An Approach for a Model Based Development Process of Cybertronic Systems

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ABSTRACT

Modeling today's products means modeling interdisciplinary 'product systems' integrating various authoring systems with the technical-administrative product structure and the related processes. This paper introduces System Lifecycle Management as key concept to cope with risen requirements in the development process for so called Cybertronic Systems. Along with an approach based on methods of Model Based Systems Engineering the outlined challenges are studied in the research project mecPro². The overall concept considers engineering processes as well as engineering data. Within the project a framework for modeling a product system in the early development phases (left wing of the V-model) will be defined which guarantees traceability and also manageability of such complex Cybertronic systems.

Index Terms - System Lifecycle Management, Model Based Systems Engineering, Cybertronic Systems, Traceability

1. INTRODUCTION AND MOTIVATION

Today's high-technological products are multi-disciplinary and complex "systems" which are developed by multiple engineering disciplines. The requirements on these systems are rising constantly, e.g. caused by more and more functionalities, new upcoming legal requirements and the need for robustness in cross-linked environments. All these requirements lead to a complexity explosion, especially with regard to the information flow within a product development process [1]. Additionally, as a result of the increasing networking of technical products, "systems", via the virtual world of the internet (cf. "Internet-of-Things"), the complexity of both system and process information will increase furthermore.

A single engineering discipline is not able anymore to develop its own partial systems without the need for interacting with other disciplines. A multi-disciplinary system development requires a rethinking of common methods, processes, IT-solutions and organizational forms as they are known in product development today. Further, to cope with complexity and to assure fulfillment of new requirements, traceability throughout the entire system lifecycle is needed. Today, traceability of requirements in a Product Lifecycle Management (PLM) [1] [2] solution manifests itself only in relations defined between product requirements and elements of the bill of material. New interdisciplinary methods for product development are needed which take into consideration that on the one hand the procedures of engineering disciplines differ in processes and data and on the other hand a common understanding and collaboration is essential.

For a successful development of a product, a common understanding of all stakeholders already beginning from the early phases of the product development process is inevitable. This paper considers System Lifecycle Management (SysLM) [3] as a key concept for the definition of engineering design processes. Model Based Systems Engineering (MBSE) [3] [4], as essential part of the System Lifecycle Management concept, is a multi-disciplinary engineering paradigm to guide the design process in the early phases and to achieve traceability. MBSE gives several

suggestions how different disciplines can work together on a multi-disciplinary system level. To enable the engineers of the involved disciplines, to interact and link their discipline-specific data and processes with the multi-disciplinary system level, the creation of a model of the common understanding is needed. The MBSE approach ensures that both data artefacts and processes can be matched on different abstraction levels between multi-disciplinary and discipline-specific models. Supplementary, in the context of MBSE also a new approach for a comprehensive system description based on an extended V-model [5] will be presented.
As an example for the development and application of both SysLM concept and MBSE approach, this paper presents the procedure of the research project mecPro² which is supported by the German Federal Ministry of Education and Research (BMBF). It will be described which problems companies face today while developing so-called Cybertronic Systems (CTS) and which needs they have as a result. Further, an overview of the concept and of the objectives of the project will be given.

2. RELATED WORK

This chapter gives a brief overview of previous work and research on the topics of System Lifecycle Management and Model Based Systems Engineering, with a proposed extension on the V-model within, performed at the Institute for Virtual Product Engineering (University of Kaiserslautern, Germany) [6] [7] [8] [9].

Remark:
In the following of this paper, the usage of the term "system" means products and related services which are intelligent, multi-disciplinary as well as cross-linked and communicating with each other.

