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SERVICE
ORIENTED
CROSS-LAYER
INF**R**ASTRUCTURE
FOR**D**ISTRIBUTED
SMART**E**MBEDDED
DEVICE**S**
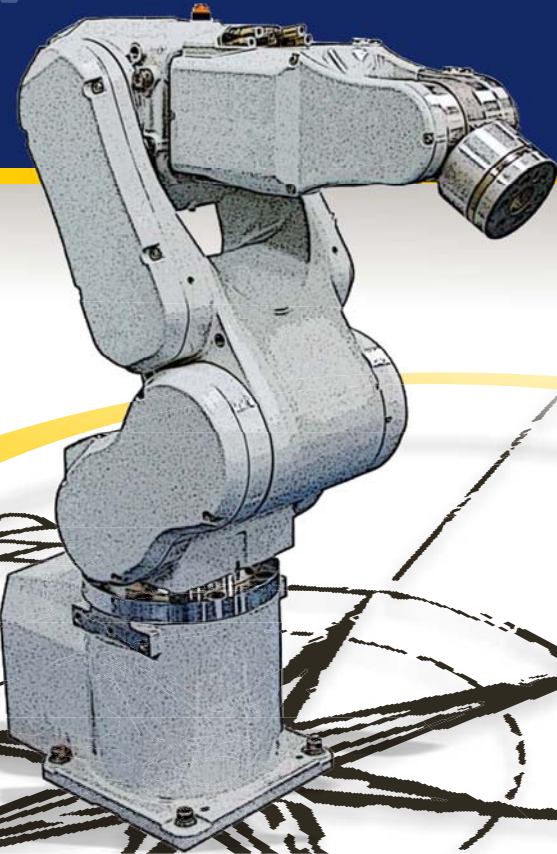
SOCRADES ROADMAP

The Future of SOA-based Factory Automation

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## The Future of SOA-based Factory Automation

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PREFACE

Production plays a vital role in economy and society, remaining fundamental to creating stable employment. The relevance of manufacturing in European economy is clear and widely accepted from heterogeneous stakeholders: business, policy-makers, and academic communities. In order to boost performances of European manufacturing companies, product and process technology innovation is more and more needed. Indeed, in order to maintain competitiveness, manufacturing companies cannot avoid considering appropriately technological innovation, especially in those markets where demand is extremely variable and where stakeholders are very demanding in terms of product performances and price but also in terms of environmental and societal impacts. In November 2008, the European Commission adopted a specific action, "Factories of the Future", in the "European Economic Recovery Plan", thus positioning the improvement in the use of technology in manufacturing as one of the priorities to increase Europe's competitiveness in the short and long term. Once again, this confirms the important role of technological innovation in European manufacturing.

In this context Information and Communication Technologies (ICT) play an important role to boost performances of European manufacturing companies. SOCRADES (Service-Oriented Cross-layer infRAstructure for Distributed smart Embedded devices) is a European research and advanced development project, funded by the Information Society Technologies (IST) initiative of the 6th Framework Programme, addressing ICT innovation for industrial automation applications. The primary objective of SOCRADES is to develop a design, execution and management platform for next-generation industrial automation systems, exploiting the Service Oriented Architecture paradigm both at the device (i.e. smart I/O, PLC, etc.) and at the business application level (i.e. MES/ERP, etc.). The basic aim of the project, therefore, is to develop tools and methods to achieve flexible, re-configurable, scalable and interoperable collaboration on a network of decentralised and distributed embedded devices and systems. Specifically, the project aims both at:

- · Developing of a comprehensive device-level SOA infrastructure – based on the Devices Profile for Web Services (DPWS) – for encapsulating intelligence and sensing or actuating skills as services, as well as to specify associated frameworks for management and orchestration of device- and system-level services.
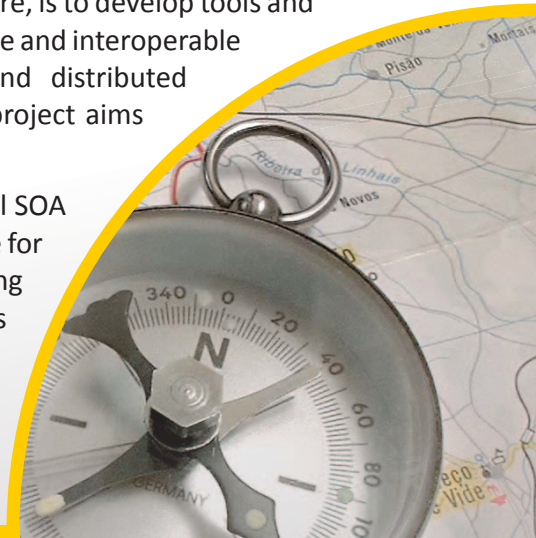
· Defining of a methodology for describing services with semantic mark-up that can be interpreted and processed by agents (Semantic Web Services), for the discovery, selection and composition of resources.

SOCRADES consortium is made up of 15 partners from 6 European countries, including the major European and global players in the industrial automation and IT-business sectors, as well as some of the most prestigious European universities.

SOCRADES shows how the convergence of solutions and products towards the SOA paradigm adopted for smart embedded automation devices contributes to the improvement of the reactivity and performance of many industrial processes, such as manufacturing, and logistics. SOCRADES approach allows intelligent systems behaviour to be obtained by composing configurations of devices that introduce incremental fractions of the overall required intelligence. In this manner, the use of the SOA paradigm at the device level enables the adoption of a unifying technology for all levels of the enterprise, from sensors and actuators to enterprise business processes. This approach leads to information being available "on demand" and allow business-level applications to use high-level information for such purposes as diagnostics, traceability and performance indicators – resulting in increased overall equipment effectiveness and business agility. A SOCRADES service is then a software component encapsulating automation device-specific functionalities. These functionalities are advertised/exposed to the outside world as "Services", so to be located and invoked by other networked devices and/or applications without the latter being aware of how the functionality is implemented. Hence, one of the main benefits of this is that it allows adaptability and reconfigurability of automated processes on the factory and in real-time production control and management scales.

During its life, SOCRADES developed models and methods for Factory Automation that were demonstrated through industrial prototypes and trials, showing the benefits of the adoption of SOA paradigm. Even if SOCRADES has already taken several steps further, in order to go towards implementation and adoption of SOA-based Factory Automation still several challenges need to be tackled. These challenges are important to be addressed to ease future application and diffusion of SOA-based Factory Automation system in real environment. This roadmap intends to start addressing some of these challenges by identifying, both from business and technology perspective, the main research needs that have to
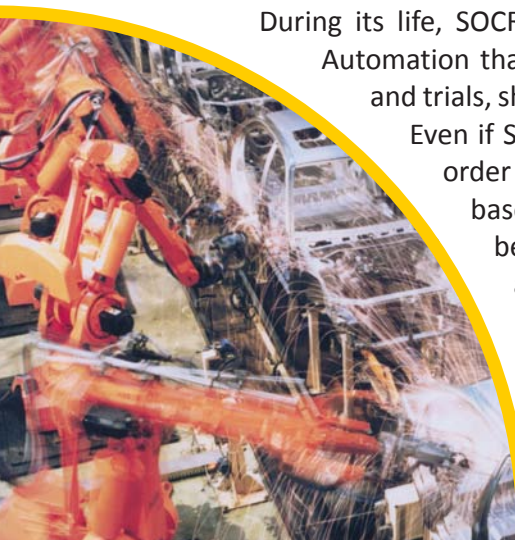
be addressed in order to facilitate the diffusion of SOA-based Factory Automation.

The aim of SOCRADES Roadmap is therefore to provide stakeholders (policy-makers, industry and academy) with a vision on business relevance of SOA paradigm for industrial automation and to identify the main building blocks of technology research that are needed in order to address industrial challenges coming from real applications.

This document addresses both managers and engineers by showing both business benefits and technological roadblocks in the adoption of SOA paradigm for industrial automation.

An introduction to SOA-based Factory Automation is provided in the second chapter. Main current trends in manufacturing are presented in the third chapter to provide insights on business needs that can be tackled through the adoption of SOA-based technologies. The fourth and fifth chapter address the analysis of benefits and barriers in the adoption of SOA-based Automation Systems. Finally research topics for future investigation are provided in the sixth chapter and concluding suggestions are proposed in the seventh chapter.

This document is the output of an extensive research activity that involved experts belonging both to SCORADES consortium as well as to the international community involved in the SOA for industrial automation domain. In particular an International Roadmapping Workshop was held in Cardiff (within IEEE INDIN 2009, June 25th, 2009), in which experts coming from 11 countries gathered together to discuss about the future of SOA-based Factory Automation. We are really thankful to all the participants for their inputs and suggestions. Moreover, several anonymous contributors provided with their inputs and suggestions through an on-line survey that was available in the last 6 months through SOCRADES Website (www.socrades.eu).

We hope that this document can provide useful information and can stimulate discussion on the business opportunities that come from the exploitation of SOA paradigm in Automation of Future Factories.

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INTRODUCTION

SOCRADES

In the last years traditional paradigms adopted for industrial automation are becoming more and more inadequate to currents trends and business needs of manufacturing players. There is a need for more flexible and scalable production systems that are able to handle variability at reasonable cost with real-time reactivity.

SOCRADES adopts the "collaborative automation" paradigm where the aim is to develop tools and methods to achieve flexible, reconfigurable, scalable, interoperable network-enabled collaboration between decentralised and distributed embedded systems. In particular, SOCRADES technical approach is to create a service-oriented ecosystem, where networked systems are composed by smart embedded devices interacting with both physical and organizational environment, pursuing well-defined system goals. Taking the granularity of intelligence to the device level allows intelligent system behaviour to be obtained by composing configurations of devices that introduce incremental fractions of the required intelligence. This approach favours adaptability and rapid reconfigurability, as re-programming of large monolithic systems is replaced by reconfiguring loosely coupled embedded units.

From a functional perspective, the focus is on managing the vastly increased number of intelligent devices and mastering the associated complexity. From a run-time infrastructure viewpoint, the focus is on a new breed of very flexible real-time embedded devices (wired/wireless) that are fault-tolerant, reconfigurable, safe and secure. For example, auto-configuration management is a new challenge that is addressed through basic plug-and-play and plug-and-run mechanisms.

From technological and infrastructural viewpoints, the use of the Service-Oriented Architecture (SOA) paradigm implemented through Web services technologies enables the adoption of a unifying technology for all levels of the enterprise, from sensors and actuators to enterprise business processes. This means that low cost devices (i.e. approximately few euros) can communicate directly to higher-level systems thanks to the adoption of SOA approach.
Building blocks of the collaborative automation system, which are built upon SOA will present their functionalities and production operations as Web services in the building block network and form the desired production process by collaboration using the communication methods provided by web technology.
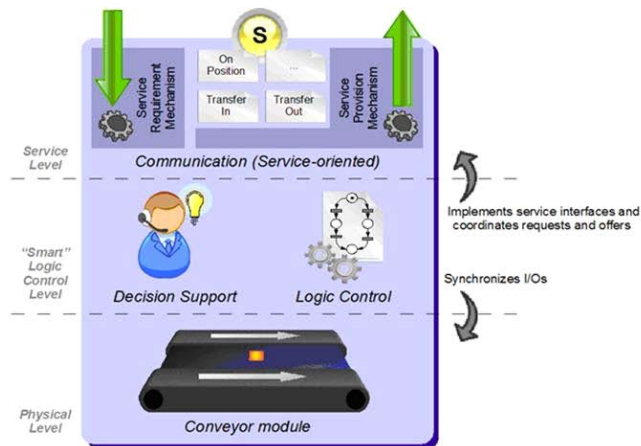
- **Mechatronics, Communication and Control integrated in something called "Collaborative Unit"**
  Mechatronic transport device offers transport functions
  A Gripper offers "Pick" and a Robot-arm offers "Place", then both offer "Pick-and-Place" when they are composed following architectural and behavioral specifications

- **Operations are exposed as Web Service (Transfer Interface)**
  □ TransferIn(int p), TransferOut(int p), TransferStop(), TransferInCompleted(Pallet p), GetStatus(Status s),…

- **Device offers additionally WS standard plug'n play functions for description and discovery of the Device / Transfer Service / Supervisory Control Services (Infrastructure Services)**

figure 01

The benefits of service-orientation are conveyed all the way to the device level, facilitating the discovery and composition of applications by re-configuration rather than re-programming. Dynamic self-configuration of smart embedded devices using loosely-coupled services provides significant advantages for highly dynamic and ad hoc distributed applications, as opposed to the use of more rigid technologies such as those based on distributed objects.

Applying the collaborative automation paradigm typically means that all the participating groups such as control vendors, machine builders and system integrators will be confronted with the subject to migrate from legacy manufacturing system to new systems composed of building blocks.

