Feature Models as Support for Business Model Implementation of Cyber-Physical Systems

Kurt Sandkuhl
The University of Rostock
Rostock, Germany
kurt.sandkuhl@uni-rostock.de

Abstract

From a business perspective Cyber-Physical Systems (CPS) can contribute to process innovation, product innovation or business model innovation. In this paper, the focus is on business model innovation based on CPS, i.e. we take the perspective of enterprises using CPS as basis for new customer services. In order to create viable CPS solutions, stakeholders from different enterprise functions should be involved, including business perspective and technical perspective. However, the business-related stakeholders often do not understand the technical possibilities and the technology-related stakeholders do understand the business opportunities. The paper proposes to use feature models as mediation support between business-oriented and technology-oriented stakeholders. Feature models conventionally are used for controlling variability, i.e. as a means for engineers to plan and design features for configuration and implementation. We propose to use them as a way to identify value propositions based on features. The main contributions of the paper are (a) to identify the potential feature models for alignment of business and technology-related stakeholders, (b) to propose feature model "slices" as support for business model development of CPS, and (c) an industrial case illustrating feasibility and utility of the approach.

Keywords: Cyber-physical systems, business model, feature model, feature model slice, business context.

1. Introduction

Cyber-Physical Systems (CPS) are considered as an important element of future technological solutions and new business models for the next industrial revolution [1]. From a technical perspective, CPS integrate physical systems and IT (cyber) systems in real-time [23]. CPS include control infrastructures, which usually consist of different levels of resources, such as sensors, actuators, computational nodes, services, etc. From a business perspective CPS are supposed to support higher flexibility and efficiency of operations, which can lead to process innovation (see [20] for an example from manufacturing), product innovation (see [26] for a health care example), or new kinds of business models [25]. In this paper, we take the perspective of companies using CPS as basis for new customer services, i.e. the focus is on business model innovation based on CPS. Such new services need to be defined with the processes for implementing them, the organisational roles involved in the company, resources required and how the CPS is used for delivering the customer services.

In order to create viable CPS solutions from a business and a technical perspective, stakeholders from different organizational functions should be involved, including marketing, controlling, operations management, system design, operations and human resource management, as the business services and products depending on the CPS will have to be integrated in the enterprise's business processes, need qualified personnel, are part of the enterprise service structure. This gap between implementation of technical and business aspects has been addressed by the some research projects (e.g., [25]) but is not fully covered yet.

In this context, a challenge frequently experienced in the development of CPS is the mapping between business perspective and technical perspective [27]. One of the causes why cyber-physical systems offer new business opportunities are the sensors and actuators built into CPS. If we consider these components in isolation, each of them usually is motivated by specific technical requirements, sometimes with no or limited business value. But the combination of several components can form the basis for value propositions to the users or clients of CPS.

However, the business-related stakeholders often do not understand the technical possibilities and the technology-related stakeholders do understand the business opportunities. Our proposal is to use feature models as mediation support between business-oriented and technology-oriented stakeholders. Feature models conventionally are used for controlling variability, i.e. as a means for engineers to plan and design features for configuration and implementation. We propose to use them as a way to identify value propositions based on features. This uncommon way of applying feature models turned out to be valuable.

This paper investigates the above approach based on a use case from transportation industries. More concrete, we define a feature model as addition to a previously developed enterprise model and explore its usage in supporting business model implementation. The main contributions of the paper are (a) to identify the potential of feature models for alignment of business and technology-related stakeholders, (b) to propose feature model “slices” as support for business model development of CPS, and (c) an industrial case illustrating feasibility and utility of the approach.

The remaining part of the paper is structured as follows: Section 2 will give a brief overview to background for this work including feature modelling, CPS and business models. Section 3 presents the research approach used for our work and section 4 the case from transportation industry motivating the context for our work. Section 5 introduces the feature model and discusses its use and the “slices”. Finally, section 6 summarizes the paper and discusses future work.

2. Background

Background for our work comes from cyber-physical systems, business models analysis and development, and variability modeling.

