Evaluating the potential of a service oriented infrastructure for the factory of the future

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***Abstract*—The Service Oriented approaches are seen as a key trend for managing the demanding future factory infrastructure. Within SOCRADES [1], an advanced infrastructure based on SOA has been designed and implemented in order to accommodate envisaged needs of the factory of the future. As a proof of concept, several prototypes have been implemented. Our goal was to demonstrate that we have realized a really innovative approach for device to business connectivity, which can have a significant impact on the business side, going well beyond existing approaches. We have made an evaluation of the SOCRADES approach for the automation domain, where we investigate the benefits and opportunities that may come from adopting the SOCRADES approach, such as cost reduction, improved performance and new opportunities. We also take a critical view on possible barriers or disadvantages such as technology and human related issues that may not make the SOCRADES vision a reality.**

I. Motivation and Methodology

Monitoring and control (M&C) heavily depends on the integration of embedded systems. The world M&C market is expected to grow from 188 bn€ in 2007, by 300 bn€, reaching 500 bn€ in 2020 [2]. The M&C European market follows the same trends as the M&C world one in terms of product repartition and also markets products evolutions. The European M&C market will be reaching 143 bn€ in 2020; this will have a significant impact in several domains and more specifically in manufacturing, process and smartgrid domains. We consider that the architectural and technological concepts developed within SOCRADES [1] have the potential to empower early-adopters as possible technology leaders in Service-Oriented Process Monitoring and Control.

Despite the relevance of the market is manifest, impacts of Service-Oriented Architecture applied to Industrial Automation domain are not yet investigated. Since real implementations are missing, quantitative evaluation is not possible at present. However qualitative analysis of the heterogeneous impacts of the adoption of such a pervasive approach can be performed; this is required in order to provide the potential adopters with a clear picture of opportunities and threats related to SOA-based Automation Systems.

To fill this gap, we have conducted telephone interviews, discussed with key experts and assessed feedback from one workshop organized especially for this goal. The 30–60 minutes telephone interviews were conducted with 15 industry and academic experts. The aim of the telephone interviews was to get a general view of the SOCRADES approach, the architecture and a detailed understanding of the already implemented demonstrator. The interviewed persons were asked to answer a couple of classification questions about their background and field of work, in order to find out which input they can contribute, and to determine the focus for the interview, e.g. technical or economical aspects concerning the architecture or the approach, or costs and benefits of the demonstrators. The interview participants were asked to evaluate the overall SOCRADES approach, especially determining the opportunities and threats, as well as specific features.

Last but not least, interviews were conducted not only with SOCRADES members (who were more aware of the specific technologies developed), but also with external experts coming from the scientific community related to SOA-based Automation Systems; the latter interviews were conducted to provide for an evaluation from an external point of view, increasing the robustness of the evaluation. They took place on a face-to-face basis in Cardiff, UK on June 25th, 2009 (within the IEEE INDIN 2009 conference) where several experts in SOA-based Automation Systems domains participated in the "SOCRADES Roadmap Workshop".

II. SOCRADES: A SOA based integrated infrastructure

The SOCRADES approach can be summarized as the application of the Service-Oriented Architecture paradigm to next generation industrial automation systems [1]. The Service-Oriented Architecture concept has been developed within the Information and Communication Technologies (ICT) domain in order to increase the modularization of software. This enables several features such as reusability, distribution of control, etc. Similar benefits are expected through the adoption of the SOA paradigm in production systems, where their autonomous components (devices) can cooperate and interact in a distributed manner. Nowadays, even if SOA is a well-known concept and several applications use it at an enterprise level, the adoption of the SOA paradigm at device level in

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order to support the automation of production systems is still in an early development phase. If we consider the hype cycle representation developed by Gartner [3] to represent the maturity, adoption, and business application of specific technologies, we can say that SOA technologies for Industrial Automation Systems (from now on SOCRADES technologies) are still in the Technology Trigger phase. Due to the early diffusion stage of these technologies, it is quite difficult to evaluate benefits coming from their adoption. Hence to point out the specific value of SOCRADES, in this paper we qualitatively address the distinguishing features of the SOCRADES approach and identify benefits that come from its adoption as well as disadvantages that represent current barriers for its diffusion.

There are different features that distinguish the SOCRADES approach: we highlight the most relevant ones.

