# A SERVICE ORIENTED ENGINEERING APPROACH TO ENHANCE THE DEVELOPMENT OF AUTOMATION AND CONTROL SYSTEMS

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Abstract: In order for the manufacturing industry and closely related engineering disciplines to be competitive and productive, business structures and practices have to adapt to global changes and harder competition on all levels of operation. An engineering approach based on engineering services provides a foundation for commercial of the shelf services to be combined and utilized between engineering enterprises in the development of automation and control systems. A service based operations model would enable the utilization of expert services as a part of the development process to improve system quality, increase productivity and provide better work process management as well as allow easier integration to later life-cycle operations. This paper presents opportunities this kind of a conceptual approach offers and outlines some of the related research challenges that need further investigation.

## 1 INTRODUCTION

Globalization and the transition to a post-industrial society have had a significant impact on the manufacturing industry and the business structure of today. As a result from manufacturing facilities moving to cheap labour countries many associated businesses are under constant pressure to keep up with increasing competition. This also affects related engineering disciplines, such as automation and control system design, which have to cope with global competition and interweaving work processes in a distributed network of business partners and sub-contractors.

In order for these engineering businesses to be competitive they have to increase their productivity and be able to organize their services more flexibly across organisational boundaries. In addition, the quality of systems designed has to improve as requirements on system properties such as reliability, accuracy and maintainability are tightening.

Business re-engineering and the restructuring of business processes towards a service based operations model brings agility and flexibility to better adapt to changing circumstances and business needs. An engineering process composed of individual services can increase productivity by providing easier management of involved operations. Some of these services are commercial solutions from external service providers and some are redefined and restructured from existing in-house activities. While many of the tasks in development still require active human participation there are possibilities to implement some of the services as automated IT-based services. As a result, the management of well-defined service units, their compositions, and their interaction and orchestration becomes easier to handle from a workflow point of view.

From the business point of view services should be seen as repeatable tasks that perform some actions in order to complete a larger assignment. Service-orientation, the next generation of business automation, is a way of organizing and integrating business processes from these services. It should be noted that in this context services are considered as parts of the business processes, and service-oriented systems offers a way to provide existing functions and enable new business process models.

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Service-oriented architecture (SOA) is an implementation-agnostic architecture for linking activities and resources that each addresses a specific task. From a technical perspective service-oriented systems allow encapsulation and componentization of functionality into reusable services with well-defined specifications that can be discovered, bound and invoked by service consumers. At the same time an SOA approach needs to consider business processes both in general and with domain specific special characteristics in mind. Therefore it is different and much more complicated to provide engineering as a service compared to services such as online ticket reservations.

The engineering business needs to be viewed within a service-oriented context to consider additional requirements on current practices and technological infrastructure. This paper introduces some of the current practices and problems in automation and control system design and highlights related challenges during later life cycle phases. Based on these presumptions, following is a discussion on what could be enhanced and a conceptual presentation of possible solutions based on services and the sophisticated utilization of information systems available.

## 2 RELATED WORK

Service-orientation has been a popular catchphrase during this decade. A lot of research work has been conducted and considering software engineering especially in the fields of enterprise systems and business intelligence. Service based engineering and workflows have also been studied and according to Bergman et al. (2002) future users will request engineering services automatically from an automated server in the same manner as stock quotes and weather services are requested today. Bergman et al. have studied the challenges of providing engineering as services and developed an automated workflow system prototype in the aerospace telecommunication domain to support engineering activities. They concluded that applications of this type require considerable domain specific input, have strong dependencies on the environment and typically require a large number of parameters.

A service-oriented architecture is an architectural approach of organizing software units focusing on services and their interaction. The approach considers both service provider and consumer needs and enables the use of services in the business model. For IT systems this means automatic utilization of services as a part of the business process. Lee et al. (2007, 2008) have studied the use of services in product development in the mechanical industry and developed an engineering framework for composing services supporting QoS attributes and methods typical to business process management such as BPEL (Business Process Execution Language).

Thramboulidis et al. (2008) have studied SOA-based embedded system development for industrial applications and utilized semantic web technologies in their prototypes. In their research, they outlined a conceptual model of a semantic web-based framework containing services, such as the ones for component and device repositories, to be embedded in service-oriented development environments. They also created prototypical Web services for embedded system development environments and demonstrated the applicability of the proposed approach.