2.1. Cyber-Physical Systems

CPS integrate resources of the physical world, like vehicles or manufacturing equipment, and the information technology world [13, 14]. The term CPS is closely related to concepts, such as Industry 4.0, Web 4.0 [15, 16], the Internet of Things [17, 18, 19] or smart connected products. In research, there is a substantial amount of research work on CPS, cyber-physical networks and applications of CPS, for example in manufacturing [20] and logistics [21]. CPS belong to the class of variable systems with dynamic structures. Such systems require communication, computation and control infrastructures with often several separated layers for the physical and IT “world” and with resources such as sensors, actuators, network nodes, computers, services, etc. [22].

Based on an analysis of the state-of-research and of different CPS approaches with their supporting technologies, 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” [23].

This means that the essential structure of a CPS under development has to be built in advance based on the analysis of the required functionality. Models of business processes or enterprises can be a valuable information source in this context, as such models describe various aspects of a company: processes, acting units, their competences and relationships.

2.2. Business Models

The business model of an organization in general includes the essential elements creating and delivering a value proposition for the organization's clients or customers [7]. Business models also include the economic model with its underlying logic, the essential resources and core business processes [5]. Zott and colleagues identified in their analysis of recent academic research three major streams of work in business model development [12]:

- Business models for e-business and the IT-use in organizations,
- The strategic role of business models for creating competitive advantages, value creation and organizational performance,
- Value creation models in technology management and in innovation areas.

For CPS we consider both value-creation-oriented business models for the service industry and work for e-business [6, 11] as relevant. Approaches for the elicitation of business models or their representation, like the business model canvas from Osterwalder and colleagues [4] and the value model representation proposed by Weill and Vitale [10], often are used as they support stakeholder communication. However, these techniques just capture the basic idea of the business model, but no details, control structures or refinements of key resources and key processes. Thus, there is a need to also support implementation of new value creation structures with focus on the required organizational and technical infrastructure.

2.3. Variability Modelling and Feature Modeling

Discussion of the terms cyber-physical system and business model indicate that variations in configurations of systems and components of CPS and in business services or service delivery to different target groups are a common feature and need to be understood and tackled in efficient system and business model development. The area of variability modeling offers concepts how to deal with variability in complex systems, which might be applicable for CPS and business models and will be briefly presented in this section.

Variability modeling offers an important contribution to limit the variety of the variants of systems by capturing and visualizing commonalities and dependencies between features and between the components providing feature implementations. Since more than 20 years, variability is frequently used in the area of technical systems and as element of software product line implementations. Among the variability modeling approaches, feature models are considered as in particular relevant for CPS. A feature is a "distinctive and user-visible aspect, quality, or characteristic of a software system or systems" [28]. The purpose of a feature model is to capture, structure and visualize the commonality and variability of a domain or a set of products. Commonalities are the properties of products shared among all the products in a set, placing the products in the same category or family. Variability are the elements of the products that differentiate and show the configuration options, choices and variation points that are possible between variants of the product, aimed to satisfy customer needs and requirements. The variability and commonality is modelled as features and organized into a hierarchy of features and sub features, sometimes called feature tree, in the feature model. The hierarchy and other properties of the feature model are visualized in a feature diagram. Feature diagrams express the relation between features with the relation types mandatory, optional, alternative, required and mutually-exclusive. Different approaches in the field and the exact syntax of feature diagrams is explained in [2].

3. Research Method

Research work in this paper started from the following research question, which is based on the motivation presented in Section 1: *When exploring new business models based on cyber-physical systems, how can feature models support the cooperation between business and technology stakeholders?*

The research method used for working on this research question is a descriptive case study. We decided to perform a case study in order to gather in-depth information for the subject area.

Qualitative case study is an approach to research that facilitates exploration of a phenomenon within its context using a variety of data sources. This ensures that the subject under consideration is not explored from only one perspective, but rather from a variety of perspectives which allows for multiple facets of the phenomenon to be revealed and understood. Yin differentiates various kinds of case studies [3]: explanatory, exploratory and descriptive. The case study presented in this paper has to be seen as descriptive, as it is used to describe the phenomenon of CPS development and the real-life context in which it occurs.

The case study focuses on the development of a cyber-physical system in transportation industries including its integration into an existing organizational context. The case study covers the complete development process from business idea and business model development to designing processes, organization structures and the IT-architecture of the CPS, including its implementation (see section 4). In the case study, we had the possibility to participate and observe the development process, interview the stakeholders and analyse the artefacts developed in the course of CPS development.

