any parameter of interest, anywhere in an operating industrial process, to increase knowledge and improve automation performance.

5.3.2 Description of Ideal Concept

Reliable and accurate sensing and metering are vital components in achieving a better understanding and improving the operation of complex industrial processes. Improved measurements are also important for the continued development of tomorrow's control and maintenance systems. Future measurement systems must be available online and communicate valuable information at a rate sufficient for the application.

Challenges

A common measurement challenge in heavy industrial process plants is the harsh environment, which can include heat, dust (dirt), vibrations, dampness and corrosion. Depending on the severity of these conditions, solutions range from the heavy-duty (rugged) encapsulation of sensors to the use of proximity-based technologies such as optical or electromagnetic sensors. In the most extreme environments, it may be beneficial to utilise disposable sensors that are sacrificed during the measurement process, never to be recovered. See Figure 6 which exemplifies an industry with very high demands on heavy duty encapsulation of sensors (mining) and usage of disposable sensors (steel making).

Other challenges with process sensing and measurement concern communication with the sensing devices. Cables are often expensive and installation costs are high, and in some application

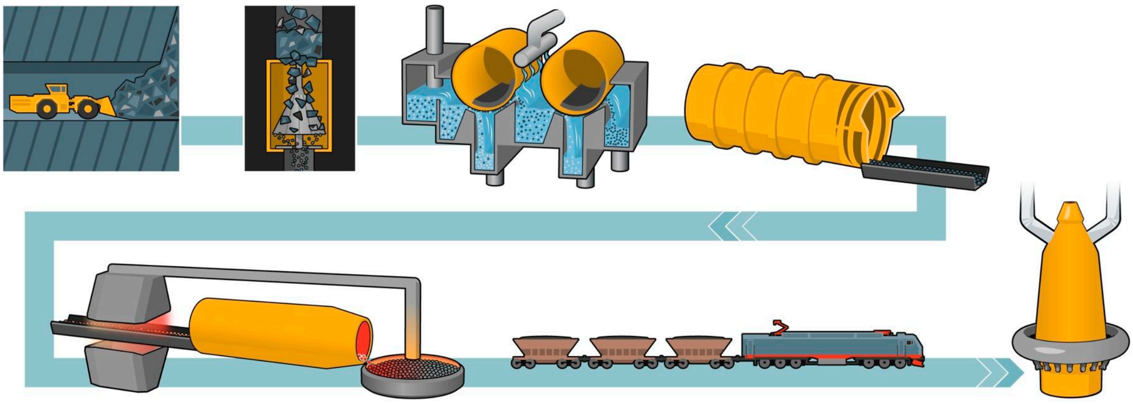

Figure 6: To measure any parameter of interest, anywhere in an operating industrial process in real-time. Mining and steel making as examples of processes with high demands on sensor encapsulation and usage of disposable sensors.

wired solutions may not even be an option. While wireless technology can reduce the installation costs of cables and connectors, it also faces other challenges such as EMC disturbances and material barriers that limit the throughput of radio-wave propagation.

Equipping disposable sensors with wireless communication capabilities will enable new measurement possibilities and support improved process monitoring and control, as measurements from the process core will become available in real time. Non-disposable wireless sensors will require a long-term energy supply to measure and report relevant information. Because heat, flow and mechanical movements are common in industrial processes, the technologies of energy harvesting and short-term energy storage are prerequisites for the successful deployment and utilisation in industrial process monitoring and control systems.

Envisioned technological challenges that the ideal concept might encounter include the following (depending on the environment):

- Device durability
  - Extremely low-powered electronics for long-term deployment.
- Harch environment
  - Robust/rugged encapsulation and design of electronics (including material parameters).
- Energy availability
  - Autonomous energy management, using energy scavenging and storage.
- Metallic barriers preventing RF-signals
  - Wireless communication in challenging environments.
- Tracking devices to follow the actual process flow.
- Proximity sensing technology.
- 3D positioning of tools and devices.

5.3.2.1 Trends Supported by the Ideal Concept

Several identified trends in the process industry will directly or indirectly benefit from measurement and network technological advancement. Mentioned below are identified trends that this ideal concept supports.

- **Increased availability and uptime:** Emerging problems can be found at an earlier stage, and planned stops can be used to replace faulty components before they break down, and causes expensive unplanned stops.
- **Required management to secure proper quality:** This can be enabled through improved measurement technologies.
- **Low capital-intensive technologies:** The price of sensors should be low compared to the overall operating cost, but they should contribute a significant impact/savings.
- **Improved management during abnormal mode:** Early identification of deviations in the process or the products.
- **Shorter product life-cycles:** Online re-configuration of process control, measurement and maintenance systems are benefitted by better measurement.
- **Rapid technology adaptations:** To support the development of increasing numbers of sensors and devices, communication compatibility is a key issue.
- **Agile production:** With real-time access to more control parameters of the process, the introduction of new operating schemes will require less effort to alternate the production.

5.3.2.2 Visions and Long-Range Goals supported by the Ideal Concept

This ideal concept, in many respects, also supports the vision of future process plants; some of the most highly related visions and long-term goals are mentioned below.

- **Well-developed virtual factory:** The validation and verification of the virtual factory requires actual sensors in the process plant to be accessible and available online.
- **System integration through Zero configurations:** Sensors should be designed for easy installation, require a minimum amount of configuration, and be compatible with surrounding equipment/systems.

- **Context-driven, user-centric information based on big data:** The large amount of data/information produced by online sensors and other devices enables and requires new data handling methods.
- **Fully interoperable systems, vertically and horizontally aligned in the ISA-95 structure:** Sensors should easily integrate with other system components and functions.

5.3.3 State-of-the-art Analysis

Process measurements are often made today in offline batches, thus limiting the possibility for using the information in real-time control situations. In cases where online measurement technology exists, it is primarily founded on conventional static fieldbus technologies that require converters and mediators to make communication between different buses and communication networks possible. This makes the technology expensive and limits the potential of real-time online measurement systems.

5.3.4 Proposed Actions

A wireless system utilising the principle of loosely coupled sensors will provide a more dynamic and flexible solution than current state-of-the-art systems.

- To achieve this, the development of interoperable WSN solutions using cloud-computing approaches must continue.
- Keeping systems open yet secure implies the adoption and continued development of open standards and security mechanisms for low-power wireless devices.
- To establish real-time measurements of parameters that are not accessible using current commercial technology, focused research and development on industrial-purpose sensor equipment is important, along with the adoption of low-cost technologies (originating primarily from the commercial market) and disposable tracking devices for industrial measurement applications.
- The energy management of sensor and actuator systems is a key support technology for this ideal concept to reach industrial acceptance and robust functionality.

5.3.5 Business Potential

From a process industry owner's perspective, measuring in previously inaccessible locations will increase their knowledge of the process. This knowledge can be used to improve the calibration of the control systems and to improve the operation of the automation process, including the validation of process models and a virtual factory. Additionally, the newly gained information can support the maintenance system.

From a technology supplier's view, we predict a growing market for new sensing and energy harvesting and storage technology that can withstand extremely high temperatures and other demanding environmental properties.

The approach of using online disposable devices as tracking devices will require cheap, small and robust technology.

5.4 Process Industry as an Agile Part of the Energy System

5.4.1 Vision

To make process industries a natural part of the energy systems to maximise the utilisation of energy resources and reduce environmental impact.

5.4.2 Description of Ideal Concept

With increasing energy prices and competition from non-European countries, utilising energy resources in an efficient way is already a crucial factor that will only become more important in the future.

By efficiently integrating the energy-intensive process industry with urban energy systems such as district energy systems and electrical grids, large-scale collaborative automation can be achieved with increased overall energy efficiency as the primary objective, see Figure 6. This will, however, require that the process and automation industry and the society at large invest in technology and infrastructure that can meet the requirements of tomorrow's energy systems and production facili-

ties. Where possible, the production rates will need to adapt to existing pricing circumstances (e.g., electricity, heat, fuel and raw materials).

To adapt production rates such that it matches and fulfil the energy requirements of the society in large, simultaneously as producing the orders in time, will require improved flexibility and adjusted production rates, either in time or in space (several production plants). In some cases, this may imply process overproduction capacity, leading to increased investment costs. Depending on future energy and raw materials markets, it may be beneficial for industries to endure overcapacity during time periods when pricing makes it unprofitable to produce and to compensate with increased production rates during periods when the circumstances are more advantageous.