The modularization of the production system requires the decomposition of the present "controller-oriented structure" into functional modules with a "manufacturing-task-oriented structure". Furthermore, in order to be able to use the modularized function entities they have to be described and the functional
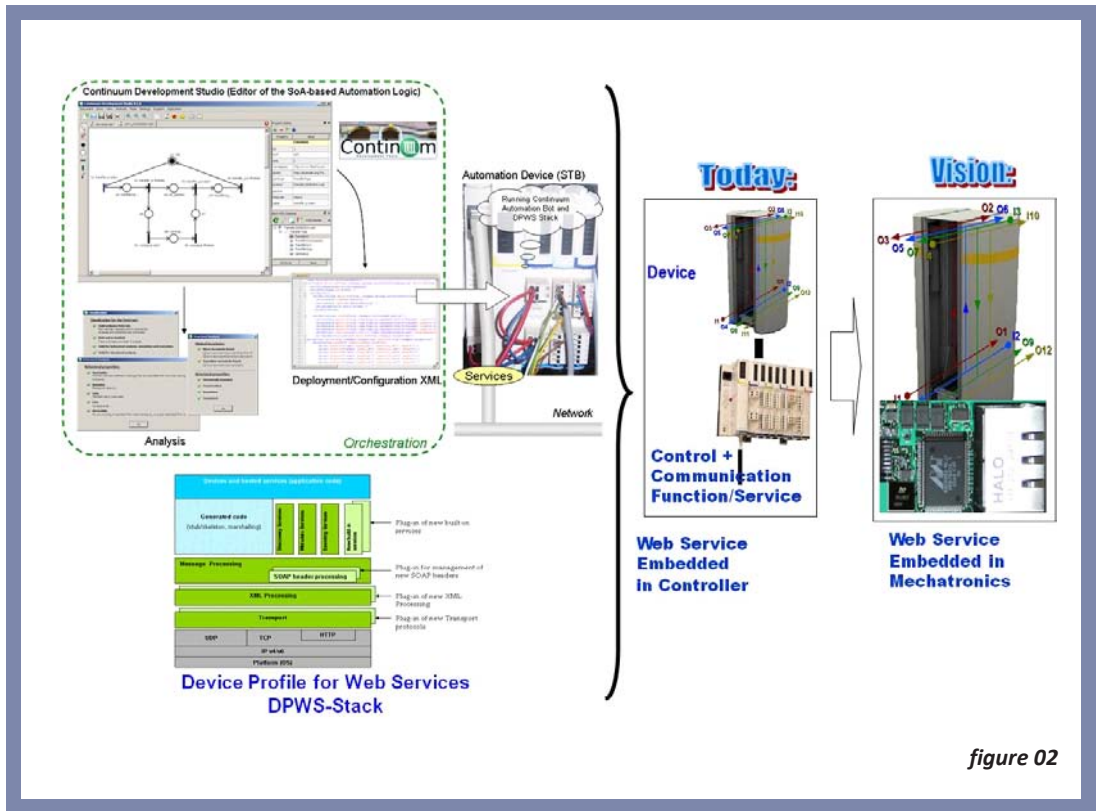
figure 02

dependencies of the latter need to be described. The functional / dependency description also has to respect the mechanical flexibility of the collaborating devices which is a crucial factor when designing a variable production process. Based on those descriptions the functional modules are aggregated again to obtain a higher level of autonomy.

The fundamental production operations are closely related to device-level and their service representation can be considered as the glue between the traditional automation area and the service-driven area. Those services do a translation of the service's input, output and event variables to process values and vice versa. Those implementations do not underlie such dynamic modifications as aggregate services do and could be implemented with less flexible constraints.

Therefore, a set of engineering tools is required for supporting a successful migration to the new automation approach. Among other tasks the engineering tool will have to provide methods for the following items:

figure 03
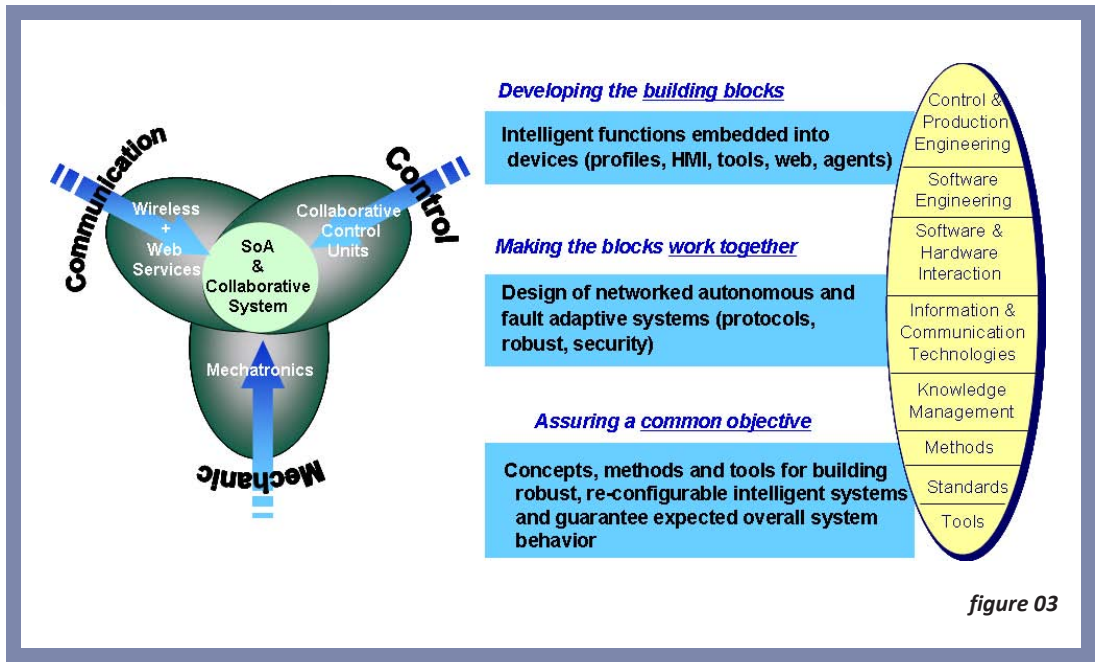
·   Modelling the entire production process or parts of it,

·   Identification of modular components,

·   Describing the architecture of the new production system,

·   Modelling language for the service orchestration,

·   Formal validation and simulation of the new production system,

·   Linkage of the modules to legacy systems.

This is a multi-disciplinary work that not only involves researchers and scientists from the academic world but also the practitioners from customers' side. The figure 03 shows the complexity of domains involved in SOA and Collaborative Automation Systems.

As said, the use of device-level Service Oriented Architecture contributes to the creation of an open, flexible and agile environment, by extending the scope of the collaborative architecture approach through the application of a unique communications infrastructure, down from the lowest levels of the device hierarchy up into the manufacturing enterprise information systems (i.e. ERP). The common

Enterprise systems
WS

Functionality Orchestration
WS

Engineering System
WS

IP network (wired or wireless)

Device
WS

Distr. IO
WS

Work-pieces
WS

Work-pieces
WS

Gateway
WS

Service Mediator
WS

WS: Service capability e.g. DPWS, OPC-UA
Device: Motor, Valve, Conveyor, robot, sensor etc.
Service Mediator / Gateway: Industrial PC,
dedicated device etc.

Wireless Sensor / Actuator Network
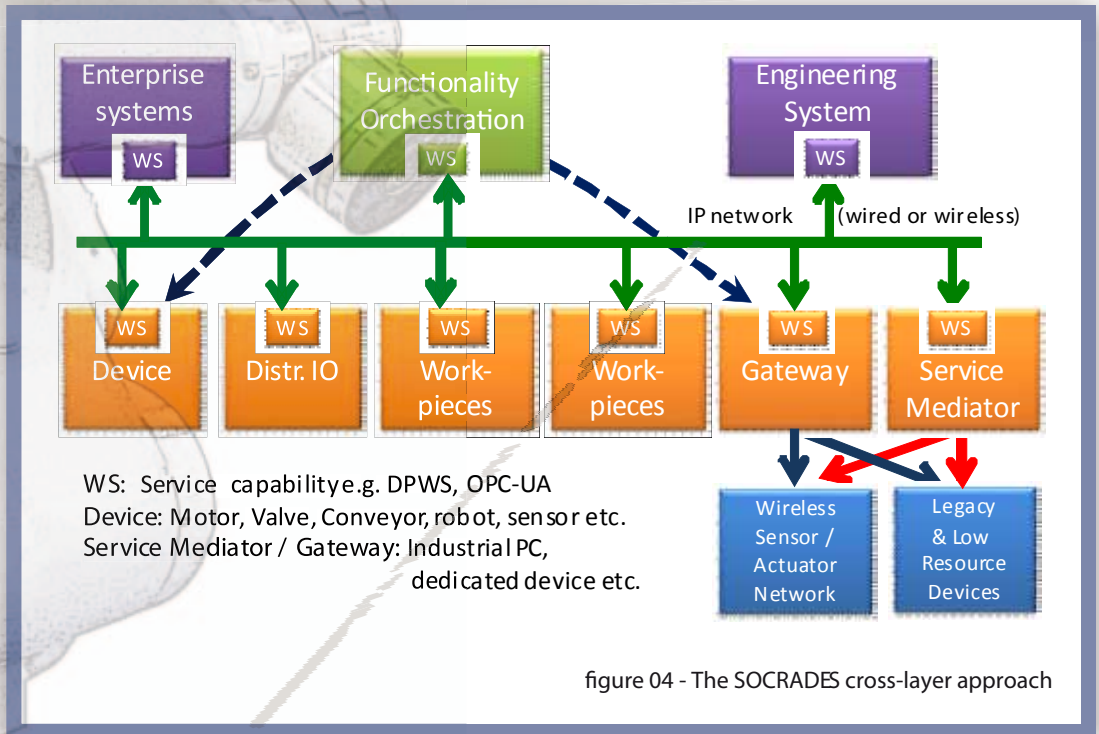
Legacy & Low Resource Devices

figure 04 - The SOCRADES cross-layer approach

infrastructure that has been developed within SOCRADES is depicted in figure 04. It shows how low level devices can be directly linked to higher-level systems such as enterprise or engineering system through the adoption of Web Service technologies.

A factory working under this technology-paradigm-confluence is composed of workplaces with emphasis on greater user-friendliness, more efficient service support, user-empowerment, and support for human interaction. A manufacturing environment where workforces are surrounded by a collection of smart distributed components that include mechatronics, control and intelligence (intelligent sensors and data processing units, autonomous, self-tuning and –repair machines, intuitive multi-modal human machine interfaces, etc.). Under these circumstances, the challenge is to develop production automation and control systems with autonomy and intelligence capabilities for co-operative / collaborative work, agile and fast adaptation to the environment changes, robustness against the occurrence of disturbances, and the easier integration of manufacturing resources and legacy systems.

Nowadays, even if SOA as a concept is a well-known and even if several applications are available at enterprise level, the adoption of SOA paradigm at device level to support

Collaborative Automation and Service Oriented Architecture
Exploitation / Addressing Customer Values

Applications deploying SoA via WS

- Distributed and Non-hierarchical (flat applications)
- No gateway, no specific interface
- Uniform communication protocols
- Vertical and horizontal integration
- Peer-to-peer asynchronous communication
- High level self describing real time protocols

Facilitating (Re)/configurability / Flexibility

- Dynamic population of new entities (devices, machines, functions, …)
- Automatic building of the application by assembling mechatronics devices
- Detect and manage manufactured pieces of equipment
- Duplicate machines or manufacturing lines (by "copy and paste" in the design tool)
- Full Plug and Play/Run at the application level
- Smooth Integration of shop floor with IT-System using Web Services