We started from the hypothesis that feature models could be useful for supporting the development of CPS, as feature model have proven their value for complex systems with many different variations and CPS also are described as complex and variable systems. The perspective we took was from the view of business models as this aspect in previous work turned out to be under-represented in research. The guiding questions for this investigation, which serve as refinements of the research question introduced in this section, were:

- Q1: What are the challenges in defining business models for CPS?
- Q2: Is there a need for feature models to support the identified challenges?
- Q3: How can feature models support the communication between business and IT stakeholders?

4. Case Study

The case study is from transport industries, which has changed in the last decade into a high-technology industry making use of modern information technology and CPS. The case study company is a subsidiary of one of the world's largest truck manufacturers that develops new transport related services based on CPS, i.e. physical systems (e.g., trucks and trailers) and IT systems (e.g., on-board vehicle information systems, sensor systems and fleet management systems). The focus in this paper is on innovative applications in trailers. Most of today's trailers are poorly equipped with electronic systems which form the potential for innovations.
From a technical perspective, the case study company installed a wireless sensor network (WSN) in the position lights of a trailer. Each position light carries a sensor node able to communicate with neighboring nodes. The nodes are equipped with radar sensors that can be used for protecting the goods loaded on the trailer against theft (the so called "electronic fence") or for monitoring the status of the loaded goods (e.g., temperature inside refrigerator boxes). The WSN is connected and controlled by a gateway in the trailer, which is linked to the back-office of the trailer's owner or the good's owner. Several business services were developed by the case study company, which exploit the possibilities of combining sensor information and IT services. An example is the business services protecting the trailer against theft when it is parked (cf. [8]). Another example is to forward information from sensors in the goods loaded on the trailer to the trailer's gateway and to the back-office. Such sensor information can be used for value-added services, like surveillance of refrigerated goods (temperature sensor in the cargo box), checking whether the goods have been securely steadied (using a motion sensor), or whether vessels with fluids remain upright or are in danger to topple over (using a piezoelectric sensor).

In this industrial case, the development of new 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 (see section 4.2) was developed. For the business model, we used Wirtz's approach to separate 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 [9]).

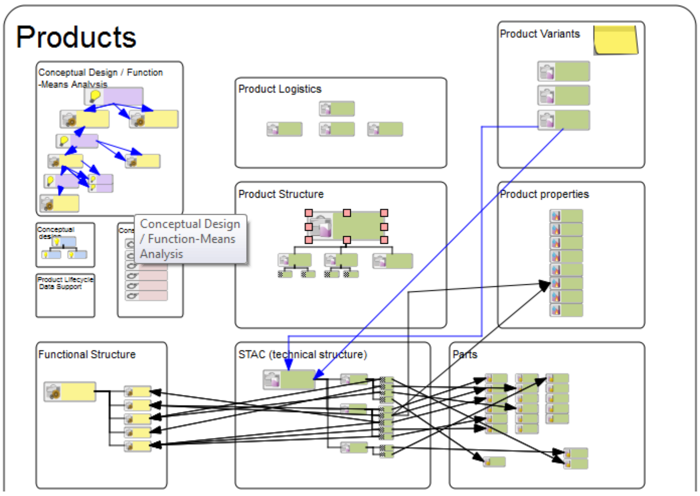

Fig. 1. Enterprise model excerpt with focus on product structure (cf. [8])

Fig. 1 shows part of the enterprise's product structure model (cf. [8]). The model includes a visualization of different aspects of a product, as for example the decomposition of a product into different components, the existing variants, properties of components required for implementing customer requirements, parts contributed by suppliers and material used in different components. In the lower part of the model, the technical structure implemented for the specific product considered in the industrial case is depicted. All aspects mentioned above are inter-related which is depicted by arrows. Figure 1 includes only a selection of relations with focus on this product.