5.4.2.1 Trends Supported by the Ideal Concept

- **Increased energy cost.** As the cost of energy increases, remaining competitive in a global market requires efficient energy usage. One step towards higher energy utilisation can be through a closer connection with other energy systems.
- **More restrictive environmental legislations.** To comply with national and international agreements on sustainability and the environment, process industries must continue to reduce their environmental impact. Selling excess energy increases overall energy utilisation.
- **Process industry as part of the smart energy system.** The clear distinction between energy providers and users will fade in favour of more integrated energy systems.
- **Dynamic disturbance management in production planning.** When excess heat is sold for district heating usage, thousands of homes, offices and industries can rely on this heat for space and tap water heating. This introduces an additional parameter to disturbance management and increases the requirements on disturbance handling and production planning.
- **Scope of automation is extended to enterprise systems. A System-of-Systems architecture is formed.** With more system-wide automation, energy supply and usage will be integrated in the large-scale automation and optimisation of process plants.
- **Increased complex regulations (environment and worker safety). More restrictive environmental legislation.** Regulation promotes higher resource utilisation and improved energy efficiency; to comply with these tougher regulations, an improved integration between industry and society with supervisory control will enable improved system efficiency.

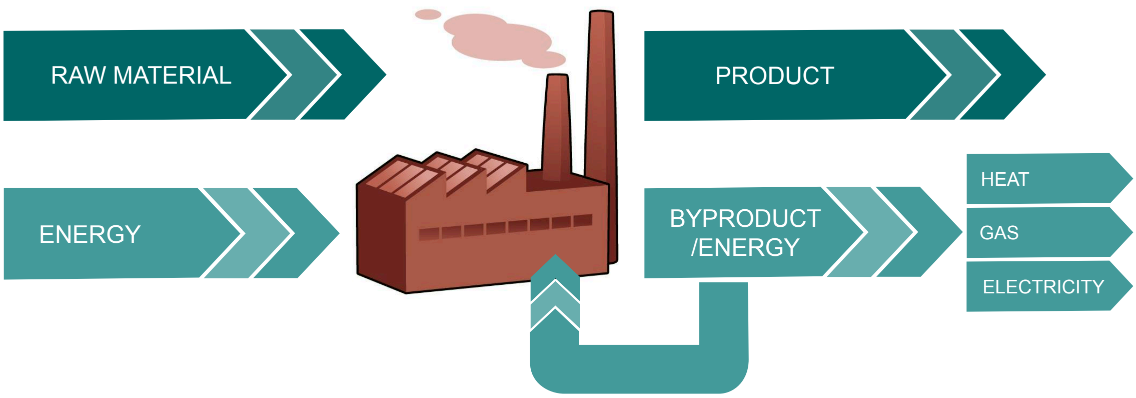

Figure 7: Energy and raw materials are the fundamental resources for producing the main product. Within the production process, excess heat and gas are often considered waste. Improved energy recovery and a better infrastructure for by-product energy usage, primarily gas and district energy systems can significantly improve resource utilisation.

5.4.2.2 *Visions and Long-Range Goals supported by the Ideal Concept*

- A well developed virtual factory.
- All purposes and multi-technology simulators. Extend the simulation model boundaries, e.g., include urban energy supply and dependencies, when simulating process plants.
- Virtualisation of the production chain as a tool to improve energy usage.
- Improved production efficiency by means of new technology and plant-wide optimisation. Reduce the use of fossil fuel and other non-renewal energy sources on a plant-wide level.
- Increased production; agility-enabling process industries to further integrate with society.
- Process understanding, operator training. Designers, engineers and operators must be aware of how their actions/work/methods affect energy usage.
- Influence the legislation design on a national and EU-level. Encourage legislators to include process and production industry in working towards a more energy-efficient society, and remind them of the great potential of large-scale automation where industry and society are integrated.

5.4.3 State-of-the-art Analysis

Large-scale process industries in Sweden and the other Nordic countries (excluding Norway) are often connected to district heating systems where excess heat can be sold as merchandise, thus creating a win-win solution for industry, energy distributors, customers, the environment and society. To increase the amount of "re-usage" of excess heat generated by industry in countries where district energy systems are not well-established, new infrastructure and distribution systems are required, and these industries may need to reconsider the production schedule to meet the energy needs of the customers.

An important factor that affects the excess heat value is the temperature of the heat. In current DH systems, the temperature must be at least 80°C to be considered useful. Next generation (4th) low-temperature district heating systems will support supply temperatures as low as 60°C, thus enabling more "low-valued" heat to be used for heating homes, offices and other buildings and saving more high-valued energy (like electricity) for other purposes. This support also implies that industrial plants that previously had low-valued waste heat can now contribute to the heating system and obtain paid for the heat they sell.

5.4.4 Proposed Actions

Today's process industry is a large consumer and producer in both thermal and electrical energy systems. However, as energy prices are expected to rise and fluctuate in the future, a more agile integration with existing energy systems is required to maintain competiveness with non-European countries.

To meet these requirements, a higher level of production flexibility is required from energy users and providers. Industrial control and planning systems must be adapted to meet short- and long-term variations in energy, fuel and raw material pricing while maintaining "societal" needs such as stable electricity, gas and heat delivery. We foresee that the integration of control, business, ERP, cap and trade and maintenance systems will be vital for reaching these goals, thus requiring more cross-domain communication between embedded systems with different application areas.

In countries where district heating is well established, there are great possibilities in further integrating industrial excess heat with available district heating infrastructure. In countries where district heating systems have not been applied on a large scale, significant investments in infrastructure (and possibly industrial reconstruction) will be required to capture and distribute the heat. To maximise the overall utilisation of energy and raw materials, an integration of control systems from various sectors is needed.

Industries must also be more agile and responsive to energy and raw material price variations. This will require new and improved automation and support systems to maximise overall plant efficiency and integrate it into the larger context of societal functions.

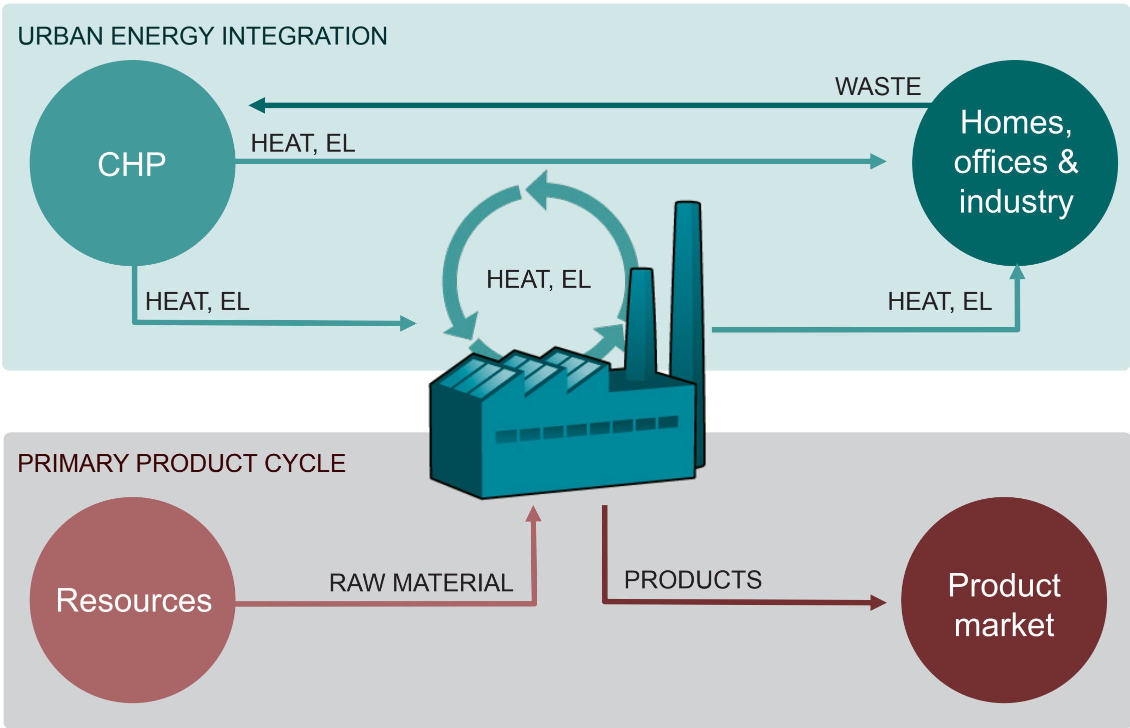

Figure 8: Collaborative automation, process industry as a central part of the future urban society.

5.4.5 Business Potential

Excess heat produced at process industries can be sold as a product to a much greater extent and has provided significant income for many process industries. This sales process does, however, require infrastructure in the form of district energy systems, along with the appropriate legislation and regulations.

The current usage of excess heat in district heating systems varies significantly among different European regions and countries; Sweden utilises the highest percentage of industrial excess heat in their district heating systems. However, even Sweden has the potential for a higher utilisation of industrial waste heat through lower system temperatures and "third-party access" to sell heat to existing DH systems.