See also http://www.youtube.com/ (SOCRADES)

figure 05

Factory Automation is still at early-development phase. If we consider the Hype Cycle representation developed by Gartner to represent the maturity, adoption and business application of specific technologies, we can say that SOA technologies for Industrial Automation Systems are on average still in the Technology Trigger phase.
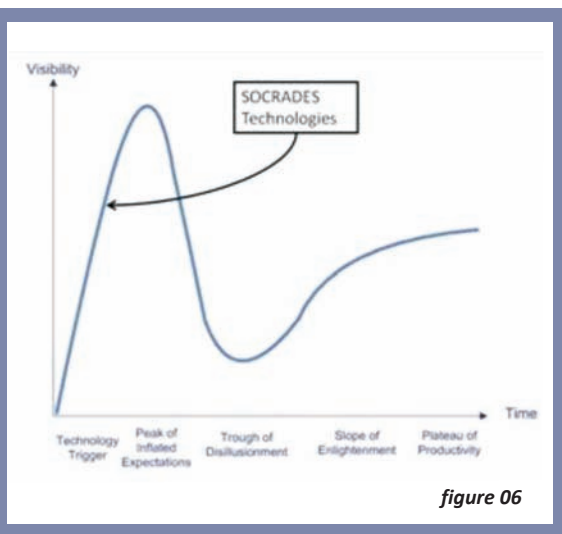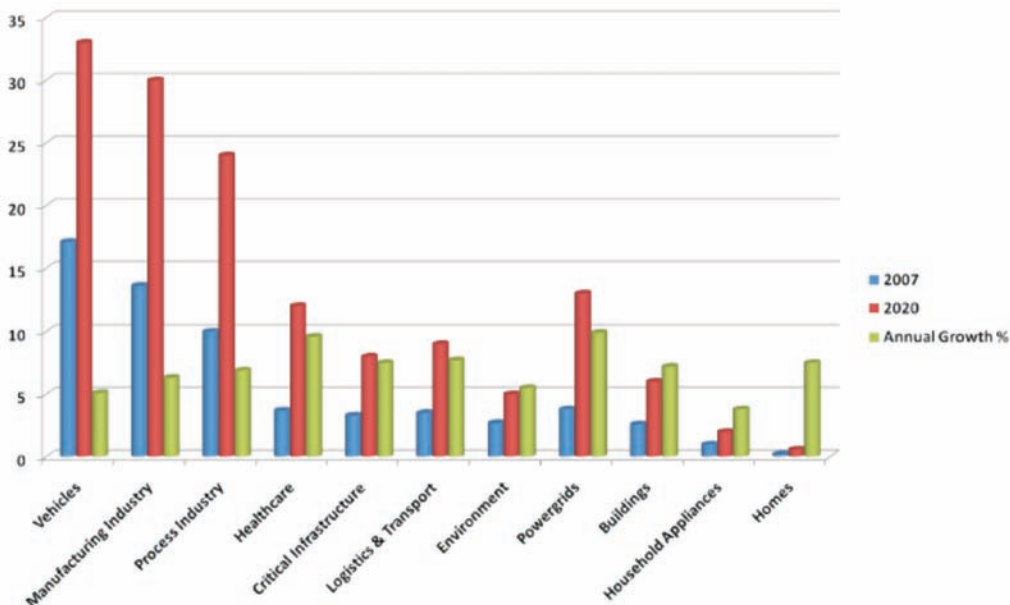

figure 06

Moreover, by looking at the hype cycle developed by Gartner in August 2005 on emerging technologies, several components of SOCRADES are included and highlighted in the next figure. This helps understand which of these relevant components will be firstly available in the future.

figure 07 - Hype Cycle for Emerging Technologies, Source: Gartner (August 2005)

Interest around SOA-based Factory Automation is growing day by day. This is driven by technological developments and by business needs. One of the main application that is pulling research on SOA-based industrial automation systems is monitoring and control. It is expected that this market will grow in the next years requiring for architectural approach to handle this application. Data on market foresights related to monitoring and control are provided in the following figure (in Bn €, data are provided by European Commission DG Information Society & Media).

figure 08 - Monitoring and Control Market 2007-2020 courtesy of CONET Consortium, Source: European Commission DG Information Society & Media, October 2008

Due to the high interest on the topic as well to the technological advancement still needed for implementation, SOCRADES Roadmap has been developed. Before going through it, a revision of present roadmaps available in linked fields is presented in the next section.
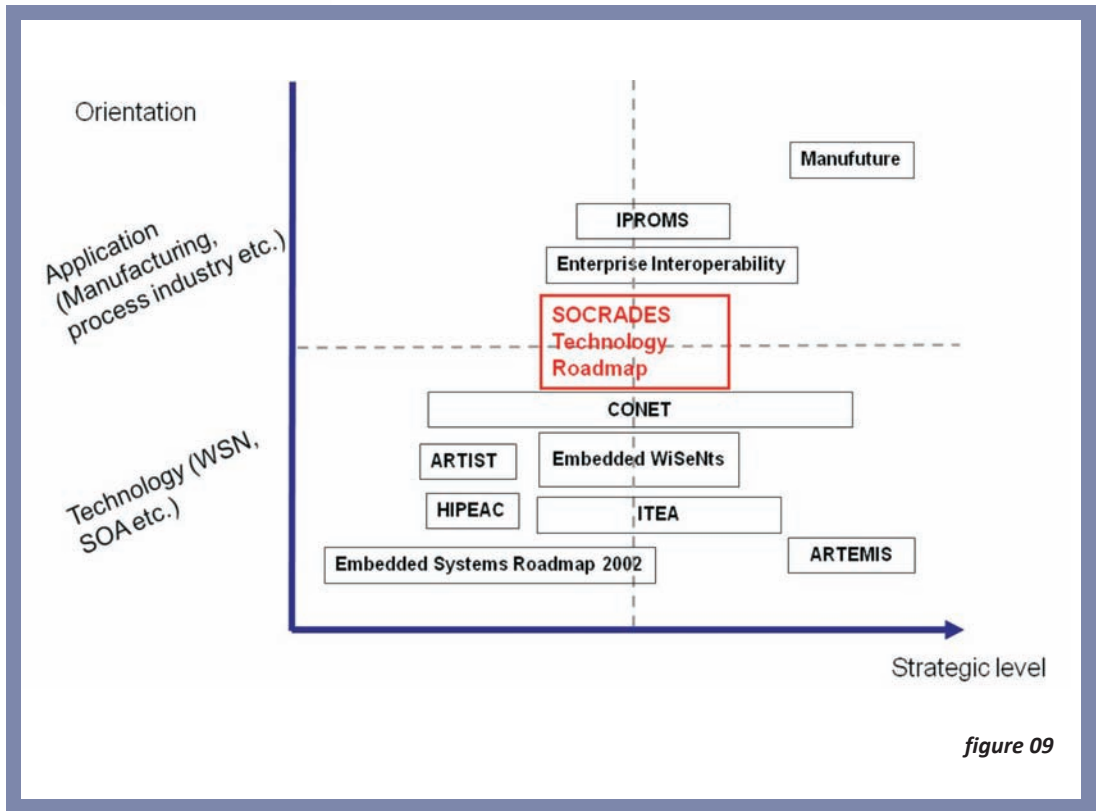
POSITIONING SOCRADES ROADMAP

In order to face transition towards SOA-based approach, a technology roadmap is required for the identification of challenges and technological needs for research. In the last years, some technology roadmaps have been created by various initiatives and in these roadmaps relevant issues in SOA-based Automation Systems domain have been tackled. These roadmapping activities have been carried out within European projects or associations such as ARTEMIS, Manufuture, ITEA, ARTIST, I*PROMS, HIPEAC, CONET. Even if these roadmaps provide interesting insights for SOA-based Automation Systems still specific roadmapping activity is required; this document aims at filling this gap.

To understand the position of SOCRADES Roadmap in comparison to other relevant roadmaps considered, a roadmaps classification can be made through two drivers: Orientation and Strategic Level.

- **Orientation:** the type of scope adopted by each roadmap. This can be based on technology or on application. This is not intended to be a sound differentiation since some roadmaps can be considered a mix of the two approaches. However understanding the prevalent orientation of each roadmap it is possible to better identify its scope and purpose. Roadmaps can be considered "Application oriented" when they investigate new research approaches and tools to solve issues related to each specific applications (manufacturing industry, process industry, home automation, health care, etc.). For example the Manufuture roadmap can be considered "application oriented". Instead a roadmap can be considered "technology oriented" when its aim is to outline future research needed in one or multiple referred technology areas. Hence, the viewpoint is on expected technology development that can enable multiple and heterogeneous applications. For example the Artemis roadmap can be considered technology oriented.

- **Strategic Level:** this driver depends on the time-frame and on the expected impact level of the roadmap. The more strategic is a roadmap the more long-term and impactful. On the other hand, the more strategic is a roadmap the less the challenges arisen can be faced in the short term. Indeed, strategic roadmaps usually face issues made of multi-facets components (e.g. cultural or organizational changes, etc.) that are difficult to be solved in the short term. Instead, roadmaps belonging to "low strategic level" typically present a list of detailed research challenges needed to solve existing problems. This driver is not related to the level of importance of the roadmaps; as a matter of facts both roadmaps dealing with complex issues and roadmaps focused on specific issues to be tackled with present technologies are relevant.

figure 09

By adopting the two drivers, SOCRADES Roadmap results as considering both application and technology perspective, having a medium strategic level. The position of the SOCRADES roadmap in comparison to other roadmaps is presented in figure 09 .

MAIN CHALLENGES IN PRODUCTION

Nowadays, some relevant new and old strategic trends are shaping manufacturing and, consequently, the requirements of production systems in terms of design, management and operations. Several research initiatives have been recently carried out in order to identify manufacturing strategies (according to stakeholders, industrial and academic experts). Among all the strategies we consider six main trends: sustainability, intelligent products, price competition, time-to-market reduction, servitization, cross-enterprise collaboration. These strategies are quite distinctive (and sometimes they create trade-offs); in real cases, combination of these strategies could be pursued:

- **Sustainability:** this trend can be defined as the "application of scientific and technical knowledge to satisfy human needs in different societal frames without compromising the ability of future generations to meet their own needs"[1]. In order to go towards sustainable development a major role will be played by manufacturing. In particular, production systems and their management and operation require consideration in a holistic fashion of environmental, societal and economic impacts (three main pillars of sustainability). In order to address these challenges driven by the on-going trend, production systems will require new performances apart from cost, and productivity: they will require for example energy efficiency (and eco-efficiency, i.e. considering the environmental impact of resources' consumption) and others.

- **Intelligent products:** with this term we generally refer to products, which are able to interact with the environment (other devices, humans, etc.). In particular intelligent products should have sensing, reasoning, inference, mnemonic and learning capabilities that enable decision-making based on the context. This trend towards next-generation products needs an environment throughout all their lifecycle in which they can exploit their functionalities. Hence, also during the production phase they could need to interact with production systems.

- **Price competition:** price continues to remain one of the most effective ways to increase sales. Even if other aspects such as quality, service, and others are more and more becoming relevant from the customers point of view, price competition is still the main driver. Companies that pursue price competition have to deal with several challenges such as cost reduction (e.g. through globalization of production), increase of productivity, etc.

1. G. Seliger, et al. "Approaches to sustainable manufacturing", Int. J. Sustainable Manufacturing, Vol. 1, Nos. 1/2, pp. 58-77, 2008.

- **Time-to-market reduction:** In order to remain competitive, manufacturing companies should produce new product in the shortest time possible. This is required in order to satisfy customer's needs and in order to reduce the risk associated to the time-to-market. The time-to-market is the time between the decision (and related investments) to create a new product is taken and the moment in which the real product can be sold to the customer. The risk associated to the time-to-market, is mainly due to possible changes (in market needs, costs, etc.) that could happen during that time. In order to reduce the time-to-market several improvements involves production systems, e.g. better integrated with engineering application (e.g. with adoption of simulation tools, etc.).

- **Servitization:** nowadays products are more and more provided with additional service components (maintenance, after-sales services, etc.) that need to be fully considered and addressed by manufacturing companies. New methods and technologies that support the provision of services are required in production domain in order to enable the transition from classical product to product-service-system delivery.

- **Cross-enterprise collaboration:** companies are more and more focusing on their core business in order to provide efficient competitive products to their customers, without wasting efforts in non-core activities. In this context, enterprises are more and more participating in networks and competing through partnerships with customers and suppliers. This is raising collaboration requirements both from technical and organizational point of view.

To face these industrial challenges next-generation production systems will require performances such as efficient use of resources, reconfigurability, flexibility, and reactivity. Reconfigurability can be obtained through the following features: reduction of installation & programming time, increased interoperability of devices, and legacy systems integration. Maintenance optimization, increased utilization of assets, optimization through better visibility, line balancing, and reduction of human errors are features that support the efficient use of resources. Flexibility is enabled by interoperability (both compatibility and cross-company) and legacy system support & migration. Reactivity instead can be enabled through appropriate exploitation of reconfigurability. Most of these features can be fully enabled through exploitation of SOA-based Automation Systems; the features are presented in the following section.

IMPACTS OF SOA APPROACH IN FUTURE FACTORIES

The business world is highly competitive, and in order to successfully tackle everyday's challenges operational managers and executives demand high-dependability and wide-visibility into the status of their business process networks. The latest is done usually via business key performance indicators (KPIs). However in order to provide up-to-date info and be able to react in a flexible and optimal way to changing conditions, real-time info must flow via all layers from the shop-floor up to the business process level. In that sense, enterprises are moving towards service-oriented infrastructures that bring us one step closer to the vision of real-time enterprises. Applications and business processes are modelled on top of and using an institution-wide or even cross-institutional service landscape. For any solution to be easily integrated in this environment, it must feature a service-based approach.