Loose-coupling: by adopting the SOA paradigm at the device level, SOCRADES approach is characterized by loosely-coupled communication. Indeed, relationships among components (devices) are not implemented through strong communication connections. Devices instead interact through messages in an asynchronous and autonomous manner. Since devices are seen as components that can provide a variety of services, the sole required information in order to allow basic interaction among devices is the list of services provided by them. Even if this feature is not tremendously new in the area of automation systems, there are few real implementations adopted by industry at present. More sophisticated interactions such as cooperation can be achieved also with infrastructure assisted services.

Modularization of systems: in a SOA-based automation system each component can be seen as an independent module that provides its functionalities through a set of services. Therefore, control does not need to be programmed on the overall system but can be done for each module, without considering the context in which it will be included. Effort in providing coordination (orchestration) among modules is the specific activity required in a SOA-based automation system. It is worth noticing that at present, the SOCRADES approach tackles modularization of automation systems in terms of software for their control, while hardware is not specifically addressed. Nevertheless, also hardware modularization will be required in the future in order to spread SOCRADES approach among industrial companies.

Distribution of control: another feature, linked to modularization, is distribution of control. The SOCRADES approach allows distribution of control beyond the level of "clustered machines", enabling control to be distributed down to the single machine level. These features can entail higher or lower benefits depending on the specific industrial domain in which the SOCRADES approach is adopted (e.g., process industry vs. discrete manufacturing).

Common communication protocol: The SOCRADES approach adopts the SOA paradigm as the unique communication architecture. This facilitates communication and interaction among heterogeneous components of the production system and in particular this leads to three specific sub-features:

- Vertical integration from low level (devices) to high level (enterprise systems): thanks to the adoption of a common paradigm, i.e. service orientation, cross-layer communication is inherently supported. Indeed, a device can cooperate with another device (same level) or with an application provided by the enterprise system (higher level) through the same approach, i.e. by exchanging information on the services required/provided by the interacting components.
- Cross-company (supply chain) seamless integration: SOA as a common paradigm allows seamless collaboration among different elements of the supply chain. Moreover, the complete process from the raw material to the final product could be represented and described in a common fashion. These features may turn into higher or lower benefits depending on the specific context in which they are applied (for example in a complex supply chain this feature could be especially useful in order to better understand the overall production process and provide reliable traceability services to the customer).
- Real-time monitoring: through implementation of the SOCRADES approach, real-time monitoring of devices that compose the production system can be obtained. Indeed, through the seamless communication infrastructure provided by service orientation, devices can directly communicate to higher-level systems in an event-based manner, enabling real-time view on production status. Timely information dissemination enables several benefits for end-users as well, such as line balancing, enhanced collaboration across the supply chain, etc.

These generic features are valid to any application of the SOCRADES approach regardless of the specific industrial domain in which they are applied. The next section will focus on benefits coming from the SOCRADES approach; in this case specification of different applications will be required in order to highlight benefits in their defined scope.

III. Preliminary Adoption Benefits

Since there is no real implementation available on the market, the benefits and opportunities that come from the adoption of the SOCRADES approach are very difficult to be measured quantitatively. However, several qualitative considerations on the specific benefits that come from the SOCRADES approach can be done. It is important to separate different industrial application domains, since they entail different benefits or at least different perceptions of the same benefits by end-users (for example re-configurability of production systems is much more seen as a benefit by cell-phone producers rather than from steel pipes producers). Hence, in this section we highlight benefits of SOCRADES by pointing out if benefits are applicable in particular to the process industry, to discrete manufacturing, to technology vendors, or to end-users.

Moreover, benefits can be clustered into three dimensions:

- Cost reduction: benefits that directly imply cost reduction

through adoption of SOCRADES approach e.g. reduced time and cost in installation of new machines.
- Improved performance: thanks to the SOCRADES approach some performance measures could be improved. This may also entail cost reduction on the final effect. However, the focus of the benefit is more directly related to improved performance (e.g. reactivity is enhanced thanks to more reconfigurable production systems).
- New opportunities: benefits are clustered under this category when they open new business opportunities, e.g. using SOCRADES approach technology providers may sell engineering tools coupled with the logic included in the automation devices.

