Impact of Cyber-Physical System Implementation on Enterprise Architectures: A Case Study

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Abstract: Cyber-Physical Systems (CPS) tightly integrate physical and IT (cyber) worlds based on interactions between these worlds in real time. The focus of this paper is on the question how CPS can be integrated the enterprise architecture (EA) and how CPS potentially affect the EA. The approach used in this paper is to evaluate a case study from transportation showing the development of a CPS. The contribution of the paper are (1) the description of a CPS case from an EA perspective, (2) an analysis of potential effects of the CPS on EA and (3) initial recommendations for CPS projects.

Keywords: Cyber-Physical Systems, Enterprise Architecture, Case Study

1 Introduction

Cyber-Physical Systems (CPS) tightly integrate physical and IT (cyber) worlds based on interactions between these worlds in real time [HG12]. CPS rely on communication, computation and control infrastructures commonly consisting of several levels for the two worlds with various resources as sensors, actuators, computational resources, services, humans, etc. The benefits and innovation potential attributed to Cyber-Physical Systems (CPS) is significant; as CPS are considered as the key to higher efficiency in many industrial domains [DBR14]. From an enterprise perspective CPS can contribute to product innovation (see [LS10] for an example from health industries), process innovation (see [Fis14] for an example from manufacturing) or business model innovation (see [SSS13]).

The focus of this paper is on the question how CPS can be integrated the enterprise architecture (EA) and how CPS potentially affect the EA. In general, an enterprise architecture captures the different conceptual layers of business model and IT in an enterprise, identifies the most important elements in these layers including their structural relationships, and shows the interdependencies between the layers. A frequently used approach in this area is TOGAF [OG14] which distinguishes between business architecture, application architecture, technology architecture and information architecture. Knowledge about potential effects of CPS on EA could be used during innovation projects for preparing CPS implementation.

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the development of a CPS. The contribution of the paper are (1) the description of a CPS case from an EA perspective, (2) an analysis of potential effects of the CPS on EA and (3) initial recommendations for CPS projects.

This work in progress paper is structured as follows: section 2 summarizes the background for our work. Section 3 briefly introduces the industrial case study. Section 4 shows an excerpt of the business processes and software architecture implemented for the CPS. Section 5 discusses the impact of the CPS on the existing EA of the case company. Section 6 summarizes the work and initial recommendations.

2 Background

This section summarizes the conceptual background for our work with focus on enterprise architecture management (2.1), Cyber-Physical Systems (2.2) and enterprise modelling (2.3).

2.1 Enterprise Architecture Management

Enterprise architecture (EA) denotes the fundamental elements and relationships of an enterprise in an appropriate model. Commonly, this includes the conceptual layers of business model and IT in an enterprise with their most important elements and structural relationships, including the interdependencies between the layers. EA models have evolved over the last decade from pure IT architecture models into control instruments that can be used by the management as a tool for their business decisions and allow an integrated view on an enterprise. An EA supports the understanding and documenting of an organizational structure with all dependencies of artifacts and information objects necessary for business performance [BDMS10].

EA management (EAM) provides an approach for a systematic development of an enterprise’s architecture in line with its goals by performing planning, transforming, and monitoring functions. The reasons for implementing an EA via EAM are manifold. On the one hand, it enables and supports the adaptation of IT to the business goals, the identification of problems or assistance coping challenges and on the other hand, it allows a detailed description of the conjunction between business and IT. This type of joint interaction results in creation of a common and consistent vocabulary for business processes and objects anon as well as for business functions and skills in the technical departments and the IT [Nie08].

2.2 Cyber-Physical Systems

As it was already mentioned, CPS tightly integrate heterogeneous resources of the physical world and IT world [Ant14]. This term is tightly related to such terms as Web
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4.0 [ANF12] and Internet of Things [SM14]. Currently, there is a significant amount of research efforts in the area of cyberphysical networks and their applications, e.g., in production [Fis14], transportation [Wan14], and many other. Such systems rely on communication, computation and control infrastructures commonly consisting of several levels for the two worlds with various resources [TSLS14] as sensors, actuators, computational resources, services, etc. CPS belong to the class of variable systems with dynamic structures.

Having analysed the state-of-the-art of different CPS approaches and supporting technologies, among the other conclusions, Horvath and Gerritsen conclude that “the next-generation of CPSs will not emerge by aggregating many un-coordinated ideas and technologies in an incremental fashion. Instead, they will require a more organized and coordinated attack on the synergy problem, driven by an overarching view of what the future outcome should be” [HG12].

This means that the whole structure of the CPS to be implemented has to be built in advance based on the analysis of the required CPS functionality. The enterprise models can be a valuable information source in this case since they describe various aspects of an enterprise, acting units, their competences and relationships.