The convergence of solutions and products towards the SOA paradigm adopted for smart embedded devices contributes to the improvement of the reactivity and performance of industrial processes, such as manufacturing, logistics and others. This will lead to information being available "on demand" and in business-level applications that are able to use them in high-level information for various purposes, such as diagnostics, performance indicators, traceability, etc. These future vertical integration capabilities will also help to reduce the effort required for integration of the affected systems in the sense of the given business scenario.

Service-Oriented Architecture paradigm applied to device level in the automation domain enables different benefits that address the industrial challenges described in the previous section. It is important to separate different industrial application domains, since they entail different benefits for end-users: for example reconfigurability of production systems is much more seen as a benefit e.g. by cell-phone producers rather than from steel pipes producers.

In this section benefits coming from SOA approach applied to Automation Systems are highlighted. They can be clustered into three dimensions:

- *Cost reduction:* benefits that directly imply cost reduction through adoption of SOA approach, e.g. reduced time and cost in installation of new machines

- *Improved performances:* thanks to SOA approach some performances can be

enhanced. This may also entail cost reduction on the final effect, however the focus of the benefit is more directly related to improved performances, for example reactivity is enhanced thanks to more reconfigurable production systems

- *New opportunities:* benefits coming from SOA approach implementation may be clustered under this category when they open new business opportunities, for example the possibility for technology provider to sell engineering tools directly coupled with the logic included in the automation devices.

Benefits are presented clustered in these three categories.

Cost reduction

Push competitiveness of device vendors: from customer perspective advantages are in terms of easier and seamless integration of hardware and software. For example a Pump A can be replaced with a Pump B without any cost in terms of integration since they are both seen identically from service point of view. This specific characteristic, enabled by SOCRADES, will increase competition among Pump producers. Generally device manufactures will be pushed to improve their cost-benefit ratio. As a matter of fact, nowadays industrial automation producers use proprietary technologies also in order to "retain" their customers, since changes of single device is extremely difficult and costly without a common/shared communication infrastructure. This benefit coming from SOCRADES approach is both referred to process industry and discrete manufacturing.

Labour cost reduction (solution sold to end-users): this a specific benefit for the end-user, since with SOCRADES adoption people will acquire high-tech skills to manage the exponentially increasing complexity. This is required to run, operate, and manage the future production systems. Furthermore it is important to note that some companies are planning not to retain knowledge on the design and management of their industrial systems. From the end-user perspective this reduces the internal need for expert (costly) workers: which can be now outsourced. Moreover, from the technology provider point of view, this generates a new gap that could be filled by providing a solution which inherently includes knowledge on industrial systems. This could be done through exploitation of SOCRADES approach. In other words, this is an on-going process from the end-user of outsourcing the activities of design and management of production systems.

Installation time/cost reduction: through SOCRADES approach agility grows up. Indeed, nowadays each automation installation is highly customized and therefore one

of a kind; this means that it is designed and built from scratch, and that deep expertise in different network technologies are required to configure, use, and maintain them (e.g. Profibus, Hart, wirelessHart, etc.). By using higher level modelling instead, it is possible to exploit modularity of production systems components in order to reduce the time required to engineer and install a new automated production system. Every few months the production line can be change, and in case of extreme customization and variable production (such as mobile market, etc.), this can happen every 1-2 weeks. These changes are extremely tough to be implemented without an appropriate support of the infrastructure.

Hence, also cost associated to production systems engineering will be reduce: in particular it is expected that a 30% reduction of engineering cost is realistic through adoption of SOCRADES technologies. Additionally reduction from 10 to 15% of installation time is also expected. In other words, SOA enables plug and produce capability by reducing the time spent for new implementation. This is valid both for discrete manufacturing and process industry. While in discrete manufacturing changes in production lines can happen frequently, in process industry even if industrial equipments remain for several years, thousands devices such as sensors, actuators, etc. need to be installed, replaced, removed. Indeed in process industry, one sensor every week is added to the production system. This demonstrates how important an infrastructure that supports easy and seamless installation of new devices is. Moreover service adoption can reduce problems in implementing devices into systems using heterogeneous software; for example a new valve tested before being introduced in the production system, could seem working but then when it is really added to the production system, it may not work due to software versions' issue. This may entail costly losses in process industry (depending on the specific industry) and this is avoided through service adoption (that exposes functionalities to the outside environment).

Interoperability (compatibility): The variation of interfaces and components used in industries leads to the need for standardisation and interoperability especially for the acceptance of SOA. Several challenges arise here. Providing knowledge, methods and tools to facilitate the interoperability of different SOA-Systems to finally reach a plug-and-play functionality is the first step. Providing reference ontologies for Service-based production systems in different industrial scenarios, as well as comparison between

particular ontologies and development of methods and tools to facilitate successful communication between SOA-Systems with disparate ontologies would further increase collaboration. Facilitation of interoperability of SOA-based Automation and Control Systems produced/generated by different vendors would minimize isolated islands at the shop-floor. Furthermore communication standards for ontologies, standardized functional units/modules especially for the field of production systems need to be developed.

Reduced complexity for technology suppliers: this benefit addresses specifically technology providers. From the technology provider point of view, if you have to supply connectivity to several systems complexity (and costs) increases; instead by adopting a common/standard way to interface devices, it is easier to supply connectivity, thus reducing production cost and increasing competitiveness among suppliers.

Programming time reduction: modularization of production systems allow higher-level programming approach. This reduces programming time for automated production systems since control software does not need to be programmed from scratch. Since today it is very time consuming to create programs for robots, this is considered an important benefit from end-user perspectives, in particular in discrete manufacturing domain.

Interoperability (cross-company): another facet of interoperability that is enabled by SOCRADES approach relates to the support of cooperation among production systems of different companies. This benefit may be exploited for more coordinated reaction to unexpected events or unpredicted demand. For example considering a manufacturing company that usually buys its raw material from two suppliers. In case one of the suppliers cannot provide in time the required material due to breakdown in its production systems, the manufacturing company can easily switch from one supplier to the other in short time and reduced cost.

Improved performances

Maintenance optimization: for the end-user (both process industry and discrete manufacturing) maintenance activity will be easier by adopting higher-level components, enabled by SOCRADES approach. Indeed, it is now possible to replace modules instead of repairing single components. The transition that happened in the automotive industry is similarly expected to occur in the industrial automation industry, where in the past in order to perform maintenance activity single components where substituted or repaired. Nowadays, complete devices are substituted instead of single parts (e.g. gearbox). A similar transition will appear in the automation industry, enabled

by the adoption higher-level components. As a result, cost related to maintenance activity will be reduced. Moreover, since automation systems are made of self-contained components that should be able to provide self-diagnosis, cost reduction in the maintenance management (monitoring and analysis) is expected. Actually, approximately one third of the total cost of an industrial system is due to installation and maintenance. If systems are provided with self-diagnosis (and predictive) capabilities they will handle problems internally and will communicate to the systems only issues that cannot be handled locally. Thus maintenance cost reduction can be obtained. Also spare parts management will be less costly, since fewer spare parts will be required to be handled.

Cost reduction through increased utilization: previously complete production systems were running continuously. With the SOCRADES approach based on the distributed control, single production devices do not need to work all time, but rather they can be activated only when required. This could turn out in 30 to 40% of cost reduction depending on the systems. The more complex the system is (i.e. number of devices, etc.), the higher cost reduction is expected thanks to the adoption of the highly distributed control system enabled by SOA paradigm.

Optimization through better visibility: thanks to the adoption of a common communication infrastructure, increased visibility and real-time monitoring is feasible. This may open the opportunity of increasing optimization of production processes. For example reduction of energy consumption could be tackled through better management of resources.

Reactivity through reconfigurability (of production lines): thanks to SOCRADES approach from the end-user point of view, production lines can be easily and quickly reconfigured, through the adoption of higher level modelling and modular systems. This benefit is extremely important especially in those industrial domains where production lines need to be modified when changes are made to products. For example in the automotive industry, approximately every 6-9 months a new product is introduced, requiring modification on the existing production lines. In the past production lines were sold after being used for a specific product, but nowadays they need stay longer operational in the factory and therefore need to be reconfigured in order to manufacture new products. Hence quick reconfiguration of production lines is an

important capability for competition in the automotive industry. Reconfigurability helps reduce in a low-cost manner the time-to-market, i.e. time required from the decision to produce a new product till the real placement into the market.

Reduction of human errors: with SOCRADES it is possible to plug-in devices that are automatically recognized by the system. This reduces reduction of human errors, and related cost. Since, physical world communicate directly to business system without people having to provide "interfaces" between physical and "virtual" world, benefits in terms of error-related cost reduction are expected. This is valid for both discrete manufacturing and process industry.

Line Balancing: real-time monitoring of production systems enables real-time awareness of production system status that may be exploited for line balancing optimization. For example real-time information could be used in order to decide the best machine to produce a new product. This could be particularly relevant in case of failures of production systems devices: for example considering a production line composed of several robots, in case one of them fails down, it is possible to reactively send products to other robots, thanks to the adoption of SOCRADES Approach. This activity usually takes time and can entail costs.

Legacy system support and migration: SOA can support legacy systems integration. This is a significant benefit in the extension of the lifetime of the legacy systems, their integration with the evolving infrastructure and finally their migration to new automated production systems. A SOA approach like the one proposed in SOCRADES can realize the migration from legacy to service-oriented infrastructure via gateways/service-mediators. This is very relevant in order to reduce cost associated with building production line, since old machines can be used together with new ones without much investment on communication architecture modifications. This is an important benefit both from end-used (process industry and discrete manufacturing) and from technology providers perspectives. Technology providers are positively affected by this benefit since production systems upgrade cost is reduce for end-users, hence increasing the possibility of investments by end-users.

New opportunities

Engineering tools offered by technology providers: technology providers may enter new businesses by providing engineering tools for end-users. Engineering tools should be simple enough to be used by heterogeneous practitioners, but they should also be able to flexibly model and operate disparate solutions of complex automation systems.

Scenarios

To show and clarify features and benefits coming from the adoption of SOA-based approach, five scenarios have been identified and explained (most of them are based on prototypes developed within SOCRADES).
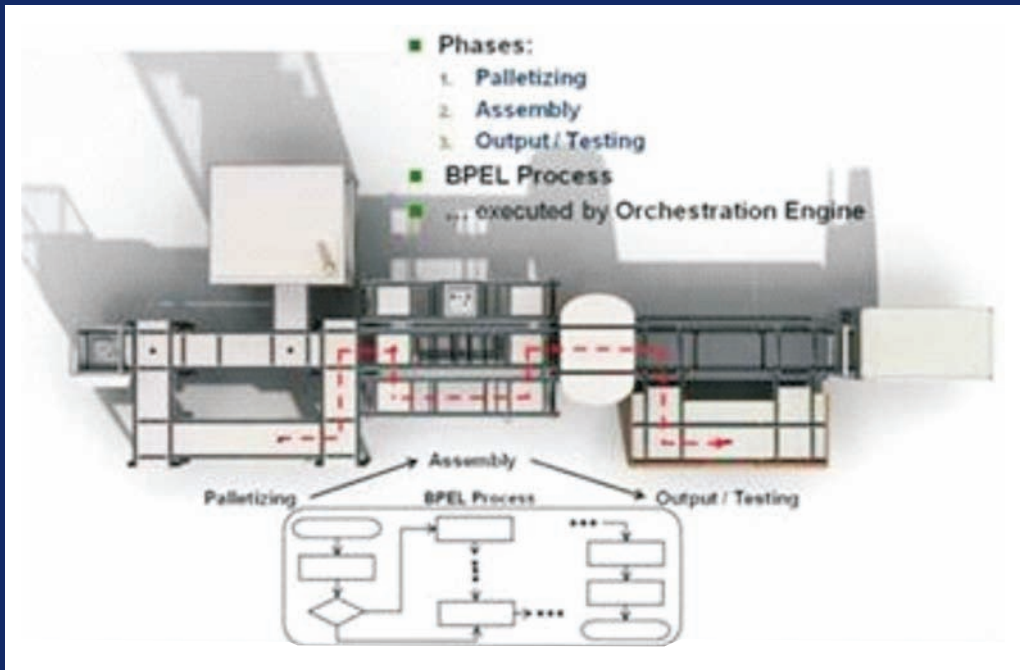
figure 10 - Use case demonstrating the service orchestration using BPEL.

Scenario: Dynamic Assembly System

Dynamic Assembly System (DAS) is a modular factory platform for light assembly, inspection, test, repairing and packing applications. DAS combines flow-oriented dynamic production control and modular automation for increased production efficiency with ergonomic solutions for manual assembly. This modular automation platform includes a range of standardized modules as workstations, robot cells, conveyors and flexible buffers *(see Figure 10)*.

Each of the segments contains its own set of workstations, and a pallet can be routed back to a previous segment through the lower conveyor line. On the left, before the start segment, there is a start lifter for moving pallets from the lower line to the main line, and after the end segment there is an end lifter for moving pallets to the lower conveyor line. This material flow can be appreciated in Figure 10.