A. Cost Reduction

Push competitiveness of device vendors: from a customer perspective advantages are possible 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 the service point of view. This specific characteristic, enabled by the SOA paradigm, will increase competition among pump producers. Generally, device manufactures will be pushed to improve their cost-benefit ratio. Nowadays, industrial automation producers use proprietary technologies also in order to "retain" their customer base, since changes of single devices are extremely difficult and costly without a common/shared communication infrastructure [4]. This benefit is both referring to process industry and discrete manufacturing.

Labor cost reduction (solution sold to end-users): this is a specific benefit for the end-user, since with a SOCRADES adoption less skilled people are required to run, operate, and manage the production systems. It is important to notice that industrial systems know-how is disappearing, due to worker movement within industrial companies. 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 need for costly expert workers. On the other side, 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 the exploitation of the SOCRADES approach, in other words, this is an on-going end user process of outsourcing the activities of design and management of production systems.

Installation time/cost reduction: through the SOCRADES approach agility grows. Indeed, nowadays each automation installation is one of a kind; this means that it is designed and built from scratch, and that deep expertise in different network technologies is required to configure, use, and maintain them (e.g., Profibus, Hart, wirelessHart, etc.). By using higher level modeling 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. Hence, also cost associated to production systems engineering will be reduced. In particular it is expected that a 30% reduction of engineering cost is realistic through adoption of SOCRADES technologies, while a reduction from 10% to 15% of installation time is also expected. As such SOCRADES 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 of devices such as sensors, actuators, etc. need to be installed, replaced, and removed. It has been confirmed that in process industry, one sensor every week is added to the production system. This shows how important an infrastructure that supports easy and seamless installation of new devices could be. Moreover service adoption can reduce the risk for compatibility problems while installing new devices into systems using heterogeneous software. This may avoid significant monetary losses.

Interoperability (compatibility): thanks to loosely-coupled approach and common communication protocol, interoperability among devices and machines developed by different vendors and at different times can be obtained. This is extremely relevant in order to reduce cost associated with building production lines, since old machines can be used together with new ones without much new investment in communication architecture modifications. This is an important benefit both from an end-user perspective (process industry and discrete manufacturing) and from a technology provider perspective. Technology providers benefit since production systems upgrade cost are reduced for end-users, hence increasing the possibility of incremental investments by end-users.

Reduced complexity for technology suppliers: 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 for a higher-level programming approach. This reduces programming time for automated production systems since control software does not need to be developed from scratch, improving the overall software quality of the embedded devices. Since today it is very time consuming to e.g. 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 the SOCRADES approach relates to the support of cooperation among production systems of different companies. This benefit may be exploited for a 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 the case where one of the suppliers cannot provide the required material in time due to a breakdown in its production systems, the manufacturing company can easily switch from one supplier to the other in short time and at reduced cost.

B. Improved Performance

Reduced maintenance activities: 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 whole devices. However the most important benefit is the on-demand maintenance and proactive monitoring with the usage of e-maintenance platforms. As a result, cost related to maintenance activity will be reduced. Moreover, since automation systems are made of self-contained components with self-diagnosis capabilities, cost reduction in the overall 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 other systems only issues that cannot be handled locally. 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 can be activated only when required. This could turn out in 30%–40% of cost reduction depending on the systems. The more complex the system is (e.g. number of devices), the higher cost reduction is expected with the use of distributed control system enabled by SOCRADES.

Optimization through better visibility: thanks to the adoption of a common communication infrastructure (IP, SOA), 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 re-configurability (of production lines): from the end-users point of view, production lines can be easily and quickly reconfigured, through the adoption of higher level modeling and modular systems. This benefit is extremely important especially in those industrial domains where production lines need to be often modified. For example in the automotive industry, approximately every 6–9 months a new product is introduced, requiring modification on the production lines. In the past, production lines were sold after being used for a specific product, but nowadays they stay longer in the factory and need to be reconfigured in order to manufacture new products. Hence, quick reconfiguration of production lines is a competitive advantage in the automotive industry. Moreover, re-configurability helps reduce the time-to-market in a low-cost manner.

Reduction of human errors: with SOCRADES it is possible to plug in devices that are automatically recognized by the system (dynamic discovery and connection). This reduces human errors, and related cost. Since the physical world can communicate directly with business systems, without people having to provide explicit predefined "interfaces" between the physical and the "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 the production system status that may be exploited for line balancing optimization. For example, real-time information could be used in order to decide on the best machine to produce a new product. This could be particularly relevant in case of failures of production system 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 the SOCRADES approach. This activity usually takes time and can entail costs.