2.1 System Lifecycle Management

To enable an early system description of Cybertronic Systems, the new concept of System Lifecycle Management is a promising new instrument for a functional description of technical systems. Rather than up to 80% of the essential characteristics of each system are determined in the early phase of its development [10]. Decisions made here are fundamental for the entire lifecycle of the system. Revising the system or changing processes in later phases causes great effort. System Lifecycle Management (SysLM) represents a concept rather than a monolithic IT-solution. Similar to Product Lifecycle Management, System Lifecycle Management is an integrated, information-driven concept to improve the performance of a system over the entire lifecycle. It achieves efficiency by using a shared information core system that helps engineers to efficiently manage complexity in the lifecycle of the product system from first definition of requirements to end-of-life activities. Thus, the SysLM concept does not provide new and innovative systems but can contribute to engineering at administrative level (see Figure 1) by providing the right information at the right time in the right context. [11]

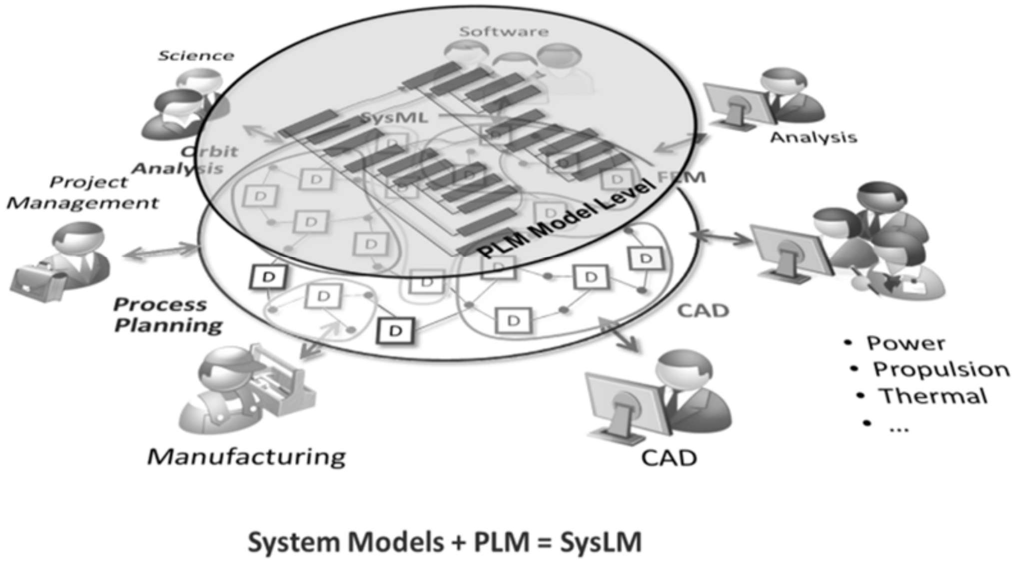

Figure 1: Two-Layer-Model of System Lifecycle Management (adapted from [3] and [4]).

Eigner et al. [11] define System Lifecycle Management as a general information management solution extending today's Product Lifecycle Management to the early phases and all disciplines including services. The concept is based on a direct or indirect integration of various authoring systems along the system lifecycle with a technical-administrative backbone for system or product models and processes. SysLM helps to improve the performance of a technical system by archiving requirements traceability over the entire development process by using the concept of Model Based Systems Engineering to provide methods to guide the cross-disciplinary and virtual product development.

2.2 Model Based Systems Engineering

Model Based Systems Engineering (MBSE) is a multi-disciplinary engineering paradigm propagating the use of models instead of documents to support analysis, specification, design and verification of the system being developed [12]. Systems Engineering as such, comprises technical as well as management processes to generate a balanced system solution in regard to various stakeholder needs and to reduce risks that can hinder the success of a project [13]. The resulting system model helps to understand and to overview the complexity of the developed system and simplifies the communication in a multi-disciplinary development team from a discipline-neutral view of the system specification. A methodical guideline for the use of the Model Based Systems Engineering paradigm has been developed and conceptually realized [7] [8] [11] through extending the V-model from VDI 2206 [5] in several steps (see Figure 2).

The V-model for Multi-Disciplinary Product Development by Eigner et al. [7] [8] enables a model-based and structured system description in the early phases of development. The systemization on the left wing of the V-model divides the system modeling process in the three levels of specification, first simulation and discipline-specific modeling. Parallel to these overlapping levels, the information artifacts or model elements of a system are differentiated in requirements (R), functions (F), logical solution elements (L) and physical parts (P), as well as elements and artifacts which describe the system behavior (B) [11].