This scenario shows how the SOA technology can be integrated in a production line through a modular approach for the control. This is achieved by de-centralizing the control logic at the lowest level by means of independent automation devices. Besides the traditional interfaces and functionality that can be found in any industrial controller, the STB offers the capability of embedding web services by means of the DPWS stack.

Several benefits can be derived from flexible service enabled shop-floors. Web services in industrial controllers can lead to increased flexibility. Moreover, adaptability can be achieved by service re-orchestration while conflicts can be resolute dynamically. This means that when a failure occur in the system dynamic re-process of the workflow can be performed on the top of real-time information of the status of the system.
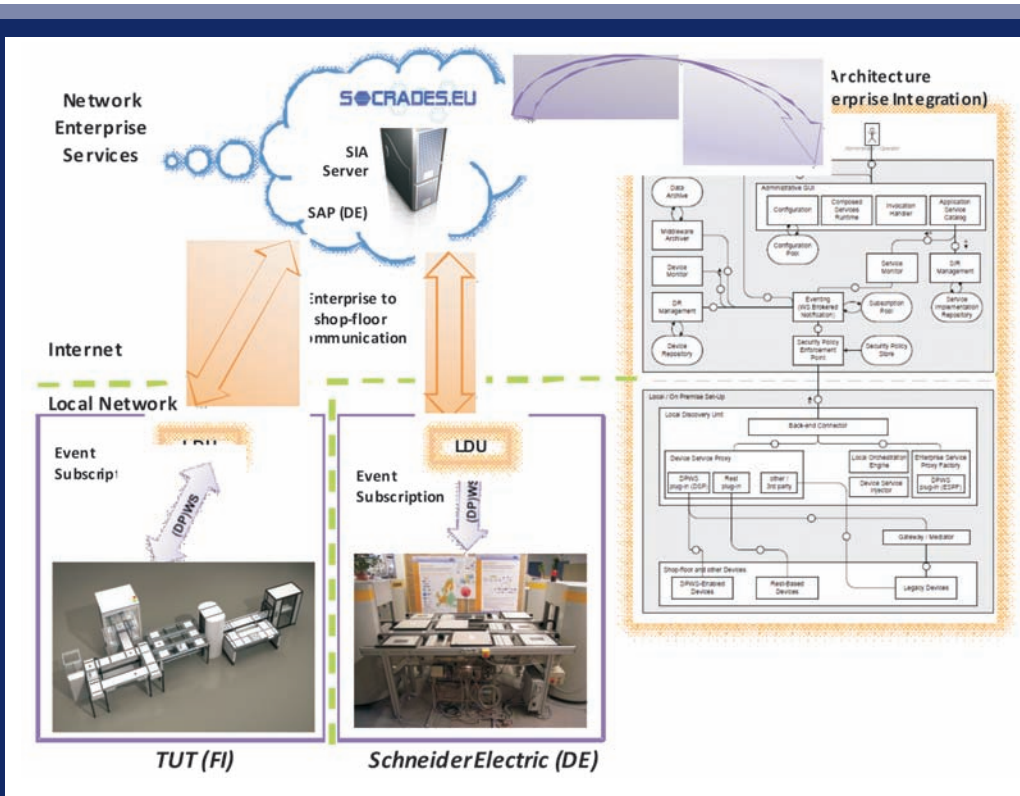
figure 11- Cross-company collaborative production based on the SOCRADES Integration Architecture

Scenario: Cross-Enterprise Collaboration

This scenario present a peculiar feature enabled by SOA-based Factory Automation. The idea, as shown in Fig. XXX, is that similar production facilities are available in remote locations (e.g. Schneider Electric in Germany or Tampere in Finland). Two prototypes were developed in SOCRADES and hosted in Tampere (TUT) and Seligenstadt (Schneider Electric); they represent two different companies that are linked with business relations. These companies are "interconnected" via the Enterprise Applications that are hosted in Walldorf (SAP).

Both facilities provide electromechanical assembly capabilities using SOCRADES architecture; this means that the components of the production

systems in these locations are abstracted and perceived externally as web services. At local level, each one of the facilities acts independently and can coordinate its service-enabled production system by using the SOCRADES tools. At global level, both facilities connect to a service-enabled ERP module provided by SAP, which is used for coordinating the production in the remote locations.

A network application is downloaded and this immediately provides discovery of devices and services (via the Device Profile for Web Services - DPWS) on the local network and connection to the backend system. Different versions of the network application can add-up functionalities e.g. proxy also specific enterprise services at local shop-floor, where they can be discovered and used by the devices and other services. The network applications provide a mean for connecting and managing devices from different premises, without needing Virtual Private Network connections to SAP premises.

The different sites involved are collaborating between them via interactions that previously were not possible or would require significant implementation efforts. As it can be seen this is an event based approach where all sites are notified about the necessary status of the production in the other side, and where the enterprise systems have full visibility on the production and can re-arrange orders in order to meet business goals.

The impact that this cross-company collaboration scenario has on everyday line of business is clear e.g. related to asset management, real-time monitoring of processes, timely communication in a cross-layer and cross-company way, as well as real-time analytics and dynamic decision making. Significant effort and cost reduction in realising this functionality, interoperability in designing cross-enterprise business processes, line balancing and optimized resource utilization is gained through SOA-based approach.
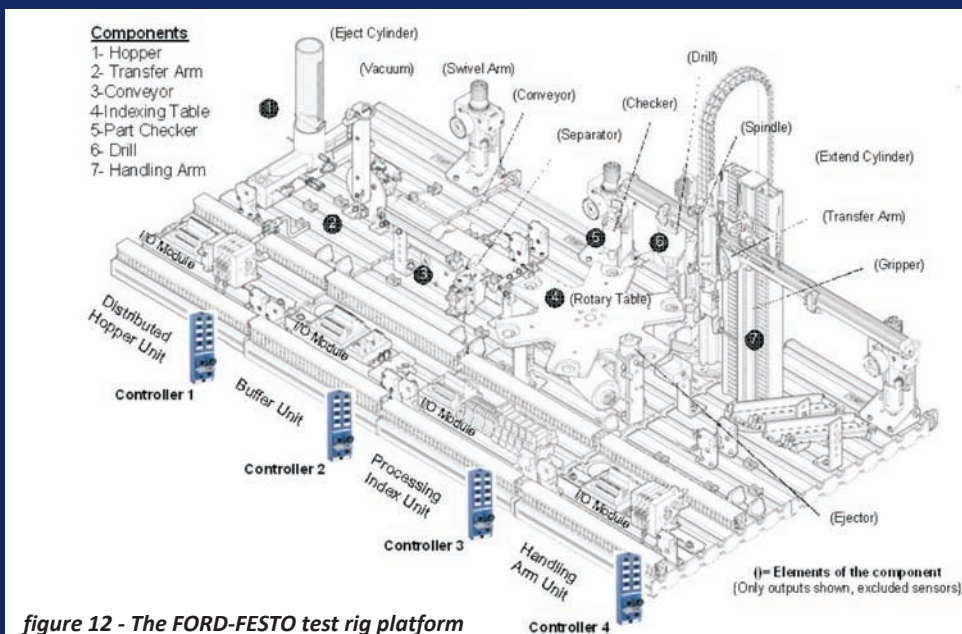
figure 12 - The FORD-FESTO test rig platform

Scenario: Car Engine Manufacturing

Another scenario that shows the actual exploitation of SOCRADES technologies based on SOA paradigm is the car engine manufacturing. The typical component-based configuration of machine system for car engine manufacturing is built from various machine subsystems. In order to represent this kind of system a test rig has been adopted in SOCRADES. The system has been divided into four subsystems (i.e. units or stations): Distributed hopper unit, Buffer unit, Processing table unit, and Handling arm unit.

Each of these subsystems contains one or more mechanical components that are connected to field devices (i.e. sensors and actuators) through a distributed FTB-based module. These device components communicate via state variables within the finite state machine behaviour of the complete system. The sequence of machine operations is defined by the interlocking of components defined at the design phase, i.e. using the engineering application tools including a process definition editor to configure an orchestration engine. The functionality of the test rig is representative of typical assembly machine and line operations used to assemble automotive engines. In the automotive

engine assembly process parts are inserted to the main body of the engine block (or head) at each station along the processing line. The complete machine application is implemented by coordination of the state behaviour related to each element associated with the system. Appropriate interlocks between elements provide the correct synchronisation.

These state transitions generally share the same commonalities in operations, such as moving from one position to another regardless of distance, axis and timing. Typical operations include i.e., "extend"; "retract"; "move upstream"; "move downstream"; "move sort"; "start : stop" and "on : off". These operations depend on the state transition logic aggregated from the component state and interlocks as the condition to movement at each stage. These component states represent the movement of the output from one position to another. The only differences between these elements are the variable names relating to the I/O ports and sets of interlocks and conditions that indicate the component state to allow the action to occur. This component definition allows the existing components to be reused by other components provided the same required functionality and state progression is needed.

The development of Web Services at factory device level exposes shop floor devices to higher level applications creating a need for support of these services and applications. This support relies on the use and definition of common ontologies and a defined architecture in terms of Engineering services linking the domains. In order to exploit this new functionality business models need to be developed and supported. In this way, engineering services can support new business models from the enterprise to factory floor.

Impacts demonstrated by this prototype include: Efficient system engineering, interoperability to guarantee horizontal and vertical openness, adaptability and easy reconfiguration of automation systems under real-time production conditions, decomposing of machine into components suitable for manufacturing powertrain assembly applications and show that such systems can be effectively engineered and controlled using Web-service based devices, illustration of potential for event-based business integration, and finally legacy device support.
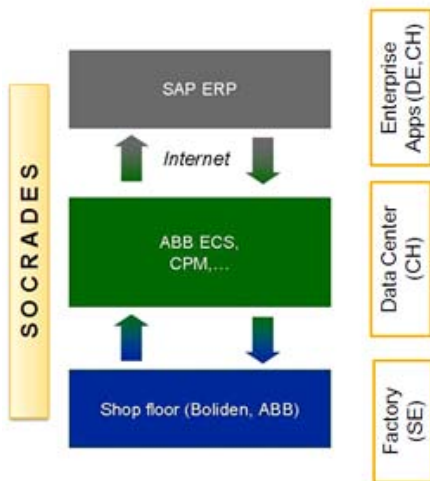
figure 13 - The Boliden Pilot Application

Scenario: Fault-tolerant Wireless Control of Continuous Processes

This scenario has been represented in SOCRADES through a pilot application, where monitoring and managing parts of the BOLIDEN plant is managed in Sweden. The events generated by the devices are transported by wireless links to the ABB ECS software, representing the SOA-enabled interface, towards the enterprise management software (SAP). Apart from monitoring, partial management is also realized as a selection of the output process characteristics. The process is controllable by the enterprise software, and monitored devices can be checked for faulty behaviour. In addition, it is possible to activate / deactivate the faulty system processing, again, from enterprise system levels. This means that near real-time monitoring and management of production devices can be easily supported through the adoption of SOA-based approach for industrial automation.

The plant at Boliden already benefits of a (wired) control system connecting the sensors and actuators to the central decision point. The wired control is to be replaced in this prototype by wireless connections in selected spots. For the wireless network that will (partly) replace the wired communication the

ZigBee protocol was selected. The sensors communicate with a network manager (access point), from where the information is sent (also wired) to the controllers in the data processing location.

Benefits of SOA-based approach that can be clearly noticed through this scenario are:

- **Vendor neutral systems:** Open, vendor neutral systems are advantageous particularly to the end-user and machine builders and could have significant impact through all lifecycle phases. They have the potential to significantly reduce costs, training requirements and interfacing problems.

- **Transparency of the communication media:** Replacement of a wired network segment by a wireless network should not influence the overall functional behaviour. Future systems will consist of a mix of wired and wireless network domains and it must be possible to transparently interconnect these domains. Additionally control systems, sensor networks or databases have to be designed to enable a seamless integration with the IT system planned for the new installation. Engineering efforts are also necessary to guarantee a proper integration with the existing IT infrastructure of the enterprise (CAD system, supply chains, production planning, etc.) and legacy systems.

- **Control over wireless links:** A majority of the applications in process industry are control of continuous systems described by dynamic models. One of the major concerns for the SOCRADES introduction in process control is to provide robust wireless control which meets the same level of control performance as of today's wired systems.