4.1. Feature Model Development

In order to illustrate our approach of using context variants, we developed a feature model for the industrial case introduced above. A simple example shall be used to illustrate the need for controlling variability and at the same time high flexibility. Let us assume we have three sensor types built into the trailer (radar sensors in position lights, sensor to control backdoor, motion sensor for the cargo area) and three sensor types potentially in the cargo goods (temperature sensor, piezoelectric sensor, malfunction of transport box). Each of these sensor types might be evaluated on its own (e.g. "IF temperature_in_cargo too_high THEN lead truck to next service point"), in combination with another sensor (e.g. "IF temperature_in_cargo too_high AND goods_not_securely_steadied THEN stop truck to check trailer and goods") or in combination with another sensor and external information from information systems and back office (e.g. "IF temperature_in_cargo too_high AND goods_not_securely_steadied AND truck_close_to destination THEN reduce speed and continue to destination"). If only 3 out of these 6 sensor types can be combined there would be already 41 potential combinations. Furthermore, for the cargo sensor types, there will be a variable number of actual sensors in the trailer depending on what goods are loaded and it is not known in advance whether or not a customer booked a certain service. Also, new types of sensors have to be integrated into the overall systems as a basis for new services.

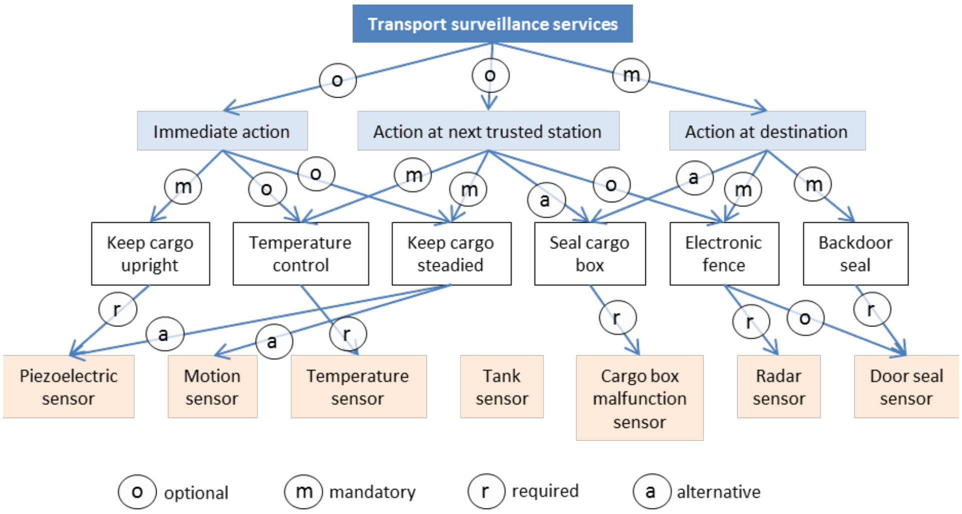

Fig. 2. Excerpt of the feature model for the industrial case

This feature model is shown in figure 2. Top-down the figure starts with "transport surveillance services" as the root, defines the service level on the next layer (immediate action, action at next trusted station, action at destination), followed by the actual services on the layer below and the sensor types on the bottom layer. It should be noted that this model is meant for the engineer of the CPS and serves as a means to visualize and structure the existing variants.

From the model given in figure 2, we can identify sub-models or partitions representing feature – sensor – transport service "slices" of the feature model. Two of the feature models slices are depicted in figure 3. The left side shows a slice for "steadying the cargo" and the right side for "securing the trailer". The model slices identify the sensor types required, which services are offered and how they relate to the sensor type and what service level to implement. Corresponding concepts, rules and constraints would have to be implemented in the ontology in order to provide and maintain a corresponding parametric knowledge set.