In a future with increasing and fluctuating energy and raw material prices, automation and ERP systems that consider energy and raw material costs in production planning will be required to optimise system operations and maximise profitability. In cases where the process industry is also a major supplier of heat, gas or electricity to external customers, the automation and ERP systems must also consider side effects such as insufficient heat to district heating systems when moving production in time.

5.5 Management of Critical Knowledge for Maintenance Decision Support

5.5.1 Vision

The right information in the right form to the right people at the right time in the right place to support maintenance-related decision-making on different organisational levels and reliable KPIs for sub-processes.

5.5.2 Description of Ideal Concept

Maintenance relies on prediction and decision-making based on the available knowledge (including data and information). In practice, industry knowledge consists for the most part of predefined reports where the quality of data is unknown. Industry knowledge does not necessarily involve the person in the maintenance position with the information needs.

In most cases, the data from various sources are difficult to combine due to the format and communication used. Manually input data are usually not effective because they are non-standardised, making them difficult to use.

There is a need for knowledge management with evaluated data and information from both independent devices and information and automation systems (including information input by humans); simulation, prediction and scenario tools are needed. The critical evaluation of the data, information and knowledge is required in terms of both quality and availability. Low reliability results may affect one low quality source or several average level sources as a sum-effect. One essential feature is context awareness, i.e., serving personnel with and only with the right and correct information according to what they are doing and where in the factory they are.

The envisioned critical knowledge management system would provide the following advantages:

- Known quality of information
  - quality, availability, speed/real time.
- Use of only reliable data.
- Focus on critical data sources.
- Technologies to avoid "too" big data – ubiquitous computing (ES), IP.
- Ubiquitous self-diagnostics to avoid the use of low quality data from critical data sources.
- Combination of data from ERP, CMMS, sensors, automation…
- Personalised information according to type of user.
- Context awareness – only the information needed
  - e.g., personnel in the plant – only the nearby equipment to PDA.
- Tools for remaining useful life (RUL), simulations, and analyses.
  - Safe and fast evaluation/ prediction of maintenance activities and their timing.
  - Root cause reasoning and backtracking.
  - Safety analysis.
  - Optimisation.

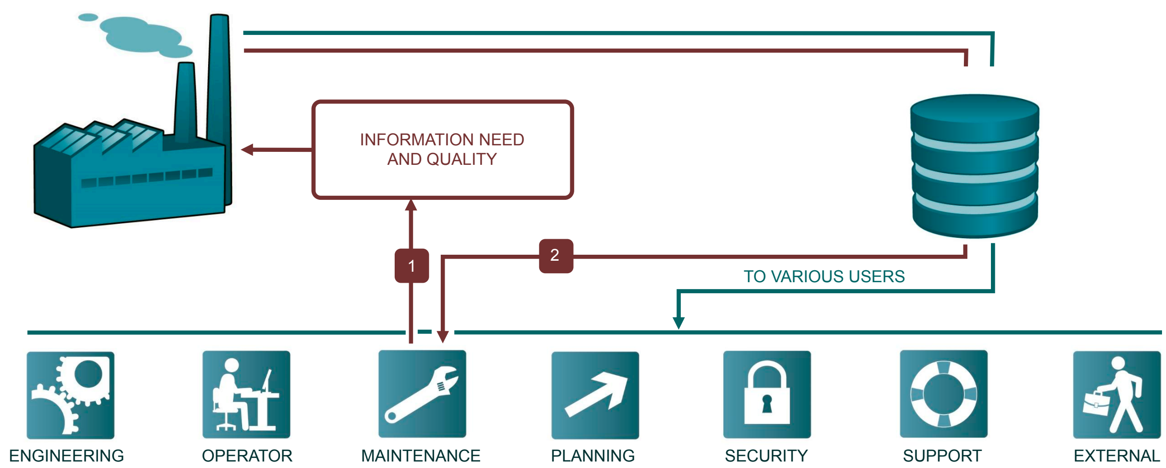

Figure 9: Practice today (blue line) and ideal case (brown line) of maintenance knowledge support in the industry.

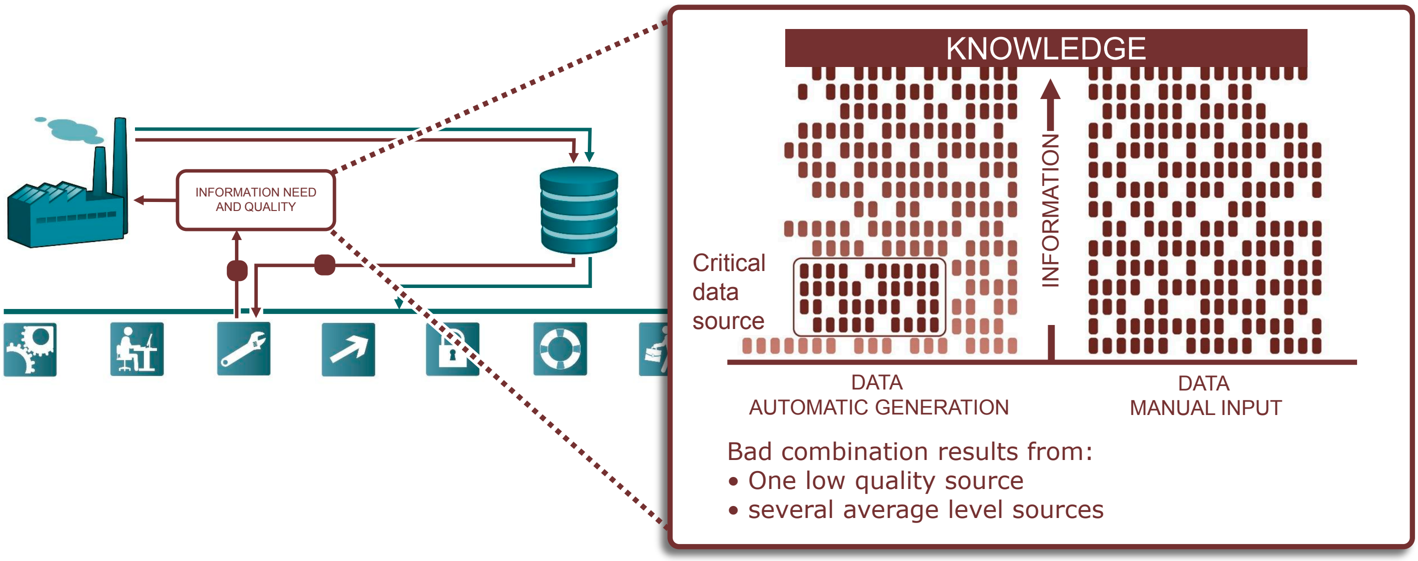

Figure 10: Evaluation of the criticality of data and information sources separately and combined.

5.5.2.1 Trends Supported by the Ideal Concept

Systems and methodologies enabling better maintenance support several existing trends, but do not solely enable them – many of the other ideal cases are required.

- **Growth without new heavy investments. Low capital-intensive technologies:** Transforming data into information.
- **Produce to order and not to stock (e.g., Vendor Managed Inventory, VIM). Mass customisation and tailor-made products. Dynamic disturbance management in the production planning. Shorter product life-cycles:** Better predictability enables the better management of disturbances.
- **Increased availability and uptime. Integrated production and asset management:** Preventive and predictive health monitoring using several data and information sources enables better planning and timing of maintenance, repair and renovation. Production and asset management are dependent on each other and should be optimised together (e.g., what is produced affects the remaining useful lifetime of a device).
- **Urbanisation affecting the onsite competence availability:** Decision supporting tools.
- **Aging factories highlight the importance of maintenance, repair and renovation to keep up with newer production plants in e.g. Asia and South America:** Preventive and predictive health monitoring using several data and information sources enable better planning and timing of maintenance, repair and renovations.

5.5.2.2 Visions and Long-Range Goals supported by the Ideal Concept

- **Increased productivity through improved ways of working:** Predictive maintenance to improve uptime and combined asset and production management.
- **Efficient data to information transition:** Various data sources are available and need to be quality-assured and combined. Tools to convert tacit knowledge to explicit knowledge and systems replacing the need of tacit knowledge and experience.
- **User-friendly design and operation of automation systems:** User interfaces are of the highest importance to ensure that personnel react to the information.

- **Improved production efficiency by means of new technology and plant-wide optimisation:** Plant-wide optimisation must consider asset management. Energy and raw materials losses and emissions are often the result of malfunctions.
- **IP based (soft) real-time services:** Decision-making and transforming data into information can be made on a soft real-time scale.
- **Access to user-friendly simulation models:** Prediction by using models.
- **Address context-driven critical information to the personnel in the factory:** Improved information targeting: the right information is presented to the right people in real time. The critical information is context-driven, including safety- and security-related information.
- **Well-developed predictive condition monitoring systems that detect machine degradation before they cause an increased security risk:** Balancing safety and production capabilities is part of a maintenance support system.