2.3 Enterprise Modeling

In general terms, enterprise modelling is addressing the systematic analysis and modelling of processes, organization structures, products structures, IT-systems or any other perspective relevant for the modelling purpose [Ver96]. Sandkuhletal. [SSPW14] provide a detailed account of enterprise modelling approaches. Enterprise models can be applied for various purposes, such as visualization of current processes and structures in an enterprise, process improvement and optimization, introduction of new IT solutions or analysis purposes. Enterprise knowledge modelling combines and extends approaches and techniques from enterprise modelling. The knowledge needed for performing a certain task in an enterprise or for acting in a certain role has to include the context of the individual, which requires including all relevant perspectives in the same model [LK09]. A best practice for identifying these perspectives is the so-called “POPS*”-approach proposed by [Lil03]. POPS* is an abbreviation for the perspective of an enterprise to be included in an enterprise model: process (P), organization structure (O), product (P), systems & resources (S) and other aspects required for the modelling purpose (*). The best practice basically recommends to always include the four POPS perspectives in a model because they are mutually reflective: process are performed by the roles captured in the organization structure, the roles are using systems and resources which at the same time capture information about products; manufacturing and design of products is done in processes by roles using systems, etc. [LK09].
The CPS investigated in this paper was developed in an industrial project in transport and logistics industries. The logistics industry makes intensive use of modern information technology and CPS for achieving high efficiency of processes and solutions in a globalized market. One of the world’s largest truck manufacturers designed and implemented new transport related services based on a CPS consisting of electronics in truck-trailers and an IT system using the information from the trailers for information logistics services. The trailers have a wireless sensor network (WSN) installed in the position lights. Each light carries a sensor node able to network with neighbouring nodes and furnished with a radar sensor. This sensor can be used for various purposes, including protection of the goods on the trailer against theft or surveillance of the trailer or its different compartments (e.g. by electronically sealing them). A gateway in the trailer is controlling the WSN in the position lights and communicates with the back-office of the owner of the trailer. Several services were developed within the project, which exploit the possibilities of combining sensor information and IT services. One of these services is additional protection of the trailer when parked against theft, also called secure trailer access control (STAC) (see [San12] for more details).

In this industrial case, the development of the STAC service and other information logistics services as part of the CPS followed a pragmatic approach including the following steps. These steps were started upon successful completion of technical feasibility studies regarding the technical infrastructure (i.e. sensor node – WSN – gateway – back-office communication):

- Business objectives: The enterprise management defined the business objectives to achieve. This included what actual services to offer in what priority, minimum number of customers, upper limit for investments into solution development and marketing, expected market share, and other general frame conditions.

- Business model: for each of the services, which were part of the business objectives, a business model was developed. For the business model of STAC, we used an approach from e-business proposed by Wirtz [Wir10] which separates the business model into partial models: capital model, procurement model, manufacturing model, market model, service offer model, and distribution model.

- CPS integration into the enterprise: as the business model does not describe how the new services will be integrated into the existing processes and structures of the enterprise delivering theses services, the next step was to design and integrate such structures and processes. This step was performed using enterprise modelling techniques (see section 2.2) and will discussed in detail in section 4.

3 CPS Case Study

The CPS investigated in this paper was developed in an industrial project in transport and logistics industries. The logistics industry makes intensive use of modern information technology and CPS for achieving high efficiency of processes and solutions in a globalized market. One of the world’s largest truck manufacturers designed and implemented new transport related services based on a CPS consisting of electronics in truck-trailers and an IT system using the information from the trailers for information logistics services. The trailers have a wireless sensor network (WSN) installed in the position lights. Each light carries a sensor node able to network with neighbouring nodes and furnished with a radar sensor. This sensor can be used for various purposes, including protection of the goods on the trailer against theft or surveillance of the trailer or its different compartments (e.g. by electronically sealing them). A gateway in the trailer is controlling the WSN in the position lights and communicates with the back-office of the owner of the trailer. Several services were developed within the project, which exploit the possibilities of combining sensor information and IT services. One of these services is additional protection of the trailer when parked against theft, also called secure trailer access control (STAC) (see [San12] for more details).

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• Specification of CPS: the specification of the CPS has to include the architecture and functional/non-functional characteristics of the technical solution and the set of operational service for managing and operating the technical solution. In section 4.3 we will focus on a selected aspect of the technical solution only: the architecture of the back-office solution

4 CPS Business Processes and Software Architecture

As discussed in section 3, an enterprise model was developed for describing the integration of the CPS into the enterprise and a software architecture as a basis for designing the actual technical system. As the enterprise model forms the basis for changes in the business architecture and the software architecture is relevant for the application, both will be briefly described in this section.

4.1 CPS integration into the enterprise

The business model developed for the CPS indicates where integration of the new service into the existing structure of the enterprise is needed. The manufacturing model defines what parts of the service are implemented in-house, i.e. from here we identify the existing roles and organization units (e.g. service operator, infrastructure operator, project manager) and resources involved (e.g. contract management, configuration environment). Procurement model and service offer model help to identify external roles, external processes and product structure elements. However, the business model is neither precise enough for specifying the exact implementation in the enterprise nor meant for this purpose. Thus, we extended the enterprise model of our case company for the new service, which also visualizes how the CPS is integrated into business processes.