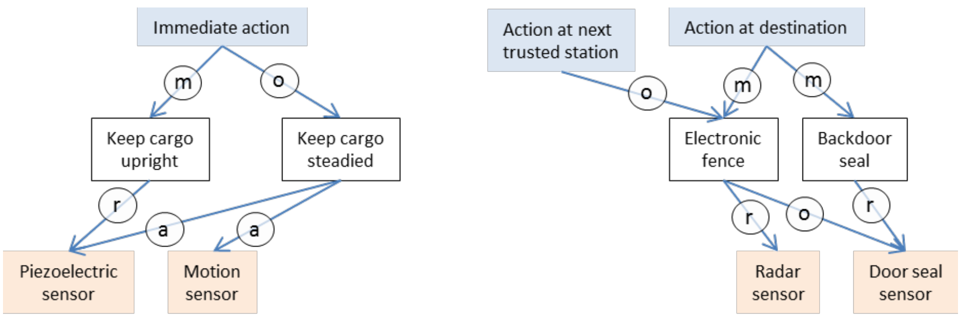

Fig. 3. Two "slices" identified from the feature model

4.2. Business Model based on Feature Model Slices

One of the business objects defined within the case is "*To establish the service of 'backdoor seal' for medium-sized and large haulers with at least 250 trailer installations and 50% cost coverage during the first two years*". Backdoor seal means to have an additional electronic lock for the backdoor which consists of a sensor informing the back-office by communicating via WSN and gateway that the door has been opened during the transport process. This "seal" is a

complement to the physical lock and meant to prevent the driver (who has the key to the physical lock) from opening the rear door of the trailer without prior authorisation.
Business model development did not only cover the above business objective, but also the business objectives for other services. The development was performed using the approach of partial business models proposed by Wirtz [11]: The *capital model* is subdivided into financing model and revenue model. The *financing model* describes the sources of the capital for business activity and the revenue model identifies sources for direct or indirect generation of revenue. The *procurement model* describes production factors and their sources, i.e. identification of suppliers is an important aspect. The *manufacturing model* covers the combination of input factors to the service under consideration. Demand structures as well as the competitive situation are described by the respective sub-models of the *market model*. The *service offer model* defines which IT services are provided to the customers, and the *distribution model* focuses on the channels used to make the IT services available to the specific customer groups. For brevity reasons, table 1 only shows the partial models relevant for defining the integration into the enterprise model, i.e. capital model and distribution model are not included.

Table 1. Excerpt from business model from "backdoor seal"

Partial models of business model		Business model of trailer theft control
Market model	Demand model	Main target group are medium-sized and large carriers operating large fleets of trailers. Within this group, different segments have to be distinguished, like hard-shell trailers for backdoor seal products.
	Competition model	For backdoor seal, conventional locks and security services can be considered as competition. The offered IT service as such up to now is unique on the market.
Procurement model		Different elements of the services are contracted to service providers: • authentication of the truck driver: provided by trust centre • communication between gateway and back-office: provided by telco • security service in case of security incident, e.g. attempt of theft: provided by security provider
Manufacturing model		The general administration services, operational services and control services all are provided from the own back-office of the enterprise (i.e. service operator, infrastructure operator, project manager, help desk, etc.) using own IT hardware and software systems (fleet management, contract management, configuration environment).
Service offer model		The backdoor seal service is offered as stand-alone IT service or as "security bundle" with the services "electronic fence" and "electronic seal".

5. Case Analysis and Observations

In order to find information for Q1 (challenges in defining business models for CPS), we analysed documents related to business model design and development in the case study company, which also included material about business services and development processes related to capabilities. The documents analysed in this step were created between May 2014 and February 2016. They included

- hand-written notes from project meetings taken by project members
- documents produced by bachelor and master students involved in the project, e.g. a report from a study project on instructions for clearing tasks, assignment work or thesis documents
- deliverables from the project and internal working documents

For Q2 (need for feature model) we compared the content of the enterprise model and the feature model. For Q3 (support of stakeholder communication) we interviewed the involved persons. The analysis results can be summarized as follows:

Q1: What are the challenges in defining business models for CPS?

The perceived challenges by the product owner are to understand what technical components would be required to implement the envisioned business services, to understand what additional business opportunities result from possibilities of the technical capabilities of the CPS and to understand the dependencies between different business services relevant for defining "packages" of service offers for customer groups

The system architect's concerns address other challenges. The architect needs to understand the dependencies between different configurations to be delivered to the customers in order to decide on a feasible and flexible architecture and to finalize the functional and non-functional requirements resulting from potential business models.

Q2: Is there a need for feature models to support the identified challenges?

The way we addressed this question is to investigate whether the existing models would contain the information required for tackling the challenges and to explore how feature models could be used for the challenges. When comparing the enterprise model, in particular the product perspective (see fig. 1) and the feature model, it becomes clear that the components of the CPS, like the sensors, and also the features and the relation between the sensors and the features are included in the product model, but the product model does not include the information about mandatory or optional features and it does not show the "required action" which is considered as important information by the stakeholder. Thus, the feature present complement to the enterprise model which is considered relevant and useful by the stakeholders.