5.5.3 State-of-the-art Analysis

Many studies have been conducted regarding the Management of Critical Knowledge to support Maintenance Decision Making, but practical solutions involve only some features of the ideal case.

DYNAMATE – Dynamic Decisions in Maintenance – was a joint European research project. Within it some new solutions for smart tags (RFID), MEMS maintenance sensor platforms, online lubricant monitoring, mobile handheld maintenance computers (PDAs), wireless communications, condition monitoring, diagnostics, prognostics, cost-effective decision support and web services were developed. The results were integrated into a service called DynaWeb. There have also been other related European projects, e.g. Socrades, AESOP, eDiana, but to date, the results have not so far been widely adopted in the process industries.

On a practical level, the evaluation of information and data quality is primarily based on tacit knowledge among the personnel. The integration of data and information is limited by compatibility issues. The personalisation of information is not widely used.

5.5.4 Proposed Actions

To introduce the ideal concept of the Management of Critical Knowledge to support Maintenance Decision Making as an industry practice, several actions must be taken:

- To ensure the quality of data and information, the methodology for analysing data and information from various sources for criticality has to be developed.
  - Quality, availability, speed/real time.
- Ubiquitous computing technologies are needed to avoid "too" big data.
- Ubiquitous self-diagnostic methods and technologies help to avoid low quality data from critical data sources.
- Methods and technologies for the combination of data and information from various levels of the ISA-95 structure (e.g., ERP, CMMS, sensors, automation) for better diagnostics and production planning.
- Methods to personalise information according to the type of user.
- Technology for context awareness – only the information needed for the tasks.
- Tools for estimating the remaining useful lifetime (RUL), e.g. simulations and analyses.
- Enhancing the virtual factory model to address the maintenance needs.
- Technologies to support specialised remote maintenance services.
- Transformation of tacit to explicit knowledge to transfer knowledge before a large number of personnel retire in coming years.
- Development of maintenance service business models.

5.5.5 Business Potential

The business potential consists of several types of products, services and systems for several business sectors, including ICT, ES, devices, and services. The volume of process industry is high, both in Europe and around the world, which makes the business potential significant.

In the ICT, ES and electronics businesses, the development of intelligent ubiquitous sensors is needed. The intelligence should cover self-diagnostics, data evaluation and refinement of data locally. Systems and devices that support context awareness must be developed to meet the challenging environment. In the SW and ES sector, tools are needed to support the integration of data and information. The systems producing the data and information that need to be integrated varies among factories. Even if the developed technologies are widely compatible, consultancy and tailoring will form a large market.

Some simulation tools exist, but they should be further developed, as there will be a growing market in coming years. In summation, industrial maintenance will be a growing market for specialised, often remote services.

5.6 Automation Service and Function Engineering

5.6.1 Vision

Industrial process automation service and function engineering that is capable of meeting the challenges from globalisation and technology trends.

5.6.2 Description of Ideal Concept

Function development processes, such as the V-process (http://v-modell.iabg.de), have been used for over a decade as a method and "way of work" to provide quality-assured function and service solutions in different industry sectors (e.g., defence, telecom and automotive). The backbone of the V-process is a model-based design (MBD) approach that uses various tools at different stages of the development process. Examples of tools used today are software-in-the-loop (SIL), hardware-in-the-loop (HIL), automatic target code generation and a variety of systems engineering tools for requirements management. Today, this work method is also used in the development of industrial process automation services and functions, though its implementation is not as profound as in other industry sectors. It is not easy to find examples of large process industries that routinely utilise a model-based development process for the verification and validation of the functionality of DCS systems.

The engineering skills of European companies, ranging from SMEs to large global companies, must continuously improve. One of the drivers for this development is the ongoing market expansion outside Europe (SMART study), where engineering skills and proven work methods will play a vital role in the process of building customer trust and meeting increased competition. This is of special importance because it is foreseen that potential future exports fall within the area of high-tech service and software solutions. Some examples are subsystems to highly integrated solutions, e.g., intelligent HW, tools and methods for data presentation and analysis, monitoring and maintenance software, operator training platforms, and other types of tools and services used to operate and optimise the OEM business. Critical technology enablers for this type of development are, for example, system-of-systems, networked services, collaborative automation, open source, and web-based marketplaces. These technologies all support the development, distribution, implementation, and payment for services and software, see

This ideal concept shows that the development process and the engineering tool chain must adapt, harmonise, and (in some situations) even fundamentally change to secure competiveness for the development of globally attractive industrial automation process products, see Figure 11. Another purpose of this ideal concept is to focus on the fact that the complete value chain must adapt and introduce an interoperable development process (and use interoperable tools) for Europe to maintain its leading position. It is impossible to cover the complete scope and every aspect of the engineering process, but given the timeframe of the roadmap, some of the main trends and visions are listed below.

5.6.2.1 Trends Supported by the Ideal Concept

- **Increased integration of production and business operations. Optimisation through cross-layer integration:** Integration requires a well-designed engineering process.

- **Process industry as part of the smart energy system:** Integration requires a well-designed engineering process.
- **Rapid technology adaptation (e.g., spare parts, new technology introduction).** Adds requirements to the engineering process (e.g., the ability to make changes and verify and validate them). Continuously strive to reduce turn-around time with improved quality.
- **Increased focus on the life-cycle for managing the automation system:** It is not possible to achieve adequate life-cycle management without the support of an engineering process and tools.
- **Scope of automation is extended to enterprise systems forming a System-of-Systems architecture:** Integration requires a well-designed engineering process. Tools for large-scale modelling and analysis must be developed.
- **Service-oriented architecture technology moves from enterprise-level to field-level devices:** Additional requirements on SW and HW (e.g., safety argument) that needs to relate to an engineering process.
- **Increased complex regulations on the environment and worker safety:** Generating a safety argument will relate to the engineering process.
- **Increased complexity of development requires involvement from different competencies and thereby extends the value chain:** Ways to cooperate.
- **Aging factories highlight the importance of maintenance, repair and renovation to keep up with newer production plants in Asia and South America:** Efficient ways of working, increased uptime, increased availability, and new tools are needed to stay competitive.
- **Increased regulation complexity. More advanced automation and measurement systems are required to fulfil the requirements:** Generation of a safety argument will relate to the engineering process.
- **Mass customisation:** Decreased turn-around time, i.e., shorter available time for testing, verification and validation. Need to do it right the first time.

Figure 11: Examples of foreseen new drivers in terms of technology that will affect the engineering of new services and functions for industrial process automation.

5.6.2.2 *Visions and Long-Range Goals supported by the Ideal Concept*

- **Increased productivity from improved ways of working:** Quality-assured services and functions.
- **Global access and distribution of automation services:** A well defined and transparent engineering process will build customer trust and enable fast responses to new market requirements.
- **Improved production efficiency by means of new technology and plant-wide optimisation:** Upholding production efficiency over the plant's life-cycle requires a well-defined engineering process.
- **Increased production agility, enabling process industries to further integrate with society:** The engineering process is one part of proving system safety at integration.
- **Adoption of Internet of Things technology in automation and maintenance systems:** The implementation of IoT focuses on the development process (i.e., validation and verification).
- **Collaboration for mobilisation of R&D resources between company sites and universities. Creation of open research development and innovation environments:** Common understanding and implementation of the engineering process.
- **Requirements management to secure the interface between client and recipient:** Common understanding and implementation of the engineering process.
- **The safety and security aspects must be integrated in the simulation models to enable risk evaluation in the design phase and during operation:** A natural part of a well-designed engineering process and tool chain.
- **Safety- and security-related tacit knowledge among the personnel are systematically captured and converted to explicit knowledge among the employees:** A natural part of a well-designed engineering process.
- **Secure operation using intrusion detection and prevention systems:** A well-designed engineering process is required for fast and correct responses.
- **Increased agility and flexibility of production processes:** Process that allows modifications and redesign.
- **Achieving a dynamic combination of competencies and continuous knowledge of entities:** Bringing them together in a common engineering process.

5.6.3 State-of-the-art Analysis

In many industry sectors, a development process that relies on a model-based design principle has been in place for many years. In the field of industrial process automation, the model-based design principle is well-developed for geometrical design (CAD, PDM), but there is a clear lack of implementation in the function and service development processes, e.g. systematic handling of requirements, development, and verification and validation.

Today, functionality is specifically designed for one HW platform, using tools and development environment specifically designed for that particular HW platform. Often this "lock" occurs early in the development phase. This approach reduce the possibilities for suppliers to deliver products to multiple platforms mainly due to increased cost for handling product (SW) variants. Plant owners have reduced possibilities to source SW and HW suppliers and the existing functionality is impossible to transfer between platforms in a cost efficient way (at for example system upgrades). The preferred solution would being generic and possible to integrate on multiple platforms, which would reduce development cost and increase flexibility and improve the competitiveness of suppliers.