- **Integration with higher level enterprise systems:** In order to maximize process agility at minimum time and cost, it is vitally important to be able to reconfigure production (sub)systems easily and quickly.
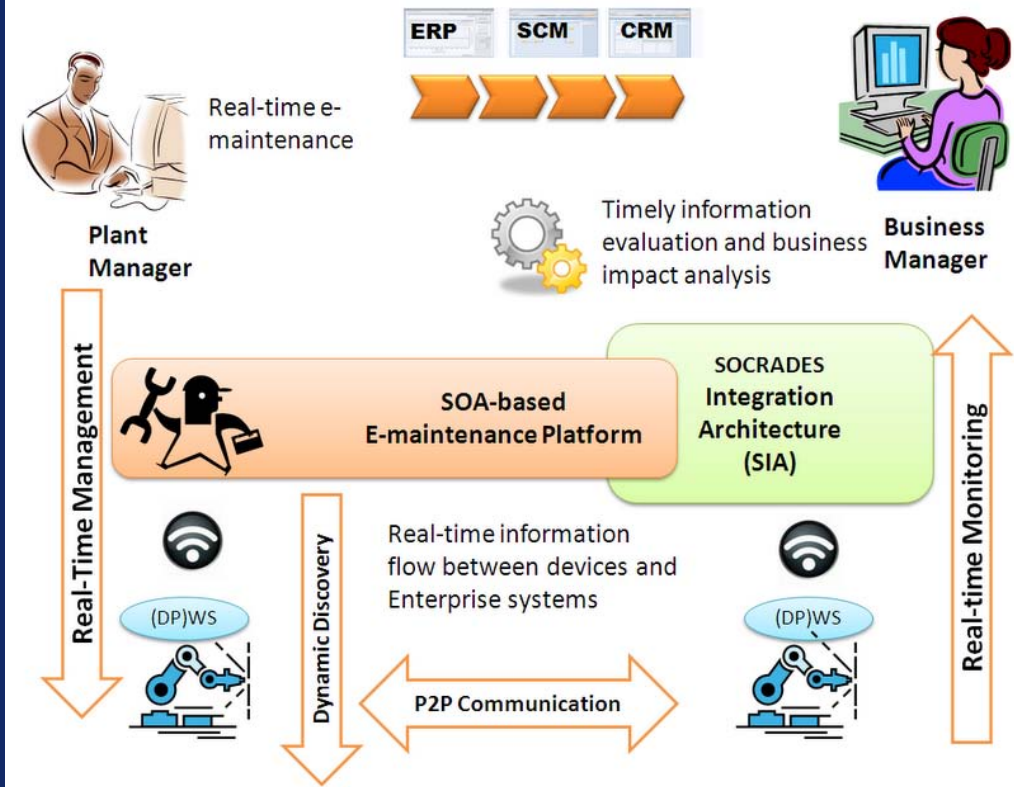
figure 14

Scenario: SOA-based e-Maintenance

This scenario shows how future industrial environments empowered by SOA platforms such as the SOCRADES one can exploit e-Maintenance applications. In particular, since the SOCRADES platform bridges the communication gap between business applications (e.g. ERP) and shop floor applications (i.e. MES), it represents a unique support to implement for example on-line maintenance or collaborative maintenance. The platform represented in the next figure represents the functionalities enabled by SOA-based approach. Monitoring and management are the two fundamental functionalities that are used by the e-maintenance platform, to be combined in more sophisticated service behaviour. As an example, device status can be monitored or an event can be raised by the device itself. As now partial

business logic can be hosted on the device, a direct mapping can be done and the e-maintenance platform knows which parts of the business process are affected. Immediately, automated tickets can be issued, e.g. a remote evaluation of the health status, exchange of the device, or even an order to the ERP system for a repair task to the nearest worker in the field. The e-maintenance platform can provide timely information that can be analysed by a Decision Support System (DSS) and, therefore, can predict or take sophisticated actions on the shop-floor with the goal of maintaining the business continuity. Peer-to-Peer communication among the devices leads also to increased flexibility, as a malfunction device, with the help of the maintenance platform can identify and delegate part of its functionality to devices that host a similar set of services necessary to realize the tasks that are pending on the malfunctioning device.

In Real-time Monitoring, SOA-ready devices provide information on their status to the higher level systems, through a bottom-up communication approach. Information is communicated on an event basis and can be propagated across several layers that support SOA interaction. Raw basic data (e.g. temperature in an industrial oven) or processed information (e.g. expected time to failure derived from condition-based analysis) can be generated and delivered by the device itself as now it hosts logic and computational capabilities locally. Through the e-maintenance platform, information can be conveyed to heterogeneous agents, e.g. plant manager responsible for shop floor operation or business manager, who need fine-grained information from the shop floor level. Moreover, though real-time management a plant manager may directly switch off a specific machine, ask for a maintenance intervention and meanwhile reroute production flow on other machines; all this can be done in a seamless and transparent way thanks to the adoption of cross-layer SOA.

Cross-company communication is already a reality, but constrained at enterprise level only. However, now the real-time connection to the devices will enable them to interact or inform actors over the company level, for their status. As such, malfunctioning of a device that may result in production slowdown may have an impact on the performance of a production line in
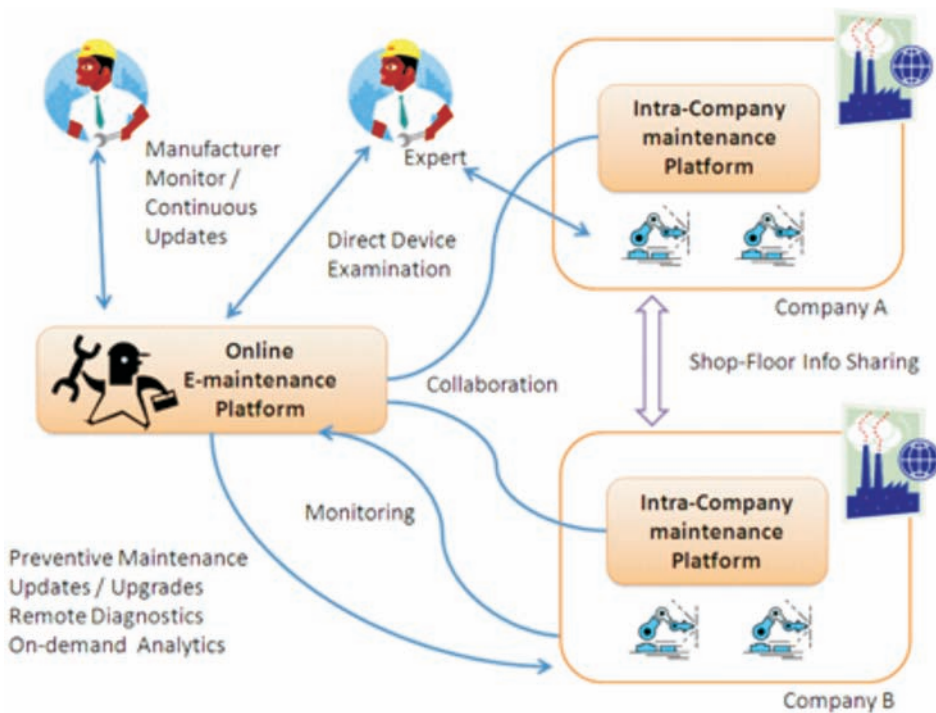
figure 15

another company, which expects input from the first one. As this can now be directly communicated, we avoid costly communication links by propagating the info on all above enterprise layers in both companies. This approach is very well suited for dynamic and short-lived interactions that can be set up, exploited and removed as easy as a simple composite service.

Cross-company collaboration allows us to realize new functionality and innovate at services offered. Especially in case outsourcing of maintenance, specialized partners can now bring in their expertise and monitor remotely the devices at the shop-floor and maintain them. Assets that the company operates on may in future not be owned by the company as such, but instead be provided to them over specific service level agreements (SLAs) e.g. a production line with uptime 99% - how this is achieved and its maintenance is

responsibility of the service provider. As a result, companies can now focus more on their core business, while service level agreements can regulate shop-floor performance that matches better the business process goals, but not how this is achieved, which is responsibility of the e-maintenance partner. This can facilitate the development of new business models based on remote maintenance service delivery through e-maintenance platform.

PRESENT ISSUES IN THE ADOPTION OF SOA APPROACH

At present besides the benefits that come from adoption of SOA approach, some disadvantages/barriers have been identified. These can limit the diffusion of this new approach in the short term. They can be considered challenges that should be addressed and overcome in further development and diffusion steps of SOA paradigm. Most of the following disadvantages are directly linked to the research needs identified in following section "Next steps in Research & Development: SOCRADES Technology Roadmap".

Also with regards to disadvantages, we can define some clusters:

- Technology-related: these disadvantages are related to technological development. Usually they are due to inability of present technology to respect industrial requirements needed for real-life implementation. In these terms they represent barriers to the diffusion of SOA approach.

- Human-related: these disadvantages are related to human factor in the introduction of new technology. For example inertia in introducing new approaches and required investments due to training activities for workers are considered under this category.

Technology-related

Technology for embedded systems (speed): present solution run very well on pc or high-resource devices. Instead when dealing with low resource devices (HW) such as PLCs, there are some problems in real-time capabilities due to excessive slowness of SOCRADES technologies. Indeed, SOCRADES technologies represent an overhead, an increase of communication flows. Proprietary communication is lighter while open communication is heavier. In the future compressed open communication protocol could be a solution (e.g. binary can be comparable with performance of proprietary protocols). Moreover, hardware on the device will evolve fast, entailing that in the future there will be no need for proprietary protocols. It is expected that in approximately ten years, devices will be able to use proprietary or open communication protocols indifferently.

Robustness: at present SOCRADES technologies are not robust enough in order to be implemented in a real production system. This is a transition problem that will be solved through continuous developments of related technologies.

Engineering tools: very powerful engineering tools are required in order to provide the end-user wit exploitable tools that support engineering, automation, and communication modeling of production equipments (e.g. robots, devices, etc.).

Safety: when dealing with safety applications SOCRADES technologies is not (at present) an appropriate solution. This is because standards for safety applications (i.e. checking if communication structure is good enough, etc.) is not available yet. The technologies are not tested enough (the main problems is resource limitation of devices, coming to "Technology for embedded systems (speed)" barrier) for application with human safety risks.

Standardization: at present standards are incomplete, or too limited. Main automation technology providers will have to decide which common standard will be adopted. This is required in order to have real wide diffusion of SOCRADES technologies. A sort of "momentum" needs to be reached; most important automation players should agree on SOA approach. However nowadays this agreement has not yet been completely reached.

Human-related

Training people effort: SOCRADES paradigm adoption in automation domain represents a revolution that requires an extensive and adapted training activity for automation operators within the end-users companies. Indeed asynchronous communication is a completely new approach for automation practitioners. Engineering will need to be re-educated.

Wide paradigm change required: Service-Oriented Architecture approach provides several benefits in B2B, B2C and B2M domains. In order to be effectively implemented SOCRADES requires an overall paradigm shift in the company towards service orientation. If this paradigm shift is done, then SOCRADES will probably be considered as a main technology to be adopted. If instead this paradigm does not happen in a company, it is difficult that SOCRADES technologies will be considered. As a matter of fact, when you adopt SOCRADES technologies you commit to SOA principles.

Lack/inertia of awareness/trust: this is an important barrier that is limiting SOA-based Automation Systems adoption. Indeed, awareness on this new paradigm needs

to be created and pushed especially in the automation domain, where there is a very conservative attitude towards new technologies adoption. A production manger would probably wait until other competitors will move first, in order to reduce risks related to automation paradigm change. The inertia in changing the way of thinking in automation field needs to be tackled.

Corporate politics: for many organizations, the relationship between lines of business and IT is strained or even antagonistic. It is not rare that business management sees IT as a high-risk money sink that places limitations on the ability of the company to execute on its strategic goals. Education in both sides (technical and managerial people) is required in order to better harmonize discussion and decision on such a critical investment.

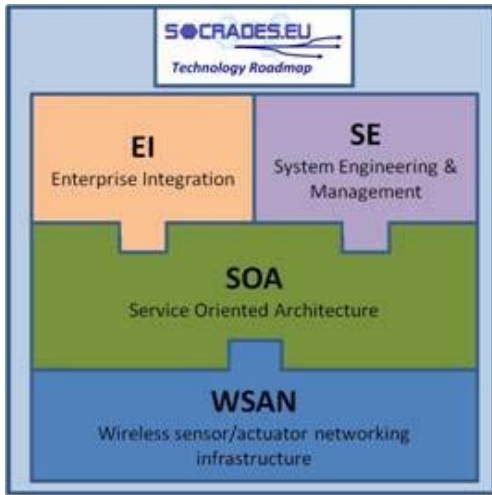# NEXT STEPS IN RESEARCH & DEVELOPMENT: SOCRADES TECHNOLOGY ROADMAP

figure 16 - SOCRADES Architecture

The first step in building the SOCRADES Technology Roadmap is to identify the research areas (called "Technology Areas") which should be addressed and investigated in the future to tackle industrial automation needs. Four Technology Areas have been identified, namely Service-Oriented Architectures (SOA), Wireless sensor/actuator networking infrastructure (WSAN), Enterprise Integration (EI) and System engineering & management (SE); they completely cover the SOCRADES architecture.