Q3: How can feature models support the communication between business and IT stakeholders?

The notion of feature has been interpreted differently in the context of feature model development and use. A number of research papers take the position that a feature is offered to the end user or what the end user is willing to pay for. This clearly business-oriented perspective is contrasted by other work considering features as distinct characteristic of a system visible to the user, which also applies for functionalities or technical features. We found that representing the business view of features and the technology view of features in the same feature model would be the most promising use of feature models in our application context. Furthermore, we observed that a third kind of feature was included in the feature model which grouped the features in situations. The process owner welcomed this information in the feature model as it eased identification of partners required for implementing the business model. Example: if situations can occur where urgent stops during transportations are needed, there has to be a network of partners with "safe locations" in the vicinity of the route. If such a partner does not exists or causes too high costs, the business services related to this situation should either not be offered or designed with alternative deployment possibilities.

Furthermore, when discussing the feature model, business and technical stakeholders developed the idea to produce feature model "slices". A slice would show what customer features could be offered with a given sensor or actuator combination. From a modelling perspective, this is basically creating views on the model. The technical stakeholder considered the slices as useful for partitioning the design of the architecture; the business stakeholder for packing services. This needs further investigation.

6. Summary and Future Work

Starting from the example of a CPS for transportation industries, the paper investigates the use of feature models and slices in the development of business models. Different information is included in business model, enterprise model and feature model. The feature model and the slices are considered as useful and relevant representation for communication between stakeholders and for developing business models.

The main conclusion from the industrial case is that the pragmatic process used for feature model development, identifying slices and using it for stakeholder communication served its purpose and revealed correspondences between the different models and possibilities to enhance the existing enterprise model. From a research perspective, the work so far is not more than the study of a specific case. However, the findings can form the starting point for more systematic work on a business and technology stakeholder integration for CPS development and innovation.

References

1. Deutsche Bank Research http://www.dbresearch.de/PROD/DBR_INTERNET_EN-PROD/PROD0000000000333571/Industry+4_0%3A+Upgrading+of+Germany%E2%80%99s+industrial+capabilities+on+the+horizon.pdf
2. Thörn C, Sandkuhl K (2009) Feature Modeling: Managing Variability in Complex Systems. In: Tolk A, Jain LC (eds) Complex systems in knowledge-based environments. Theory, models and applications, vol 168. Springer, Berlin, pp 129–162.
3. Yin, R. K.: Case Study Research: Design and Methods, Third Edition, Applied Social Research Methods Series, Vol 5; Sage Publications, Inc, 2002; 3rd edition.
4. Osterwalder, A., Pigneur, Y. and Tucci, C. (2005) Clarifying business models: Origins, present and future concepts. Communications of the Association for Information Science, 16, pp. 1-15.
5. Perkman, M. and Spicer, A. (2010) What are business models? Developing a theory of performative representation. Research in the Sociology of Organizations, Vol. 29, pp. 265-275, Emerald Group Publishing.
6. Rappa, M. (2001) Business Models on the Web: Managing the digital enterprise. www.digitalenterprise.org/models/models.html. Accessed: December 2011.
7. Sandkuhl, K.; Stirna, J.; Persson, A. and M. Wißotzki (2014) Enterprise Modeling: Tackling Business Challenges with the 4EM Method (The Enterprise Engineering Series). Springer Verlag, Berlin Heidelberg. ISBN 978-3662437247.
8. Sandkuhl, Kurt; Smirnov, Alexander V.; Shilov, Nikolay (2015): Cyber-Physical Systems in an Enterprise Context: From Enterprise Model to System Configuration. In Witold Abramowicz (Ed.): Business Information Systems Workshops - BIS 2015 International Workshops, Poznań, Poland, June 24-26, 2015, Revised Papers: Springer (Lecture Notes in Business Information Processing, 228), pp. 148–159. Available online at http://dx.doi.org/10.1007/978-3-319-26762-3_14.
9. Vernadat, F. B. (1996). Enterprise Modelling and Integration. Chapman & Hall, 1996.
10. Weill, P. and Vitale, M. (2001) Place to space: migrating e-Business models. Harvard Business School Press. Boston, MA, USA.
11. Wirtz, B. (2010) Electronic Business. Gabler Verlag.
12. Zott, C., Amit, R. and Massa, L. (2010) The Business Model: Theoretical roots, recent developments, and future research. Working paper 862, June 2010, IESE Business School, University of Navaro, Spain.
13. Antsaklis, P.: Goals and Challenges in Cyber-Physical Systems Research Editorial of the Editor in Chief. IEEE Transactions on Automatic Control, 59(12), 3117-3119 (2014)
14. Johansson, K. H., Pappas, G. J., Tabuada, P., Tomlin, C. J.: Guest Editorial. Special Issue on Control of Cyber-Physical Systems. IEEE Transactions on Automatic Control, 59(12), 3120-3121 (2014)
15. Aghaei, S., Nematbakhsh, M. A., Farsani, H. K.: Evolution of the World Wide Web: From WEB 1.0 TO WEB 4.0. International Journal of Web & Semantic Technology, 3(1), 1-10 (2012)
16. Zapater, J.: From Web 1.0 to Web 4.0: The Evolution of the Web. Proceedings of the 7th Euro American Conference on Telematics and Information Systems, April, p. 2. ACM (2014)