5.6.4 Proposed Actions

- ***Becoming a supplier of functionality for systems-of-systems:*** A key enabler for becoming a selected supplier of functionality is demonstrating and ensuring full and safe operation in a complex environment. **Model-based development** and the possibility of configuring a solution to many software and simulation platforms are of high importance. **Automatic target code generation** and **open simulator platforms** are critical technical enablers.

- *Responsibility definition:* Traditionally, hardware and software have had separate sources, i.e., one company provides the hardware, and another provides the software used to control the hardware. The ongoing trend outsources functionality and the customer requires the best performance in every aspect. This typically leads to a development process involving even more partners, making it likely that responsibility issues will arise and become more complicated when the number of partners and level of interaction increases. The remedy for this is to implement requirements management, flexible testing and modification routines, and a model-based framework over the entire development process. Flexibility and adaptation to changes are not typically handled correctly in the much-used V-process.
- *Designing verification tests for complete systems:* The responsibility for the integration tests of complete systems will always lie with the producing unit because they have the safety responsibility for their workers and the quality responsibility for their customers. Integrations tests are necessary to develop and apply new ways of handling requirements at an early project stage. The generation of subsystem verification tests must be transparent through the value chain to enable the generation of complete system verification tests. At the detection of a fault, it must be possible to backtrack the source of the fault and verify the remedy with as little manual work as possible. It is foreseen that verification tests will be done in a model-based way with strong backtracking possibilities to requirements.
- *Required engineering tools to support the engineering process:* The development and usage of engineering tools is an area that is growing fast. Some of the most important future focus areas for industrial process automation include the following:
  - Open simulator platform: To increase interoperability and cost-efficient model management over the entire life cycle. This is an important enabler for model-based design.
  - Optimisation on a plant-wide level: New findings in optimisation theory have opened the possibilities for performing large-scale optimisation for set point control.
  - Optimisation of control structures on a plant-wide level: The field of plant-wide control addresses the question of what to control and what to measure for optimal plant performance. No currently available commercial tools can perform this task.
  - Instant access to virtual factory: Online commissioning of virtual factories is a key for the successful usage of models in an organisation and for the life-cycle management of models. The benefits and drivers are discussed in the ideal case: Instant Access to Virtual Dynamic Factory.
  - Target Code generation: Automatic target code generation is used in many industry sectors (automotive and defence industries) as a means to minimise programming effort and human errors during code changes or when changing the hardware (e.g., processor). The usage of automatic code generation is very low in the process industry (if it exists at all!), and all generated code is made for one particular hardware platform. Automatic code generation is a topic that needs further research, development and implementation into the entire value chain of industrial process automation. Much of the development should carry-over from other industry sectors.
  - Model-based safety analysis: Tools that make use of existing process models and target codes to perform risk and hazard analysis.
- *Interoperability of the virtual plant and component models at all development stages:* Interoperability is important for successful model-based development. An open simulator platform, as discussed in other sections (ref), will enable full interoperability.

- *Safety, security, and trust for solutions provided via collaborative automation and networked services:* Key enablers are a well-documented development process and provide the ability to demonstrate functionality prior to implementation, i.e., in a virtual surrounding.
- *Faster introduction of devices, e.g., Internet of Things:* It is foreseen that the introduction pace of new intelligent devices (e.g., sensors) will continue to increase with, for example, the introduction of Internet of Things and machine-to-machine communication. This will increase the requirements on the engineering process, where a model-based development is required together with the verification of functionality, safety, and security before commissioning.
- *Design and debugging ecosystems:* The development of engineering tools and processes should strive for open-source architecture to promote and enable new innovative products. The challenge is to achieve this development in such a way that even safety-critical functionality can be developed and designed in an open source environment.

5.6.5 Business Potential

Engineering processes and tools that fulfil the requirements originating from technology trends will become an enabler for successful product development and the generation of new business. Except for delivering well-functioning and verified solutions, the engineering process will be such that it clearly contributes to the process of building and maintaining customer trust.

Tool and process interoperability will make it possible to always choose the best possible suppliers in an easier and less time-consuming way than currently supported. This will improve OEM operations and enable suppliers to enter new markets.

5.7 Open Simulator Platform

5.7.1 Vision

To optimise the efficiency of simulation-based development through full interoperability between simulation tools over the complete development process.

5.7.2 Description of Ideal Concept

Enhanced learning and improved decision-making processes for the different parties involved in engineering are some of the primary drivers for developing simulation technology. In the future, dynamical simulation technology will be used daily throughout the engineering life-cycle (e.g., research and development, marketing, concept study, detailed design, testing, operation, product updating, problem solving, maintenance, operator training). It is foreseen that the model of the future simulation business will not be based on separate simulation platform licenses but rather on simulation components, model configurations and services on top of open and modular operating simulation systems.

The complexity of multi-disciplinary computer simulation requires integrated methods with transparent interfaces. There is also a growing need for the use of intelligent systems and adaptive processes; such needs are common to most problems in computational engineering. It is expected that a common platform that enables the development of commercial tools and interface connections to various application-specific programs will lower the threshold for developing effective 'shareware' modules for different users while enabling other features to be added to coupled models, see Figure 11.

5.7.2.1 Trends Supported by the Ideal Concept

- **Growth without new heavy investments. Low capital-intensive technologies:** An open simulator platform provides possibilities for generating new services in a global market.
- **Increased integration of production and business operations. Optimisation through cross-layer integration:** From a method and solution point of view, this means integrating a variety of simulation models.

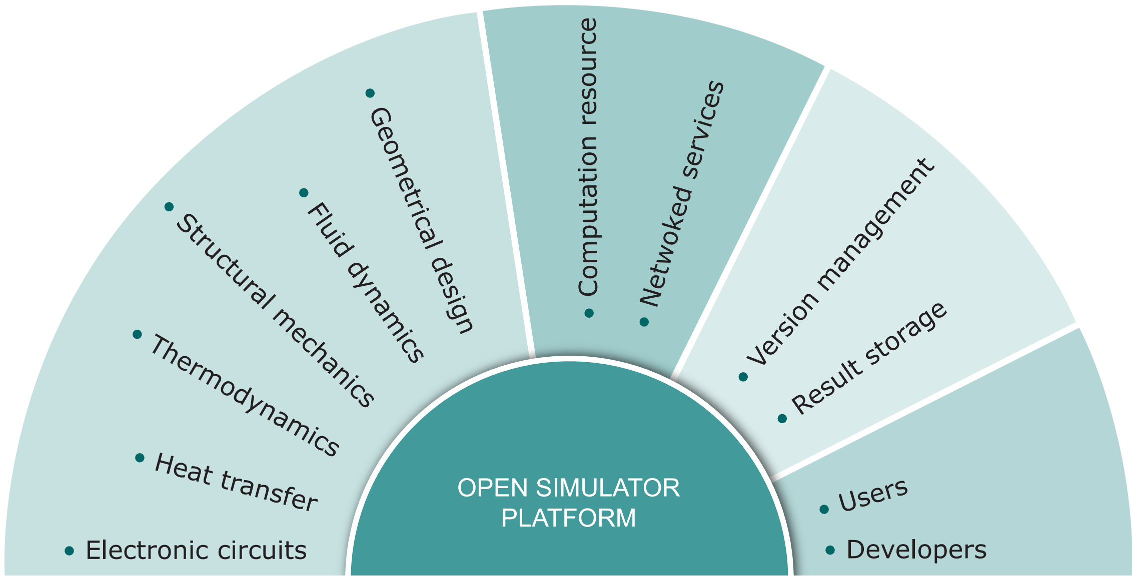

Figure 12: Different aspects of an open simulator platform in terms of human interface, virtualisation, data management and computation.

- **Rapid technology adaptation (e.g., spare parts, new technology introduction):** It will be possible to handle many model sources.
- **Increased focus on the life-cycle for managing the automation system:** An open simulator platform serves as an integration platform for the virtual factory.
- **Increased complex regulations for the environment and worker safety:** A framework to handle various simulation models and simulation views is needed.
- **Increased complexity of development requires involvement from different competencies, thereby extending the value chain:** A shared virtual representation will clarify and reduce potential misunderstandings (e.g., compare to CAD for geometrical virtualisation).
- **Increased regulation complexity. More advanced automation and measurement systems are needed to fulfil the requirements:** Building a safety argument will be performed in a model-based development process that requires a framework for operating of a variety of models.