Francois Jammes and Harm Smit (2005) have studied service-oriented paradigms in industrial automation and networking of intelligent devices. They considered Web services as the enabling technology for service-oriented applications to be flexible and adaptive to changing strategies. Fuji and Suda (2005) have in general studied dynamic composition of complex services. Dynamic composition is needed in order to dynamically provide new services in an intuitive form based on the semantics of the service. This kind of composition will be vital especially in flexible design of automation and control systems. According to Fitzgerald et al. (2006) and Kontogiannis et al. (2007) this is also of importance in achieving third generation service-oriented systems supporting context-determined composition in a dynamic ad-hoc manner.

To be able to integrate design processes and information in general both semantics and mapping rules are needed to allow utilization and combination of information sources. The Semantic Web is about data and its meaning (W3C). Firstly it is about interoperability in integrating and combining information from diverse sources. Secondly it is about relations between data and real world objects. This allows, for example, information in different formats to be interpreted concurrently at run-time. The research and efforts contributed to the semantic web are needed also to support the concepts of cloud computing and operation models such as software as a service (SaaS) in heavily integrated application environments. In this perspective, both the solutions provided as services and the data information itself require semantics for integration and utilization.

## 3 CURRENT PRACTICES AND CHALLENGES

Automation and control systems, manufacturing execution systems (MES) and related information systems are vital for smooth production in industrial manufacturing. Requirements posed on these systems are increasing as more functionality is needed and as system integration and information utilization extends all the way from the enterprise level to field devices. The rapid development of emerging technologies and new standards requires designers to stay updated and to constantly develop their professional skills. Design time work support for design decisions generally relies on previous experience and the support from colleagues within the same team.

All this puts heavy pressure on engineering work developing automation and control systems. The applications easily become large and complex, consisting of subsystems and integrations to and from various existing systems. As a result also project management becomes challenging and fulfilling all functional and non-functional requirements demands careful design and implementation. This is an issue also because parts of the development may be outsourced. At the same time quality requirements on reliability, correctness, accuracy and maintainability, to name a few, are increasing.

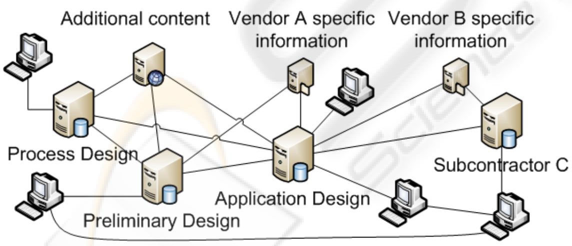


Figure 1: Interweaved design activities and information exchange between project parties.

Figure 1 illustrates a collaboration scenario and the transfer of necessary information between the different parties in the development process. Developing automation and control systems is, in general, characterized by requiring years of experience and professional competence. Also vast amounts of design information need to be transferred between development phases, e.g. application design requires source information from process and preliminary design phases. A lot of information is available both during design and plant operation but the challenge is to know what is needed and how to use it. During recent years, XML has made its breakthrough as the data transmission standard partly because of its interoperability. Despite its platform independent nature, it is not enough when the amount of information increases and corresponding data models with different structures and semantics are used concurrently. This does not only concern design time data, but also information needed while the system is operating, for example information on system components for maintenance or modernization purposes. While information systems evolve during the plant life cycle both data models and the way of accessing information may change in a manner that requires adaptation. Profound semantics are therefore needed to provide the meaning of the data to fully utilize the information available in a reasonable manner.

The importance of validation and testing cannot be stressed enough for mission-critical systems. Increased functionality results in more complex systems and the validation and testing of design decisions and implementation becomes challenging. In cases where simulators and testing tools are utilized as a part of the development the solutions are mostly based on custom applications for specific cases. The use of specialist services as a part of the development is therefore laborious in most cases while there is not any easy way to integrate outsourced expertise into the development process.