Service-Oriented Architectures (SOA)

A service-oriented architecture (SOA) is a set of architectural tenets, i.e. services, for building autonomous yet interoperable systems. In SOCRADES domain, a service can represent, for example, a simple intelligent sensor, a part of a modular machine, or also a complete production system. The adoption of this paradigm, in industrial automation, can improve reconfigurability and flexibility of production systems.
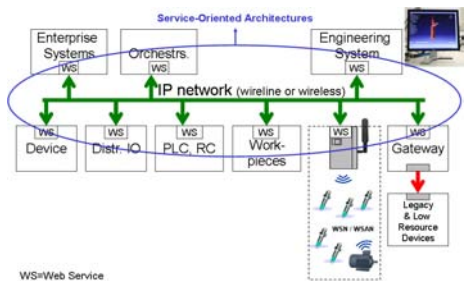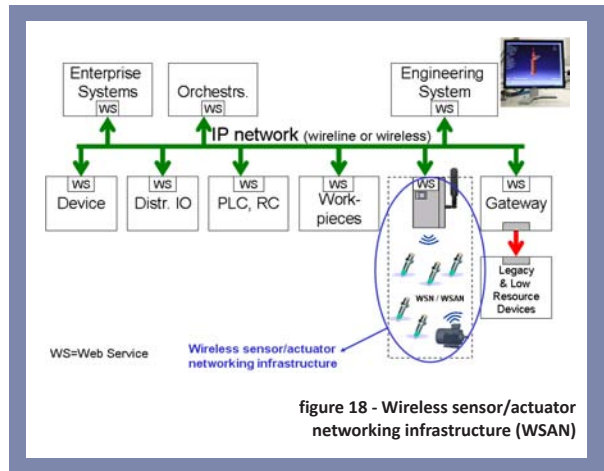

figure 17 - Service-Oriented Architectures (SOA)

# Wireless sensor/actuator networking infrastructure (WSAN)

A WSAN is a distributed system of sensor nodes and actuator nodes that are interconnected over wireless links. For future industrial automation solutions, each individual sensor/actuator will be equipped with a freely programmable processor. This will allow changing paradigm from centralised to decentralised automation. Still, some design issues are not yet completely solved, depending on the actual application.

figure 18 - Wireless sensor/actuator networking infrastructure (WSAN)

Enterprise Integration (EI)

In Enterprise Integration the focus is on seamless link between application layer (i.e. ERP, etc.) and device layer (i.e. PLC, etc.) through a common technological approach, based on the service-oriented architecture (SOA) paradigm. In the industrial automation domain, this will help create real-time enterprises, and exploit intelligence distribution to obtain active participation of devices in business process execution.

figure 19 - Enterprise Integration (EI)
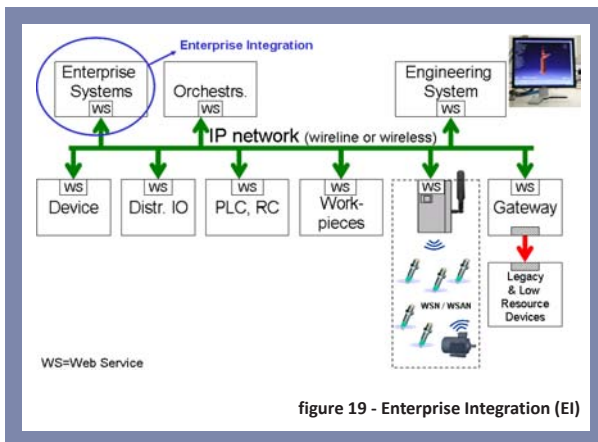
System engineering & management (SE)

System engineering and management (SE) focuses on modelling and logic design of distributed industrial automation systems. SE tools should have the potential to not only automatically generate control logic software but to allow the support of multiple aspects of the production systems engineering life cycle. They may enable higher level design, reconfiguration and visualisation of industrial applications in a virtual environment.

figure 20 - System engineering & management (SE)
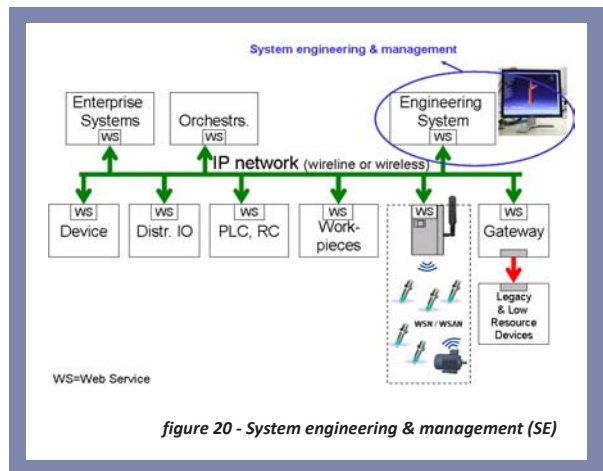
Here, we present the most relevant research topics identified by SOCRADES Project. These research topics are divided following the technology area classification.

Service-Oriented Architectures (SOA)

1. **Orchestration:** the practice of sequencing and synchronizing the execution of services, which encapsulate business or manufacturing processes, is denominated orchestration. An orchestration engine implements the application logic necessary to orchestrate atomic services, and provides a high-level Web Service interface for the composed process. Orchestration represents a key enabling technique, in order to implement and adopt an efficient and effective SOA. The nature of orchestration makes it to be self-evolving: i.e. the orchestration can adapt itself to the requirements of the system in terms of number of services to be orchestrated and ways of

orchestrating them. The issues of scalability, dynamicity, etc. could be addressed with the current concept. However in the future optimization of the orchestration process may increase its complexity; this is due to the increasing number of dimensions of systems (so increasing number of orchestrations, dynamicity, scalability, etc.).

2. **Standardization of basic functionalities (provided by services):** in the future standardization of basic functionalities is needed. This means a list of generic services that are adopted world-wide; UDDI repository can be considered a starting point. A further step is the evolution of standardization in different domains and cross-domain, depending on the specific applications. A separation between the standardization of the communication technologies (such as XML, SOAP, OWL-S, etc.) and the standardization of basic functionalities provided by services is needed. Standardization of basic functionalities is expected to be an active field of research and development.

3. **Legacy Integration:** nowadays existing automation systems are not designed to be interoperable. However it is unlikely that most of the systems will be replaced to be SOA-compliant in the next years, since this could result in an unaffordable investment. Hence, it will be important to support the transition from previous approach to SOA approach. Integration of existing systems (i.e. legacy systems) into SOA paradigm will be required; this could be done through mediators or similar components that provide an interface between previous systems and Service-Oriented Architecture. Hence, legacy integration will be relevant in order to spread the SOA paradigm, since it will be possible to apply SOA paradigm, without having to replace the complete automation systems in an industrial environment.

4. **Decision Support System:** since Orchestration by itself cannot solve every problem arising during the operation of the system, a DSS is expected to increase its importance in the system. Some issues can be handled locally at the lower levels (through orchestration), but by implementing all functions in same level could neutralise the flexibility of the system, so external DSS (implemented with Expert Systems, MAS, etc.) are

expected to become necessary to address complexity and reconfigurability. As an example Real-Time Scheduling will need to be investigated as flexible scheduling will become more prevalent.

5. **Context-aware services: t**his is the capacity of services being aware of devices, of factors such as service location or service state and in general of their environment and reacting, by adapting their functionality. Semantic description of services and ontology should be the proper tools in order to describe context, however the present state of the art does not fully address how the implementation should be carried out. Main limits are: no language to describe context and no ability to make context composition.

6. **Run-time behaviour of a SOA:** model of concurrency is core of a real-time program. Whilst concurrency model of high-integrity systems is well understood and has found representation in subsets of languages, the model is conservative. There is a need for more expressive subsets. Further solutions for handling concurrency, embodying multiple levels of abstraction have to be researched. Moreover, further study of Quality of Service models suitable for SOA (e.g.: Service Level Agreement, etc.) is required.

Wireless sensor/actuator networking infrastructure (WSAN)

1. **Quality of Service:** in the future Quality of Service at WSAN level will be the main important feature. This includes Real-time performances as well as Determinism, and Reliability of sensors.

    a. **Real-time service:** Discrete manufacturing requires data sampling rates in the millisecond range, motion control even in the sub-millisecond range, while process control applications are satisfied with hundreds of milliseconds. These are challenges to current WSANs as, firstly, wireless links by nature are less stable than wired ones and, secondly, such real-time
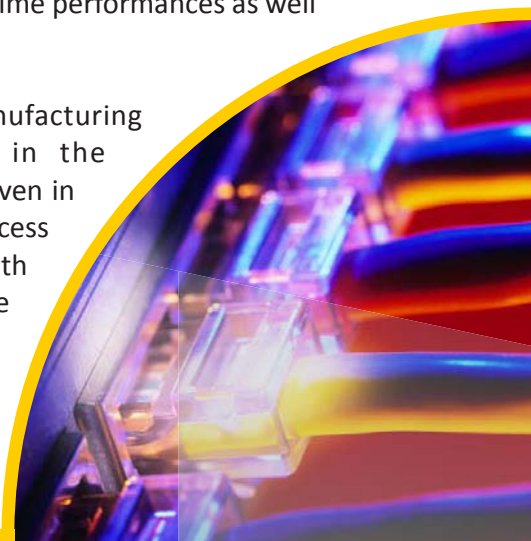
requirements imply a higher degree of energy consumption than non-real-time. WSANs currently do not meet the hard real-time requirements of motion control and discrete manufacturing while those for Process Automation are within reach. However, minimization of delays needs to be tackled; this may be done through performance improvements of software and hardware and/or by changing from time-based event-based data exchange (see also "Enhanced Efficient Data Processing").

b. **Determinism:** this is related to the reliable delivery of data packets with a guaranteed (mainly maximum) delay within a WSAN. As the wireless medium is an open one and subject to inference by machines or other wireless networks, this requirement is difficult to fulfil especially for hard real-time applications in discrete manufacturing or motion control.

c. **Reliability of sensors:** in particular concerning the integration of support for dependability and real-time, continues to be an important research topic (both from a timing specification and scheduling perspective). High-level dependability mechanisms (including application-level ones) are complementing low-level mechanisms so that the distributed application running on the sensor network as a whole exhibits reliable/dependable behaviour even if parts of the HW/network fail. This can be achieved for instance by reassignment/relocation of important tasks to working nodes.

2. **Interoperability (heterogeneity):** today's WSAN technologies are mainly proprietary and do not provide product and/or vendor interoperability. This incurs higher costs and slows down market adoption. The emergence of WSAN standards (ZigBee, ISA SP100, WirelessHART, 6lowpan, etc.) should facilitate the deployment of increasingly large industrial wireless networks at both plant and field levels. Since the integration of different smart embedded devices will enable a huge number of application

possibilities, this research topic is extremely important. A key issue is the development of new models to deal with the complexity involved in such large and scalable systems.

3. **Self-X Features:** for reasons of easier engineering, easier maintenance, etc. features like self-organization, self-optimization, self-healing, self-configuration, self-stabilization, self-describing etc. are of highest importance. In their maximum extent this would mean a WSAN which does not need any engineering, maintenance, configuration, or human care at all. Even if simpler self-x features already exist, as e.g. self-description, higher levels of self-x, as e.g. self-optimization, are more or less only in their infancy. R&D should be done in order to investigate how a completely autonomic system can be controlled/configured from outside, taking into consideration the different needs for autonomicity in various automation scenarios.

4. **De-centralization:** intelligence and processing tasks are shifting towards devices/field level; examples are management, control and data processing tasks carried out by sensors and actuators instead of a central gateway, controller or network manager. In order to reach de-centralization, the elimination of the network coordinator, even within large networks, will be required in the future. Of course, de-centralization should not be considered a dogma for all devices: some might still be communicating directly to the central unit. Generally decentralization can add robustness, flexibility and scalability to the system by reducing the number of centralized critical points. For factory Automation de-centralization at the moment is impossible due to the requirements for real-time and determinism. In Process automation applications with less stronger demands for real-time and (in some cases) determinism, first degrees of de-centralization and meshing are already realizable. One main issue that should be solved in order to support this feature is the related to standards, in particular concerning cross-layer communication.