5.7.2.2 Visions and Long-Range Goals supported by the Ideal Concept

- **Well-developed virtual factory:** The need for virtualisation will continue to grow and a platform for model and user management is required. The life-cycle and quality management of models is of special importance.
- **Increased productivity from improved ways of working:** Model-based development is the foundation for improving ways of working. An open simulator platform is an enabler for efficient model-based working. There is a significant potential for improving the process by using the same platform from concept study to aftermarket.
- **Global access and distribution of automation services:** Generation of new services based on (or in) a simulator platform.
- **Virtualisation of the production chain as a tool to improve energy usage:** Energy usage in a production unit is built from a variety of different supplier systems and processes that result in a variety of virtualisations that must be brought together in a simulator platform.

- **Access to user-friendly simulation models:** A simulator platform should support organisation-wide virtualisation, bringing simulations into everyday engineering. Reduce the gap between real and virtual.
- **Collaboration for mobilisation of R&D resources between company sites and universities:** A platform for cooperation.
- **Efficient automation engineering and collaboration characterised by model-based engineering, reusability, and requirements management:** Tools are necessary to manage a model-based development process.
- **Communication and virtualisation are key technologies for achieving a well-functioning distributed production process:** A common design platform is required for collaborative automation.

5.7.3 State-of-the-art Analysis

Co-simulation through various integration protocols and methods has been used in the industry to achieve simulator interoperability. The setup typically requires large amounts of manual work in terms of simulator interfaces to achieve numerical stability. Furthermore, the parameterisation is often based on completely different data sets for each model, resulting in the low interoperability of the models.

It is very common today for different models to be used at different stages of the development process, e.g., dynamic models that are implemented in different tools that do not integrate with CAD and PDM systems.

Several initiatives have developed a simulator platform, including the following:

- A semantic open-source platform consisting of a semantic database and a client SW based on the Eclipse framework. Developed by the Finnish technical research centre VTT, current users are Finnish nuclear power producers.
- Salome open source platform, originating from French industry. Focuses on the interoperability between CAD, FEM, and CFD modelling.
- CAPEOPEN: provides model exchange and co-simulation and is used by Aspen Tech, Honeywell and BP.
- Functional mock-up interface similar to CAPEOPEN originating from the Modelica community. Developed in the ITEA2 Modelisar project. Primary focus is on the automotive industry.

The industrial usage of open simulator platforms that couple all necessary steps for virtualisation over a product or service life-cycle is rather low; significant development effort is still needed.

5.7.4 Proposed Actions

- Seamless support for simulation at different levels (i.e., conceptual-level simulation at the beginning of the product life-cycle, more detailed simulation in later phases) and seamless switching between these levels.
- There should be a way for software component-based simulations (i.e., model algorithms) to be developed, added, removed and changed at runtime as part of a larger model.
- Support for multi-domain and multi-physics simulations.
- Model configuration must be neutral, i.e., it should not be simulation tool-specific.
- Need for distributed simulation model configuration and usage, including version and access control.
- Simulation data visualisation using suitable and modern methods of computer graphics (two-dimensional, three-dimensional, and augmented reality) should be common for different models and different levels of details. In this way, the results from these models can be visualised in a common and intuitive way.
- There should be better links from simulators to different engineering applications or tools. This is the only way to make simulation part of everyday engineering.
- Support for validation and verification of simulation models should be a built-in feature within a modelling and simulation framework.

- There should be general, unified model composing and modification tools for different background tools.
- Runtime adaptive tools should be available for high-level component modelling, meshing, model topology editing, and simulation management.
- The simulation system should provide a seamless exchange of model and simulation results data between different modules in the simulation process.

5.7.5 Business Potential

Quality of work and knowledge management for improved plant performance and product offering.

- Tool interoperability will integrate, hasten, and assure the different stages of the development process.
- Interoperability enables companies to always choose the best available simulation tool without "losing" or translating previous development.
- The need for calibration and verification data is continuously increasing. Collecting, quality assuring, and distributing data to various stakeholders (users) is therefore an essential part of a successful simulation framework.

5.8 Automation System for Flexible Distributed Production

5.8.1 Vision

To have production capacity "anywhere for anything" to meet the rapid fluctuations in production requirements in a cost-efficient way.

5.8.2 Description of Ideal Concept

In early days of process automation, the goal was to distribute the feedback control and calculation to separate computing units and simultaneously centralise the monitoring and management into control rooms. That concept proved to be efficient because the efficiency of the manpower increased. Even though there are still challenges within local automation systems to solve, competitive advantage is today often approached by satisfying customer requirements in a more timely fashion.

As a consequence of this development, industries are experiencing volatile demand, fierce competition, and innovation pressure. They have responded by shortening life-cycles and decreasing time-to-market, both of which require flexible production. Industries are moving away from bulk production towards tailored customer-specific products (batches).

To increase flexibility, the requirement for advanced automation, specialised personnel and shorter set-up times at each plant must increase. In other words, the importance of automation increases.

Flexibility can also be obtained through economy-of-scale. If the company has several plants and each plant has a different product portfolio, the company is able to flexibly adapt its offerings. Traditionally, economy-of-scale has been understood as a means for decreasing the share of fixed costs, thus decreasing unit costs. In the future, economy-of-scale will also mean increased flexibility.

Despite this new meaning of economy-of-scale, resources must still be acquired globally. The global simultaneous presence in several markets, the global acquisition of resources and sourcing of raw materials from global sources are all challenging management issues. A company must operate and (at least partially) be managed locally by considering local regulations and culture. From an international company viewpoint, this implies distributed management. However, the company should still be centrally managed to obtain the benefits of economy-of-scale.

While increased automation can provide more information about production, production costs and resources, flexibility can be increased through promoting economy-of-scale. In the future, new players such as venture capitalist (VC) firms can play a more important role in these industries. Automation can enable further development and greater flexibility can attract VCs into manufacturing industries.

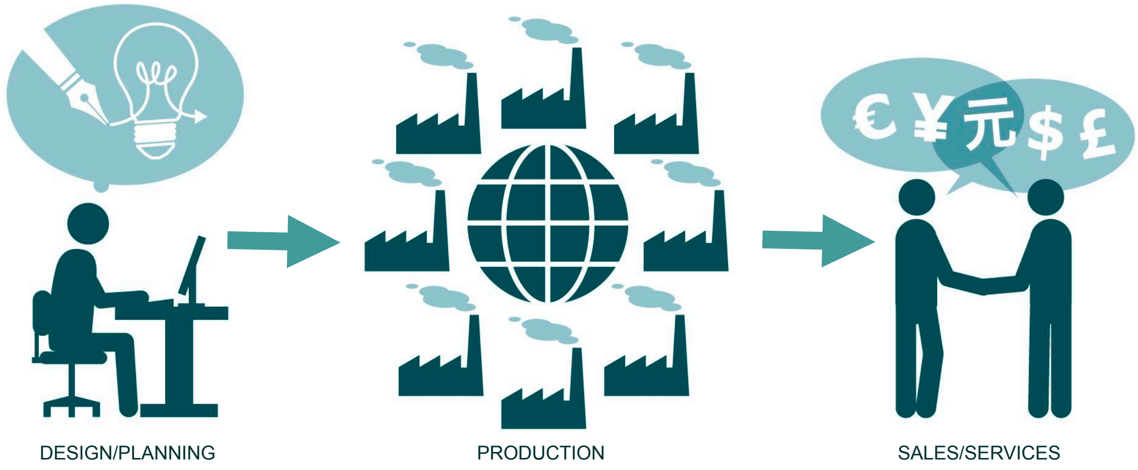

Figure 13: Distributed production.

5.8.2.1 Trends Supported by the Ideal Concept

- **Produce to order and not to stock (e.g., Vendor Managed Inventory, VIM). Mass customisation and tailor-made products. Dynamic disturbance management in the production planning. Shorter product life-cycles.** The trend towards customised tailor-made products limits the production of large stocks of products; more rapid and agile production is required.
- **Increased integration of production and business operations. Optimisation through cross-layer integration.** With improved ICT-solutions, a more direct connection between production and business emerges, thus enabling cross-layer integration and production optimisation between geographically distributed production facilities.
- **Increased availability and uptime. Integrated production and asset management.** The importance of production availability and uptime increases with global competition. A reliable and integrable automation system will be of increasing importance.
- **Scope of automation is extended to enterprise systems, forming a System-of-Systems architecture.** With cross-layer communication and the introduction of service-oriented architectures, an automation system can expand towards an enterprise-wide system with several subsystems.
- **Production becomes more geographically distributed, requiring advanced communication solutions.** Production is becoming more distributed within large enterprises. Continuing in this direction requires interoperable and integrated ICT-solutions compatible with the Internet.
- **Increased production.** Production off-shoring requires well-functioning ICT-solutions and remote operation equipment.
- **Design anywhere, produce anywhere.** With an increasing amount of off-shored production facilities, product design and composition must be remotely controllable.
- **Expansion in transportation sector provides efficient trading conditions.** Efficient transportation is one of the keys for enabling distributed production.
- **Increasingly volatile market demand combined with fierce competition.** The rapid changes in market demands require flexible production facilities that can quickly adjust production volumes and adapt products according to these market demands.
- **Mass customisation.** The trend towards mass customisation of products increases as each customer requires products with special characteristics. Flexible production lines and dynamic automation systems are key elements in meeting this demand.