In the automation and control engineering industry it is common to use subcontractors in larger projects. There are also firms offering specialized services, such as simulation or knowledge on advanced control methods. However, these are typically limited to specific parts of the system, independent subsystems or certain phases in development. For example, the initial design phase is performed by a subcontractor and only the final design artefacts or the outcome is returned and integrated manually or semi-automatically to the following development phases. The same applies to integrating design artefacts such as subsystems or application components from different parties. Also the simulation of these subsystems or other critical elements of the application requires a lot of additional work. For instance, even a simple verification of impacts caused by a change in design can be demanding. This shows that work processes are not accommodated with current design systems so they could be managed autonomously and so that external services could be utilized effectively as a part of the development process.

Manufacturing systems and production plants generally have a long lifespan that requires various supporting activities for optimal operation. Automation and control systems are usually connected with a large number of existing systems such as ERP and systems related to manufacturing and quality control. Examples of associated systems are also condition monitoring and maintenance systems. For instance, if maintenance is outsourced to a third party the service provider is typically only informed of events reported by monitoring systems at the plant. The service provider may have to use many existing systems at the plant to access all necessary information, including design data, in parallel with the service providers own systems. Although expensive integrations are made between systems, well-defined information management is hard to achieve and the effective use and integration of services is difficult.

# 4 ENHANCED DEVELOPMENT PROCESS

To meet the challenges presented some improvements could be made. Most of the changes, however, can be limited to design systems and IT systems involved so that actual work processes merely have to be defined more precisely. The aim is, although, to enable a more service based operations model during system development that also supports further life cycle activities.

## 4.1 A Service based Approach to Improve Information Exchange

In distributed engineering environments crossing organisational boundaries design information and development artefacts are fragmented into different systems and databases. The ideal solution would be to use uniform standards and information models for instant interoperability and easy integration. This will presumably never be a feasible solution as there are different needs depending on the system under design and the task being performed. Therefore the integration of design data should be made on a deeper semantic level so that this information could easily be combined and mapped to suitable information models for the parties concerned. This would also benefit all other supporting activities such as simulation, testing and special expert services.

Open and compatible standards are a basis for interoperability between new systems, but the large number of systems used also contains old legacy. Therefore customized adapters and service wrappers are needed to support existing systems and data models. The technology exists to integrate systems and to bring more semantics to service discovery, information usage and the handling of work processes. A service oriented architecture utilizing semantic web technologies would provide means to make the design of automation and control systems more flexible and effective. It would also enable the use of commercial services as part of the application development process. A shared service framework with standards based communication procedures would be of common interest to support the integration of design tasks and transformation of design information from one system to another. This would enable engineering companies to specialize and offer their expert services for others to utilize as a part of the development process.

To be useful the service framework should be easily expandable with new services and allow mappings to new data sources and information models. For instance, if design information was semantically annotated, vendors of devices and components could offer related information and special knowledge automatically to support the development process. Empiric knowledge from previous experiences could also be utilized this way or it could be offered to partners and sub-contractors as a service that automatically provides supporting information during development.

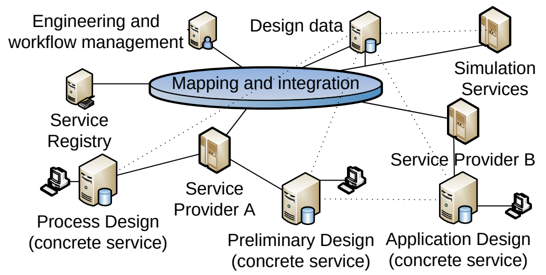


Figure 2: Service based design and information integration.

Figure 2 illustrates a service-oriented development architecture with a subset of engineering activities distributed into service units representing specific development phases. The figure also presents information exchange enabled through mappings on a common semantic level between services as well as integration of simulation services to the design data.

### 4.2 Integration of Expert Services to the Development

There are a wide variety of services that could be enabled through this kind of a framework. Testing design and implementation, for example, is troublesome and it is important to find errors as early in the development as possible. Simple syntactic testing is possible but more advanced testing and verification could be enabled through intelligent services. These services can be automatic and utilize a wide range of background information making deductions. For example, statistics gathered from similar systems already in production, information on previous similar designs or specifications on devices and components can be used to evaluate design. The services could also be performed manually by a third party specialist, e.g. an experienced engineer. However, on a service description and interface level it should integrate into the development process as any other engineering service.