Legacy systems support: SOCRADES support legacy systems integration [4]. This is an extremely important benefit in the transition phase from former to new automated production systems. Since SOCRADES can realize the migration from legacy to service-oriented infrastructures through gateways/mediators, opportunities to spread SOCRADES technologies while keeping existing systems are expected.

C. New Opportunities

Engineering tools offered by technology providers: technology providers may enter new business domains 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.

		End-Users		
Focus	Benefits/opportunities	Discrete Manufacturing	Process Industry	Technology Provider
Cost reduction	Push competitiveness of device vendors	●	●	◔
	Labor cost reduction (solution sold to end-users)	●	●	●
	Installation time/cost reduction	●	◕	○
	Interoperability (compatibility)	●	●	◕
	Reduced complexity for technology suppliers	○	○	●
	Programming time reduction	●	◔	○
	Interoperability (cross-company)	●	●	○
Improved performance	Reduced maintenance activities	◕	◕	○
	Cost reduction through increased utilization	◕	◑	○
	Optimization through better visibility	●	●	◔
	Reactivity through re-configurability	●	◕	○
	Reduction of human errors	◕	◕	○
	Line balancing	●	◔	○
	Legacy systems support	◕	◕	◑
New opportunities	Engineering tools offered by technology providers	◔	◔	●

Figure 1. Impact of benefits of SOCRADES on specific industrial domains

In Figure 1 the different benefits coming from SOCRADES adoption have been qualitatively aggregated following the categories presented before in order to show a comprehensive and simple view on the potential business impacts of SOCRADES adoption. The qualitative description presented before has been represented through a five level grading. The empty circle (○) represents the lowest impact of the benefit on the related cluster. The more the circle is filled, the more the benefit is envisaged on the specific cluster. The fully filled circle (●) means that the specific benefit clearly impacts the referred target.

IV. Adoption Barriers

At present, some disadvantages/barriers have been also identified. These can limit the diffusion of SOCRADES technologies in the short term. They can be considered challenges that should be addressed and overcome in further development and diffusion steps of SOCRADES technologies. Also with regard to disadvantages, we can define some clusters:

- Technology-related disadvantages/barriers: 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, hence representing barriers to the diffusion of the SOCRADES approach.
- Human-related disadvantages/barriers: these disadvantages are related to human factors in the introduction of new technologies. For example, inertia in introducing new approaches and required investments due to training activities for workers are considered under this category.

A. Technology-related

Technology for embedded systems (speed): present solutions run very well on PCs or high-resource devices. Instead when dealing with low resource devices (HW) such as PLCs, there have some problems in terms of real-time capabilities. Indeed, SOCRADES technologies represent an overhead, an increase of communication flow. Proprietary communication is lighter while open communication is heavier. In the future, compressed open communication protocols could be a solution. Moreover, hardware on the device will evolve fast, entailing the required computational performance needed by SOCRADES. It is expected that in approximately ten years, devices will be able to use proprietary or open communication protocols indifferently.

Robustness: 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 with tools that support engineering, automation, and communication modeling of production equipments (e.g., robots, devices, etc.).

Safety: when dealing with safety and mission critical applications, SOCRADES technologies are not (at present) an appropriate solution. The technologies are not tested enough (the main problem is the resource-limitation of devices leading to "Technology for embedded systems (speed)" barrier) for application with human safety risks.

Standardization: main automation technology providers will have to decide which common standard will be adopted. This is required in order to achieve a wide diffusion of SOCRADES technologies. A sort of "momentum" needs to be reached; most important automation players should agree not only SOA (this is already widely accepted), but on the specifics of how this is applied in an open and standardized way. Today, this agreement has been not yet completely reached. For widespread industrial use, this needs to be resolved (e.g., by making sure that implementations adhere to a test suite).

B. Human-related

Training people effort: a 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. Engineers will need to be re-educated.

Wide paradigm change required: SOA approach provides several benefits in B2B, B2C, B2M, and even M2M domains. To be effectively implemented, SOCRADES requires an overall paradigm shift within the company towards service orientation. If this paradigm shift is done, then SOCRADES will probably be considered as main technology to be adopted.

Lack of awareness/trust: this important barrier 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 manager would probably wait until other competitors move first, in order to reduce risks related to automation paradigm changes.