5.8.2.2 *Visions and Long-Range Goals supported by the Ideal Concept*

- **Well-developed virtual factory:** Management of distributed production is foreseen to relay on a model-based framework.
- **Increased productivity through improved ways of working:** Scaling production capabilities in the most efficient way for increased productivity.
- **Higher degree of IP-enabled devices to support cross-vendor and cross-level communication:** Better information access solutions are needed to implement dynamic and flexible production.
- **Global real-time access to all devices at field and automation level:** Access to information is needed to implement centralised and flexible production.
- **Collaborative automation using networked services.**
- **Increased agility and flexibility of production processes.**
- **Orchestration and portfolio management to control and optimise what and where to produce.**
- **Communication and virtualisation are key technologies for achieving a well-functioning distributed production process.**

5.8.3 State-of-the-art Analysis

In general, today's implementation of automation solutions relies heavily on the versions of automation systems that replaced manual solutions. New automation functions are primarily generated by configuring the parameters of standard control structures. This approach has a clear lack of flexibility and was designed to provide automation implementations that, once generated, can and should remain unchanged over the life-cycle of the production process.

To improve the flexibility of the production process, recent developments have focused on the integration of digital control loops with both production management systems and planning systems. These development principles are primarily adopted from the field of information sciences (especially from the software industry) and their application to mechatronic units.

However, the currently available methods are not flexible enough to provide cost-effective automation solutions for rapidly changing value chains and market demand.

5.8.4 Proposed Actions

- Development of principles and methods to automatically generate the requirement specifications for distribute automation systems.
- Methods for automatically generating cost-effective temporal solutions for the rapid replacement of production units and their respective roles that are not stable but dynamically evolve.
- Automatic reconfiguration of the aforementioned unit interfaces (i.e., venture capital-owned companies can quickly respond through automated solutions).

5.8.5 Business Potential

Providing decision support tools at different organisational levels within an enterprise (and among a network of companies) to increase flexibility and adaptation of production will create new business potential, both from a system supplier and process industry point of view.

- Attract new customers by achieving shorter delivery and higher production rates.
- New automation system technologies will generate new business opportunities for automation suppliers and system integrators.
- Higher equipment utilisation, new tools and automation systems will enable better production prediction possibilities.
- Providing services in model-based simulations and prediction with multiple scenarios.
- Enabling tools for global service providers for remote operation, monitoring, managing, audit and approval.
- Providing common communication platforms for sales and production: sales can predict resource usage while production can provide timely delivery estimates.

5.9 Balancing of System Security and Production Flexibility

5.9.1 Vision

To ensure production availability, plant safety and supportive advanced risk management through system-wide information assurance, data validation and reliable communication.

5.9.2 Description of Ideal Concept

The ideal concept target is to improve process uptime, reliability and safety through secure and redundant information exchange in the context of next-generation system-wide flexible control, maintenance and support systems.

Information integrity and assurance are vital for establishing reliable production, thus avoiding the production interference that can limit production volumes and affect operational safety. New technical approaches/paradigms such as Internet of Things and Service Oriented Architecture can enable improved functionality, operational flexibility and system overview. However, the principles of these architectures make more devices available online and increase their exposure to possible threats. To ensure reliable production using the abovementioned technologies, secured communication channels becomes increasingly important, as more of the process control and management systems will be accessible online and therefore exposed to hacker attacks and other external or internal threats. Some of the more prominent system security challenges include:

- Confidentiality
- Authentication
- Integrity
- Freshness
- Availability
- Robustness
- Resiliency
- Energy efficiency
- Assurance
- System scalability.

Ensuring safe operation and high dependability requires the identification, verification and validation of both measurements and sensor reading. An advantage of service-/SOA-based systems is that more advanced information verification methods can be implemented as they are needed without expensive additional hardware. In the ideal concept, new technology (including IoT and SOA) will enable more advanced verification and redundant functionality. In addition, the communication to each connected device will have a security profile (including cryptography and intrusion detection mechanisms) that minimises intrusion possibilities (intentional or unintentional).

As system flexibility is increased to improve production efficiency, safety and security risks are also increased. Maintaining safety and security risks at present levels (or even reducing the risks resulting from increased system flexibility) requires that security aspects are evaluated and considered throughout the system design and implementation process. Supportive risk management tools might include models supporting risk evaluation and hazard analysis. During long-term process operations, the performance of the process may change due to the degradation of components or changes to control parameters, resulting in an invalid initial hazard analysis. An automatically updated and continuously executed hazard analysis could be a powerful tool for improving system safety and ensuring secure process performance.

5.9.2.1 Trends Supported by the Ideal Concept

- **Increased integration of production and business operations. Optimisation through cross-layer integration.** The access to devices and systems throughout an automation system increases the possibilities for risk management at the system level.
- **Increased availability and uptime. Integrated production and asset management.** Increase the uptime by guaranteeing access to required data and information. Information assurance will provide information that can be used to analyse system status and support asset management.

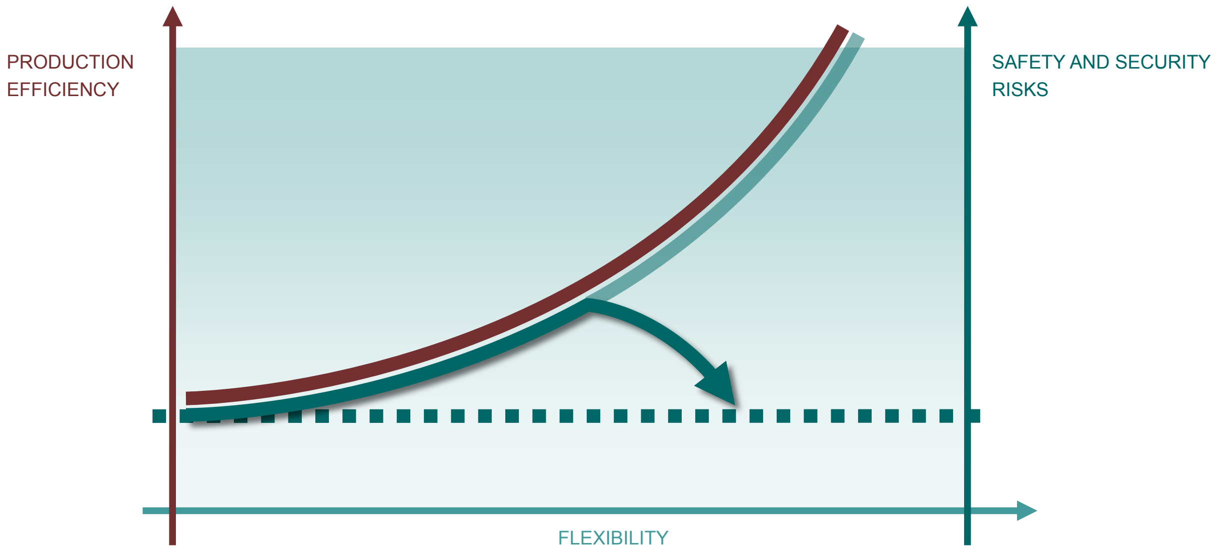

Figure 14 : Increased production efficiency can often be achieved through improved system flexibility (green line). As a result of increased system flexibility, safety and security risks also tend to increase. This indicates the importance of including security aspects in an early stage when designing future generation flexible automation systems.

- **Rapid technology adaptation (e.g., spare parts, new technology introduction).** The security properties of new components must match available security levels while not compromising system security and safety.
- **Fast degeneration of performance for advanced process automation solutions.** The degeneration resulting from the combination of poor maintenance and upgrading of automation systems can affect the reliability and security of the system.
- **Scope of automation is extending to enterprise systems. A System-of-Systems architecture is formed.** To support System-of-Systems architecture, security profiles must be compliant with large-scale deployment and cross-domain communication.
- **Open innovation environment.** To achieve a shorter "time to market" for new security enhancing methods and technologies, an open environment between universities, research institutes, industries and standardisation organisations is desirable.

5.9.2.2 Visions and Long-Range Goals supported by the Ideal Concept

- **Collaboration for the mobilisation of R&D resources (e.g., between sites and universities).** Establish standards and collaboration initiatives for developing safety and security in emerging technologies.
- **Well-developed virtual factory.** The virtual factory will be an important tool for ensuring safe operations with changing product requirements and process adjustments.
- **Collaborative automation using networked services.** The degree of safety and security differs between levels of an organisation and even more so between companies and organisations. When establishing cross-level automation, safety and security issues must be addressed to ensure reliable operation for all parties.
- **System integration through zero-configuration.** The safety and security aspects must be included in any zero-configuration approach. Zero-configuration integration should also reduce implementation and configuration errors.