Simulation is also an important activity during development, especially for critical systems. However, simulations are not used as widely as possible partly because the creation of simulation models is labour-consuming and requires special expertise. If design information were available in a format generally understandable, the automatic or user-assisted generation of simulation models would also be possible. This would enable the use of simulation services to enhance the quality of the system under design. Design models representing the control application behaviour, for example, would be useful to be simulated.

The use of design time information is worthwhile also in supporting life-cycle services such as maintenance. The share of repairing maintenance compared to preventive or predictive maintenance is often too high in the manufacturing industry. Design information on system structure and components used is valuable evaluating and preparing maintenance schedules. Combined with advanced condition monitoring systems problematic parts of the systems can be analyzed and identified. In addition, the information found may also be of significance for future systems to be designed.

### 4.3 Improved Design Workflow Management

A service-oriented approach organizing service activities provides better management of involved activities and improves much needed process agility. Advanced business process modelling techniques and modelling languages provide tools for analyzing and orchestrating processes composed of services. High-level rules describing workflows and the use of advanced reasoning for automatic service discovery and utilization bring flexibility and efficiency to the development process. For example, invoking testing or simulation services after changes to the design could be automatic, either for the whole systems or only a part of it.

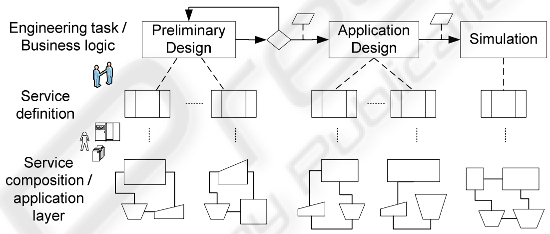


Figure 3: A subset of engineering activities, corresponding service definitions and service compositions.

Figure 3 presents some engineering activities and their relationship to services in a development workflow. To be able to implement tasks in the development process presented the offered abstract higher level services need to be defined with clear and concise service level agreements for discovery, binding and invocation. These abstract services may then be composed of smaller services such as Web services or activities performed by humans. The challenge is to provide well defined service interfaces, to bind them to services on different levels of granularity and to control the activities in the development process.

The key benefits of organizing design activities into services and a common framework are in interoperability, work process management and new business opportunities for utilization of specialized expert services. Based on a common service framework, services could be customized for each company, based on individual needs with common building blocks without huge development resources. This would allow businesses to specialize in special sectors and make possible the utilization of this special expertise as a part of the development with feasible resources and efforts. This would also imply the transfer of business models and invoicing practices from licenses and agreements to be based on service usage. A service-oriented approach based on a common, sound information models also enables separation of concerns between different parties and engineering disciplines.

## 5 CONCLUSIONS AND FUTURE WORK

System integration and the broader utilization of information is becoming the cornerstone of effective operation in all businesses. This paper has presented some concepts for a new operations model implementable as services with semantics to provide enhanced information exchange between engineering enterprises and support during the design of automation and control systems.

A service based operations model can offer a new level of flexibility and interoperability, and support agile business practices and efficient management of design work processes. A development process based on services will also enable new business opportunities for specialized expert services and allow integration of these services to the engineering process easily. The automation and control domain has also established practices with suitable standards and information models for the development process to be implemented in a service-oriented fashion. A service-oriented approach based on a common information integration layer will also support various other design approaches, such as model-driven methods for example, to be utilized in the design process.

In order to fully utilize a service framework in the development process many obstacles still have to be overcome. Mapping services to business processes needs further research concerning infrastructure and strategies aligning processes with service components. In addition service definitions and service level agreements need further investigation and considerable domain specific input. The run-time discovery and composition of Semantic Web services also need established practices and there are many ongoing efforts addressing this, e.g. OWL Web Ontology Language for Services (OWL-S). The adoption of service-oriented systems depends among other things on the usability and the added value the associated process models bring. Special attention is needed to support a gradual transition from current practices to a service based operations model.

The information content in design systems, for example, is diverse and the amount of data is huge. Efforts are needed to be able to utilize the information, e.g. by semantically describing the data. Modelling of complex design processes is also needed in order to manage distributed design activities in a more automatic manner. Knowledge modelling and information management is needed to be able to control information flows in new flexible design environments. Therefore proof of concept solutions with implemented services and process management are needed to evaluate the functionality and benefits of the service based operations model. This paper has presented some concepts and observations that are being explored in ongoing and commencing research projects.

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