In Figure 2 we present the disadvantages described together with a qualitative indicator of impact on the different perspectives: End-Users (Discrete Manufacturing and Process Industry) and Technology Providers. Similarly to the approach used for Figure 1, empty circle (○) means that the barrier does not affect the specific target, while full circle (●) means that the barrier fully impacts it. In order to overcome Technology-related barriers, several challenges need to be solved. These challenges have been identified in the SOCRADES Technology Roadmap [5], hence links to those technological challenges are provided in Figure 2.

V. Discussion and conclusions

The SOCRADES approach enables enterprise-level applications to conveniently interact with and consume data from a wide range of networked devices using a high-level, abstract interface that features web services standards. Those standards already constitute the standard communication method used by the components of enterprise-level applications. Web-services are the commonly communication used for business processes, which are frequently modeled as orchestrations of available web services. This allows networked devices that are connected to the SOCRADES middleware [4] to directly participate in business processes.

Focus	Disadvantages /barriers	End-Users: Discrete Manufacturing	End-Users: Process Industry	Technology Provider	Links to SOCRADES Roadmap
Technology-related	Technology for embedded systems	●	●	●	In SOA TA: • Lean data generation and processing • Common Language • Run-time behavior of a SOA In WSAN TA: • Energy autarky • Enhanced Service oriented Features • Enhanced Efficient Data Processing In EI TA: • Device to Business Integration
	Robustness	◕	●	◑	In WSAN TA: • Robustness • Security (cross-layer) In EI TA: • Security / Service Policy Compliance
	Engineering Tools	●	●	◑	In WSAN TA: • WSAN deployment tools In EI TA: • Cross-layer Adaptive Modeling In SE TA: • WSAN deployment tools • High level process definition • Collaborative, integrated, distributed business-driven engineering • Service-oriented engineering
	Safety	◕	◕	◑	In WSAN TA: • Security (cross-layer) In EI TA: • Security / Service Policy Compliance
	Standardization	●	●	●	In SOA TA: • Standardization of basic functionalities provided by services • Common Language
Human-related	Training people effort	●	●	◑	---
	Wide paradigm change required	◕	◕	◑	---
	Lack/inertia of awareness/trust	●	●	◔	---

Figure 2. Impact of SOCRADES barriers on specific industrial domains

Table I
OPPORTUNITIES AND THREATS

Opportunities
Greater visibility of internal processes
Enabling reconfiguration
Integration of management view
Improved reusability of resources and devices
Simplifying usability through interoperability and reduced complexity
Threats
Development costs
Expenses related to additional testing occur
High amount of labor costs (trainings, hiring new IT staff)
Difficulties with compatibility of out of date legacy IT systems
Business reluctance towards introducing new IT

In traditional IT architectures, business process activities, applications, and data are locked independently and often incompatibly. Users have to navigate separate networks, applications, and databases to conduct the chain of activities that completes a business process. This absorbs an excessive amount of IT budget and staff time to maintain. Additionally, business demands enhancing reliability and real-time performance in wireless technology. Thus production systems require reconfigurability and flexibility in order to improve the efficiency of manufacturing products. The SOCRADES approach targets these business needs by utilizing the SOA paradigm at the device level, which enables the adoption of a unifying technology for all levels of the enterprise. This can enable a wide range of potential business opportunities but is also associated with challenges as depicted in Table I.

Organizations that benefit most from adopting SOA based approaches have large and complex application portfolios with a vast quantity of point-to-point interfaces like manufacturing companies, since the more complex applications and their integration architectures become, the more risky it is to change them. With a high level of complexity, the impact of change cannot be assessed sufficiently, hence test cycles become longer and more defects occur during the production process. Thus the system change cannot keep pace with business changes and the organization loses its competitive edge: the business cannot respond quickly enough to changes in market demand. This can be prevented when adopting SOA based architectures such as the one proposed by SOCRADES, which will enable the exploitation of the defined benefits in the near future.

In this paper we focused on making a preliminary analysis with respect to the benefits and barriers related to SOCRADES adoption. We provided an evaluation of the SOCRADES approach in the automation domain and discussed its benefits/opportunities and disadvantages/barriers. Our preliminary opinion is that although the approach is still at early stage with respect to industrial standards, it has been shown that it is very promising and may yield significant advantages in the mid and long term.

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