17. Skarmeta, A., Moreno, M. V.: Internet of Things. Secure Data Management, pp. 48-53. Springer International Publishing (2014)
18. Yang, S. H.: Internet of Things. Wireless Sensor Networks, pp. 247-261. Springer London (2014)
19. Atzori, L., Iera, A., and Morabito, G.: The Internet of Things: A Survey, Computer Networks, 54(15), 2787-2805 (2010)
20. Fisher, A., Jacobson, C. A., Lee, E. A., Murray, R. M., Sangiovanni-Vincentelli, A., Scholte, E.: Industrial Cyber-Physical Systems - iCyPhy. Complex Systems Design & Management, pp. 21-37. Springer International Publishing (2014)
21. Wan, J., Zhang, D., Zhao, S., Yang, L. T., Lloret, J.: Context-Aware Vehicular Cyber-Physical Systems with Cloud Support: Architecture, Challenges, and Solutions. Communications Magazine, IEEE, 52(8), 106-113 (2014)
22. Teslya, N., Smirnov, A., Levashova, T., Shilov, N.: Ontology for Resource Self-Organisation in Cyber-Physical-Social Systems. Klinov, P., Mouromtsev, D. (eds.) 5th International Conference of Knowledge Engineering and the Semantic Web (KESW 2014), CCIS, 468, pp. 184-195. Springer International Publishing Switzerland (2014)
23. Horvath, I., Gerritsen, B. H. M.: Cyber-Physical Systems: Concepts, Technologies and Implementation Principles. Horvath, I., Rusak, Z., Albers, A. Behrendt, M. (eds.) Proceedings of TMCE 2012, 19-36 (2012)
24. Michniewicz, J., Reinhart, G.: Cyber-Physical Robotics–Automated Analysis, Programming and Configuration of Robot Cells Based on Cyber-Physical-Systems. Procedia Technology, 15, 567-576 (2014)
25. Alexander Smirnov; Kurt Sandkuhl and Nikolay Shilov (2013) Multilevel Self-Organisation and Context-Based Knowledge Fusion for Business Model Adaptability in Cyber-Physical Systems. In Natalia Bakhtadze (Ed.): Manufacturing Modelling, Management, and Control.Saint Petersburg, Russia, Jun. 19, 2013. Volume # 7: Elsevier, IFAC (IFAC proceedings volumes), pp. 609-613.
26. Lee I., Sokolsky O. (2010) Medical Cyber Physical Systems, Proc. IEEE Design Automation Conference, Proc of the 47th Design Automation Conference , Anaheim, CA, USA, pp. 743-748.
27. Baheti, R., & Gill, H. (2011). Cyber-physical systems. In: Samad T. and Annaswamy A. M. (eds.): The impact of control technology, 12, 161-166.
28. Kang, K. C., Cohen, S. G., Hess, J. A., Novak, W. E., & Peterson, A. S. (1990). Feature-oriented domain analysis (FODA) feasibility study (No. CMU/SEI-90-TR-21). Carnegie-Mellon University Pittsburgh, Software Engineering Institute.