Fig. 1 shows an excerpt from the enterprise model for STAC. In the middle of the figure, the high level business process “STAC service” is depicted, which consists of “configure service”, “perform service” and “discontinue & report”. For all activities, several refinement levels exist. The figure only shows the first refinement level for the second activity “perform service”. On the lower left of the process container, the roles involved are modelled (including internal and external roles); on the lower right of the process container, the systems and infrastructure resources are shown. Above the process container, important documents (e.g. contractual elements, like terms and conditions) are modelled. The arrows in the figure are typed relations between the model elements, which for example show which role “is_responsible” for what activity in the process. Both, human resources and infrastructure resources are part of specific sub-models for the overall enterprise not shown in the figure.
Fig. 1. Enterprise model excerpt for STAC with focus on process/role/resource

4.2 Software Architecture

Figure 2 depicts the components of the general software architecture defined for the STAC service. Grey-shaded rectangles denote components newly developed for STAC, rounded rectangles represent existing IT-systems from customers or suppliers to be integrated, white shaded rectangles depict existing enterprise-internal systems to be integrated. Rectangles with dotted lines indicate that the component is optional and will be implemented in a later version of the system. The arrows indicate the direction of information flow between these systems.
The core of the software architecture is the STAC application, which manages all trailer configurations and connections, the ongoing trailer surveillances, the authentication of drivers and the management of alarms. The STAC application has interfaces to the enterprise internal ERP system for registering the performed accounting-relevant activities, and the communication with driver, trailers and (optionally) trucks. The interfaces to external applications concern the fleet management systems (FMS) of clients in order to receive basis information about the trailers to be supervised and their assignments, the clients’ ERP system for receiving information about drivers and accounting and the trust center for driver authentication. Furthermore, there is a specific job management application for registered clients which allows for status check of ongoing surveillance assignments and of changes in / new creation of assignments.

5 CPS effects on EA

When investigating how the CPS described in section 4 can be integrated in the enterprise architecture of the transportation company and how the CPS in turn affects the EA we use the TOGAF layers, which include business architecture, application architecture, information architecture and technology architecture, i.e. we discuss the integration and effects layer by layer.

In the business architecture layer, the CPS is represented in the first place with the new capabilities the enterprise has due to the CPS. These capabilities are expressed with new functions implemented in the enterprise, business services offered to the customers and business processes implemented for providing these business services. Some of the new services were already discussed in section 3 (e.g. electronic fence or STAC), an excerpt of the business processes are shown in the enterprise model in section 4.1. Besides adding new “value creation” elements to the business architecture layer, the business services implemented by the CPS also need supporting services which already are...
existing, like customer care, accounting or marketing. Since the CPS offers services which can be considered a completely new business model, even the target group is different from existing business lines, which requires new sections of customer care and marketing within the established organizational structures. However, the existing accounting capabilities can also be used for the new CPS services.

From the perspective of the application architecture, a number of new applications were added which are specific for the new services, like the core of the STAC application which controls the data traffic to the gateways in the trailers or implements the control flow for driver authentication or alarming security service providers in case of assumed trailer theft. But there are also some applications which potentially could be shared with other business areas of the enterprise. One example is the exchange of accounting information with the FMS systems of the clients or with the clients’ ERP systems. This exchange is done using a message-based middleware, like IBM’s MQ series, which can also be used for integrating some of the internal accounting systems. For the CPS integration it was decided to initially use a separate message queuing middleware installation as the volume of message to be transferred was difficult to estimate and as this middleware potentially also could be used as part of the infrastructure in trailer communication. Regarding the information architecture, the initial idea was to use the established sales and delivery, customer care and accounting information structures for the new CPS based services, which also would mean that the applications for managing this information could be used. However, it quickly showed that the parameters characterizing a “product” using the CPS were quite different from the established products in the enterprise. Thus, a new instance of the sales and delivery application had to be installed configured for the specific business related to the CPS whereas the customer care and accounting could be used with only additional configurations.

On technology architecture level, the situation was similar to the application architecture: on the one side there a new components and even a completely new infrastructure which has to be implemented (i.e. trailer gateways, communication links to the back-office, scalable compute servers for processing of events from the trailers, etc.). On the other side, some of the back-office functionality is suitable for deploying them on existing resources in the computing center of the enterprise. In this CPS case, it was decided to deploy the additional middleware services mentioned in the application architecture on already existing resources, as the capacity seemed to be sufficient.

6 Summary and Conclusions

Based on a CPS example from transportation industries, the paper discussed changes in the EA implied by the CPS. Although this is case study is just one example for CPS systems, three recommendations can be derived from the experiences collected. These recommendations have to be subject to validation in future projects:
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Recommendation 1: design the first version of the CPS architecture without taking into account the existing EA and build a prototype to gather experiences regarding critical issues of the CPS. In a second version identify overlaps between existing EA and CPS architecture and analyze potential synergies (e.g. reusable applications or scalable technology components).

Recommendation 2: During analysis of EA, pay specific attention to functional identical areas, performance, security and reliability requirements.

Recommendation 3: In the technology architecture, separate the infrastructure for control and operations of the CPS from the infrastructure for other enterprise applications.

References