5. **Energy autarky (self-sufficient devices):** as a WSAN is thought to be communicating wirelessly, it makes no sense that there are still wires left for power supply. Correspondingly, another way of
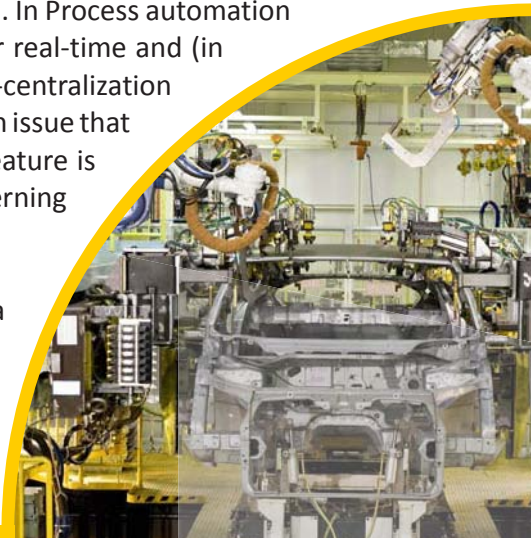
powering the single devices in a decentralized manner has to be found. This might be (very powerful) batteries, ways of energy harvesting, or a hybrid systems of both approaches. This is still a very demanding research topic with only very limited solutions. Some "wireless" way that may enable energy harvesting and energy transmitting should be developed. Another way to reach energy autarky should be improving optimization of energy usage and power management: e.g., activating sensors only when useful – in this case we may talk about Reactive Awake Device.

6. **Enhanced Efficient Data Processing:** event based control at level should be used to improve performance of data communication. When adopting "Push-based" approach, information is transmitted when ready (push logic), not when required (pull logic). For example considering a sensor moving between two checkpoints, if between them new information is generated, the information is transmitted, otherwise not. This helps in reducing waste of communication's resources. Moreover, information has to be propagated within the network through aggregation/fusion rules to avoid overloads but guaranteeing the provision of required/useful information. Finally, efficient communication is important in order to avoid energy waste. Energy use is linked to frequency of communication and to duration for each communication.

Enterprise Integration (EI)

The use of the service-oriented architecture (SOA) paradigm, implemented through Web Services technologies, at the ad hoc device network level enables the adoption of a unifying technology for all levels of the enterprise, from sensors and actuators to enterprise business processes. The benefits of service-orientation are conveyed all the way to the device level, facilitating the discovery and composition of applications by re-configuration rather than re-programming. Dynamic self-configuration of smart embedded devices using loosely-coupled services provides significant advantages for highly dynamic and ad hoc distributed applications, as opposed to

the use of more rigid technologies such as those based on distributed objects.

1. **Flexible Production with Enterprise Support:** future manufacturing plant will be connected to all its vital components: workers, machines, and products. To have automatic integration of manufacturing data, widening the view of manufacturing both vertically and horizontally is needed. This implies also concepts/techniques for autonomous production (i.e.: production orders automatically followed by self-preparation of machines, supply chain activation, production and self-qualification of produced parts).

2. **Device to Business Integration (D2B Integration):** device manufacturers are increasing the amount of embedded software in their products. Hence, devices can handle several computing/communication tasks, but they can also provide their functionalities as services. Therefore, devices can participate in business applications by providing information from their domains and consuming services at enterprise level (e.g.: devices can directly trigger an event in the business process and affect its execution).

3. **Cross-layer Adaptive Modelling:** as software development is becoming more complex, model-driven engineering technologies can help alleviate the complexity of platforms and express concepts effectively. Approaches that effectively handle service modelling and management of intelligent distributed business processes in highly populated web-service-enabled device infrastructures are needed. Business logic traditionally resided at high-level systems but in the future it will be distributed in several layers.

4. **Security / Service Policy Compliance:** the future foresees an open infrastructure where rapidly changing business processes and collaboration among companies at several layers are occurring. The openness and heterogeneity of such systems is requiring a different security approach from that of traditional systems and architectures. These security architectures must be tailored to application-specific security requirements, comply/adapt to laws, and be seamlessly integrated with security environments.

5. **Industrialization of software development:** software built for automation domain is often developed from scratch. However as the heterogeneity and applicable domains increase, it will be impossible to keep up tackling all needs at high quality. What is needed is to "industrialize" at a fine grained level the process of creating software in order to be able to rapidly configure, adapt and assemble independently developed, self describing components to produce families of similar but distinct systems.

System engineering & management (SE)

1. **Efficient/effective (re-)configuration:** ability to configure systems built from SOA-enabled modules both statically and dynamically in a standardized manner, e.g., with predictable system performance. Flexible use of systems components coupled with a high-level system configuration capability (e.g. ERPs). Whilst individual system components may be of relatively low complexity, effective overall system configuration and change management are of key importance to the end-user.

2. **High level process definition:** the ability to describe the overall behaviour of systems composed of many distributed devices in a high level process description language, which directly relates to the specific process the user is concerned with. The mapping of desired process behaviour to control systems is very time consuming and error-prone. In the future standardization of process definition and standardization of definition tools are expected in order to make the process more open and standards based.

3. **Collaborative, integrated, distributed business-driven engineering:** systems capable of being configured and managed in a global business context. Support for globally distributed engineering teams. In future Web-services offer the promise of better, more open enterprise integration. This includes SOA-enabled Cooperative Lifecycle Management Design to improve the design phase in a global scenario, and maintenance, live run monitoring tools and also tools to improve the design phase of maintenance.

4. **Service-oriented engineering:** engineering support provided primarily through the provision of services rather than on-site engineering activities, e.g., diagnostics, expert assistance, and process optimization will be remotely provided. Nowadays, it is provided on a single vendor/product basis. In a competitive globalised market the effective utilization of remote services will offer a key competitive advantage. SOA will help this type of remote support by linking various systems both physically and in conceptual terms.

5. **SOA-enabled Digital Factory:** this includes seamless integrated digital engineering, i.e. seamlessly mix the engineering of digital, and real system components. Moreover, fully digital mock-up of machines, i.e. overall digital representation of machines, including mechanical structure simulation, process simulation, and prediction/validation of production results in design-time. Finally, Product Lifecycle Management, i.e. tools to design, analyze and manage machine tool products through all their lifecycle.

6. **Systems of systems engineering:** this is a new approach that is becoming more and more relevant in engineering domain. Systems of systems engineering requires tools and methodologies to tackle the complexity of systems made of numerous systems. SOA can support by definition the transition towards systems of systems engineering, through de-centralization of control. However appropriate tools and methods still need to be developed.

FINAL RECOMMENDATIONS

Enterprise applications support business activities in companies, so that they can manage complexity and be more effective. The service oriented architecture (SOA) concepts empower modern enterprises and provide them with flexibility and agility. These concepts nowadays expand towards the shop-floor activities, down to the device level. By implementing web services on the devices natively, we are able to push down at item level SOA concepts. The use of device-level and cross-layer SOA contributes to the creation of an open, flexible and agile environment, by extending the scope of the collaborative architecture approach addressed before through the application of a unique communication infrastructure, down from the lowest levels of the device hierarchy up into the manufacturing enterprise's higher-level business process management systems. For the technology developers, the specification, design and implementation of the components of the SOA infrastructure is a big challenge and a multi-disciplinary task.

In order to go towards extensive implementation of SOA-based Factory Automation six suggestions are recommended to policy-makers and generally to stakeholders that want to support SOA paradigm in industrial automation.

1. **Engineering systems & tools:** there is a clear need for ready-to-use engineering tools that are able to support end-user in the design, execution, management and maintenance of industrial automation systems. Without these tools interesting concepts and benefits enabled by SOA approach cannot be exploited. The concept of systems of systems engineering is more and more relevant in current manufacturing domain. Tools that can handle inherent complexity of systems of systems (made of distributed embedded devices) are required.

2. **Legacy systems integration:** it is unlikely that most of present industrial automation systems will be replaced to be SOA-compliant in the next years, since this could result in an unaffordable investment. Hence, it is fundamental to support the transition from previous approach to SOA approach. Integration of existing systems (i.e. legacy systems) into SOA paradigm is required. Legacy integration is a key driving feature to spread the SOA paradigm.

3. **Technology development:** nowadays still improvements to improve technical performances of SOA-based platforms are required. Indeed, present

performances are not always enough to go for implementation in all domains. While some domains present not so strict technical requirements, some other domains (e.g. pharmaceutical, continuous process, etc.) requires performances in terms of for example communication delays and security that cannot fulfilled by SOA technologies at present. Both hardware (to improve computing capability at low cost) and software (to improve optimization of algorithms) are expected and should be pushed in the next future.

4. **Business Evaluation:** in order to reduce the gap between technical and managerial people within companies and to support fair discussion on SOA-based Factory Automation, business evaluation is required. Development of prototypes that show improved performances enabled by SOA approach and that can be economically quantified in terms of benefits and cost is required. Prototypes or trials should reproduce the same industrial setting with or without SOA-based automation systems, in order to clearly show differences of performances in the two approaches.

5. **Education & Training:** there are two domains where attention on education is raised: marketing and engineering. With regards to marketing there is a need to sell reconfigurability and interoperability as valuable functionalities, these features should be clearly understood by marketing experts in order to drive business models through exploitation of these enhanced capabilities obtained by SOA-based industrial automation adopters. With regards to engineers, education is required since in order to pass from concept of control-oriented structure to task-orientation (with orchestration of services) a real revolution in the way of thinking needs to be carried out by automation engineers. Hence clear communication and training is extremely relevant.

6. **International cooperation:** SOA-based Factory Automation can be fully exploited if several players agree on standards to be adopted. Hence in order to agree not only formally but also substantially on common methods, technologies, and standards there is a need for international cooperation though research and developments projects. This can be conducted not only at European but also at International level, leveraging existing programmes, e.g. Intelligent Manufacturing Systems (IMS).

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APPENDIX A: METHODOLOGICAL NOTE

This version can be considered an "executive summary" of the complete roadmap developed within the SOCRADES project. The methodology used to build the SOCRADES Roadmap is composed by several steps, summarised in the following figure.

figure 01
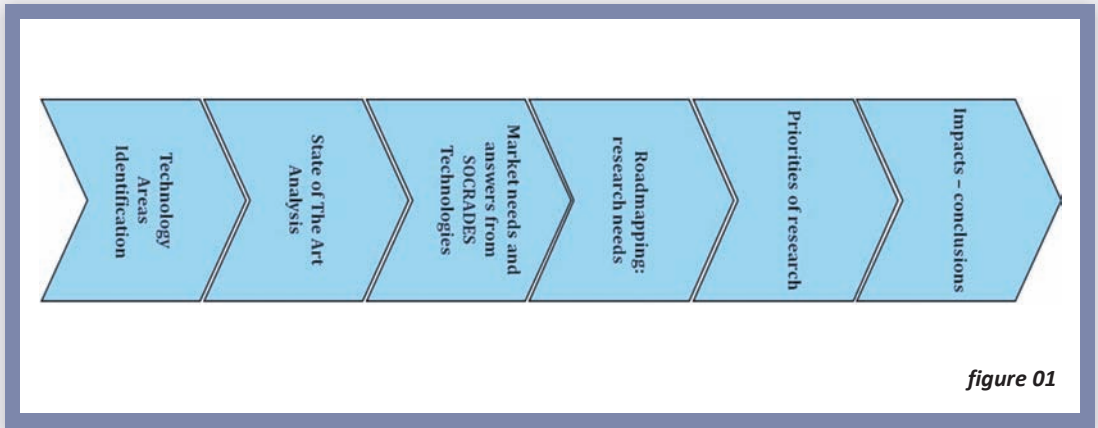
1. **Technology Areas Identification:** SOCRADES Roadmap Scope. The first step has been to identify clusters where to focus research activity. They have been named Technology Areas (TAs). These TAs constitute the scope of the document.
2. **State of The Art Analysis:**

    a. In order to have a clear picture of the Technology Areas identified a state of the art analysis has been conducted. The aim is to provide a consistent starting point of the roadmapping activity.
    b. After analysing the technologies state of the art, it is important to review existing roadmaps related to SOCRADES scope, in order to understand both their structure and the connections between their content and SOCRADES technology areas.

3. **Market needs and answers from SOCRADES Technologies**
Market needs and trends in SOCRADES Area are relevant to be included in the roadmapping process in order to support the Technology Roadmapping activity with clear business justification. Impacts of SOCRADES Technologies, that help tackle future Industrial Challenges, have been investigate and presented.

4. Roadmapping: research needs

For each technology area, research needs that are relevant for future investigation. Such research needs have been identified according to a mix of two approaches:

    a.   A data based approach, founded on the results coming from the State of The Art & Market Analyses

    b.   A workshop based approach, founded on some workshops organized with experts (both experts from SOCRADES consortium and external experts were involved in different times).

5. Priorities of research.

This section should focus on suggesting some priorities among the research needs identified in the previous step. These priorities should be considered the most relevant and effective research actions that need to be tackled. A survey based approach, founded on the results coming from the previous step has been used in order to define priorities.

6. Impacts – conclusions.

The concluding step of the roadmapping process is a synthesis of both business and technological issues in order to derive a set of recommendations/further steps to be implemented in the next future.

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