- **Service Oriented Architecture in lightweight Internet of Things devices.** The envisioned increased use of IP-based light-weight systems in the field of automation will enable the proper use of well-established security mechanisms. A Safety Integrity Level (SIL) classification of new systems and devices might introduce compatibility issues that must be addressed.
- **Increased knowledge of the automation profession.** The need for expertise in the field of security and risk management for automation systems is predicted to increase. To provide this expertise, more attention must be paid to automation-related education and training.
- **Information assurance mechanisms using intrusion detection, data verification and encryption.** Information security is highly important for establishing highly reliable systems that can be safely classified.

5.9.3 State-of-the-art Analysis

New tools for risk management and hazard analysis are required to ensure a secure process operation at a high level of flexibility.

In today's industrial automation systems, the end devices are often communicating through 4-20mA vendor-specific buses or other proprietary solutions, mostly without any active security mechanisms. An increasing number of sensors are currently equipped with wireless communication units. These wireless links introduce new vulnerabilities in the information flow where sabotage and hacking can occur. As more low-level devices become accessible online over wireless links, the possibility for system interference will increase. Methods to support intrusion detection and intrusion prevention will play an increasingly important role maintaining high system reliability.

Providing security in automation systems consisting of light-weight networked embedded devices (e.g., Cyber Physical Systems or CPS) involves issues beyond today's security systems for enterprise and desktop computing. Energy and bandwidth limitations introduce additional boundaries to the security mechanisms that must be addressed.

5.9.4 Proposed Actions

Tools and methods for emerging technical approaches within process automation must be provided to assure system reliability, security and safety. Without these tools, the adaptation of new technology will meet significant resistance from industry because systems are required to work without unplanned stops and downtime is very costly. In many cases, reliability and security also affect system safety, further consolidating the need for online hazard analysis tools.

To achieve both high production system flexibility and low safety and security risks, future systems must be able to detect e.g. tampered devices and cyber-attacks quickly to prevent financial losses or reduced safety or risk severe accidents. Intrusion detection and prevention systems, suitable cryptography methods and automated fault detection to ensure information integrity and data validation are examples of required actions that are vital for merging system flexibility enhancing technologies with industrial markets.

5.9.5 Business Potential

In order for new key enabling technology to achieve large-scale acceptance within the process industry, the systems must prove that they are secure and can support safety standards required by legislation and company policy. Many of the technical approaches involving Internet of Things, Collaborative Automation, System-of-Systems and Service Oriented Architecture will not achieve significant industrial influence unless the security and reliability of these systems can be demonstrated.

Ensuring secure production is thus not only vital for the security suppliers but also for all of the systems that require safe and secure operation.

New communication and architecture concepts (including IoT and CPS) will provide higher flexibility; however, new intrusion possibilities will emerge as more devices will be available online and vulnerable to online attacks. Reliable security mechanisms are vital to make Internet-enabled devices (whether CPS or networked embedded devices in automation systems) achieve acceptance within the industry; there is great market potential for robust security solutions.

6 CONCLUDING WORDS

To meet increased global competition, overall equipment efficiency, increased sustainability and competence management are all important challenges to the process industry. In this roadmap, we have envisioned ideal concepts to meet some of these challenges with concrete examples.

It is clear that new information and communication technologies and automation systems will play an increasingly important role in future process industries. Technical solutions and methods that have been highlighted in this roadmap to be of high importance include the following:

- Collaborative automation using cyber physical systems.
- Real-time accessible dynamical virtual factories.
- Cross-operation of maintenance and control.
- Standardisation of network communications and increased information transparency.
- Adaptation of Internet of Things technology to support distributed production.
- Standardise software, hardware, and development platforms to reach a larger market with less costly customisation.
- Better utilisation of exce}ss energy from the process industry.

A closer integration of process industries and urban society will support the development of the sustainable cities through better resource utilisation and increased overall energy efficiency.

The competence distribution among employees to guarantee that core knowledge remains accessible for a company will become even more important with globalisation and increased competition.

Ensuring the future supply of competence and expertise to the automation and process industry is also a crucial task in maintaining Europe's strong position in the process industry field.

For further clarification on how industrial automation can contribute to the ongoing and envisioned trends within process industries, see chapter 3; a set of ideal concepts were created and shown in Figure 3. The nine ideal concepts are presented without an internal priority order in chapter 5. Based on these nine ideal concepts, three primary project tracks were realistically considered to be addressed by 2020; they are presented in Figure 14 and consists of multisite, single site and tools methods and competence management project tracks.

Our expectation is that this roadmap can be used as inspiration for future research and project ideas in the field of industrial process automation.

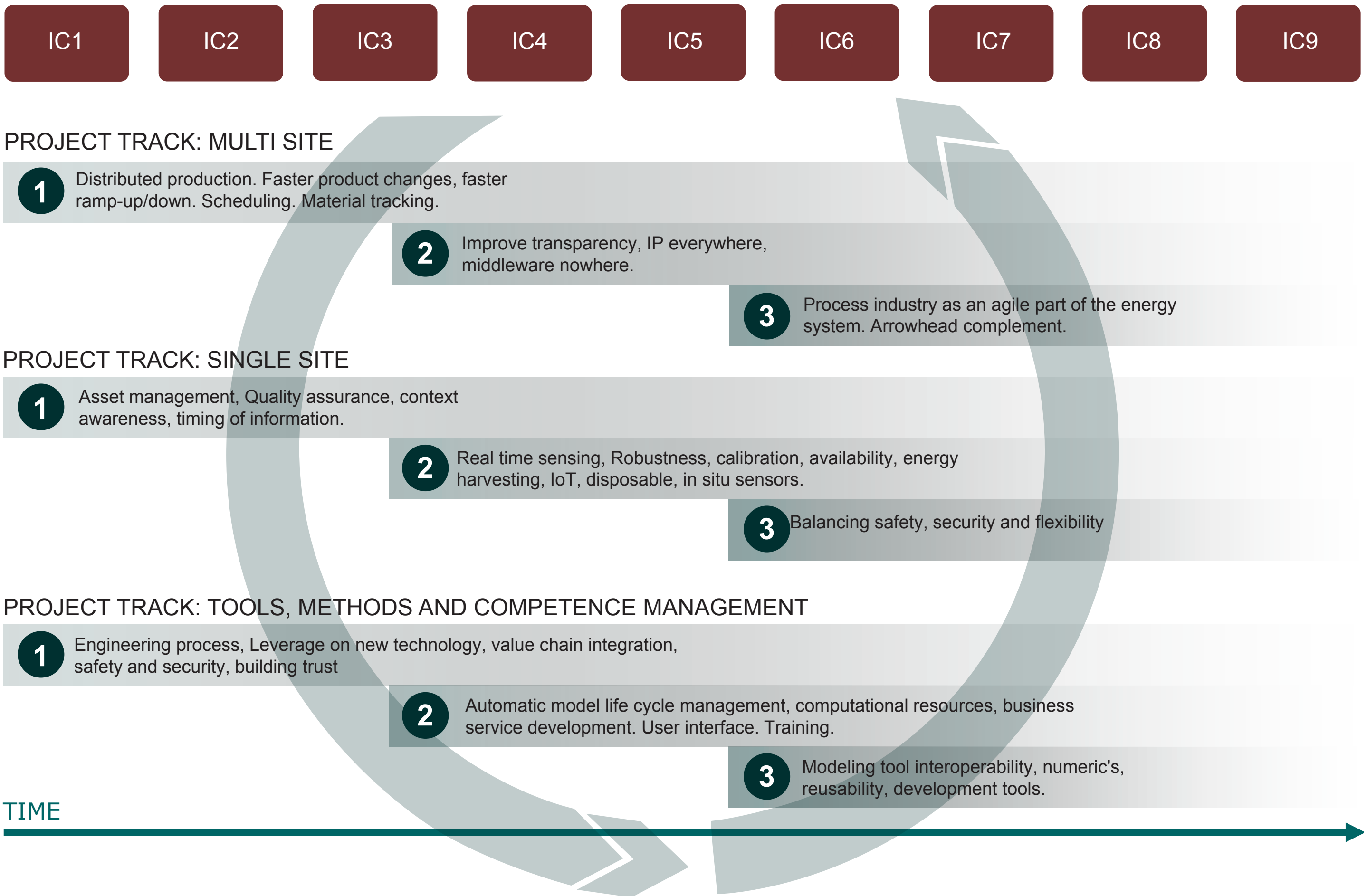

Figure 15: Implementation of ideal concepts in three main project tracks.

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