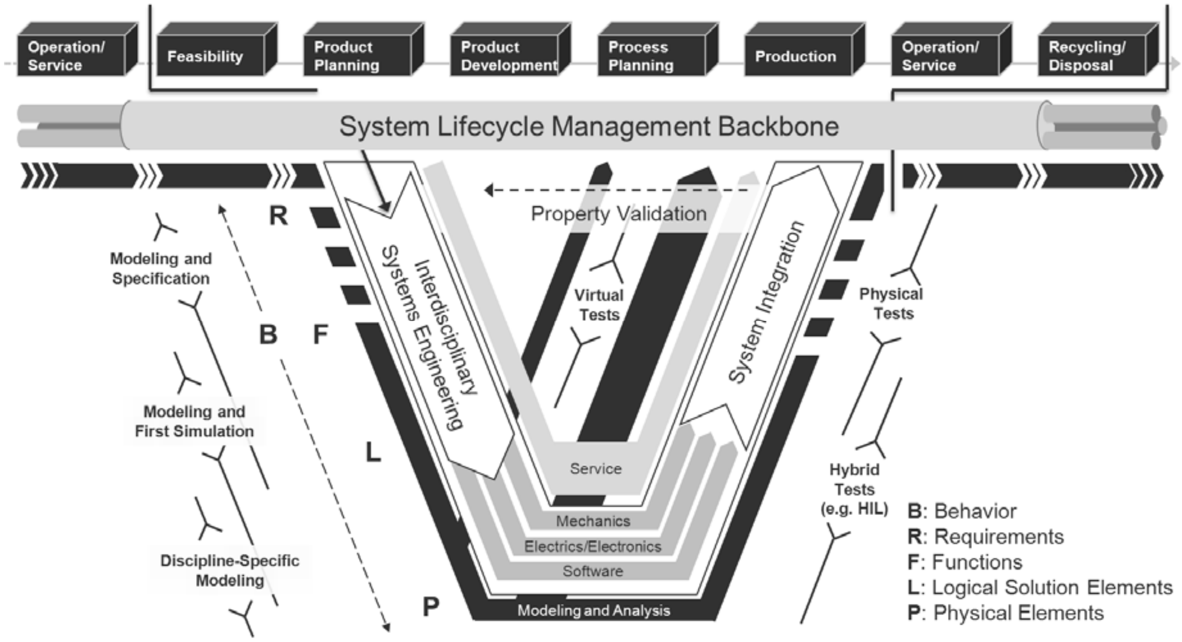

Figure 2: V-model for Multi-Disciplinary Product Development [11]

System models are created in authoring tools by using the Systems Modeling Language (SysML). SysML is one possibility to describe complex and interdisciplinary products in a formal way. A specific data scheme describes and defines the system elements as well as the semantic links between them to ensure traceability in a ‘horizontal’ and ‘vertical’ way. Furthermore, the data schema allows to integrate and to manage this information in a new System Lifecycle Management (SysLM) backbone.

The use of a formal language like SysML guarantees the possibility to administrate, version and reuse the artifacts of a system model. SysML is a universal language which can be extended by certain profiles. In the research project mecPro² (c.f. Chapter 3) a SysML profile will be developed (1) to support the early phases of the product development process of Cybertronic Systems by an interdisciplinary system model and (2) as a reference development process model as well. Both will be administrated within a System Lifecycle Management IT-solution which will be developed during mecPro².

2.3 Cybertronic Systems

As a result of the increasing networking of technical systems via the virtual world of the internet (cf. “Internet-of-Things”), the complexity of both system and process information will increase furthermore. Such networked systems which permanently inform and influence each other are referred to as Cyber-Physical Systems (CPS) [10] [14]. In the development of mechatronic systems, the basic physical system is considered as an essential component in addition to electronics and software. By the strong use of the characteristics of Cyber-Physical Systems, mechatronic systems have evolved to elements of Cybertronic Systems (CTS) that are characterized by an adaptive and autonomous behavior. Figure 3 shows the general structure of a Cybertronic System.

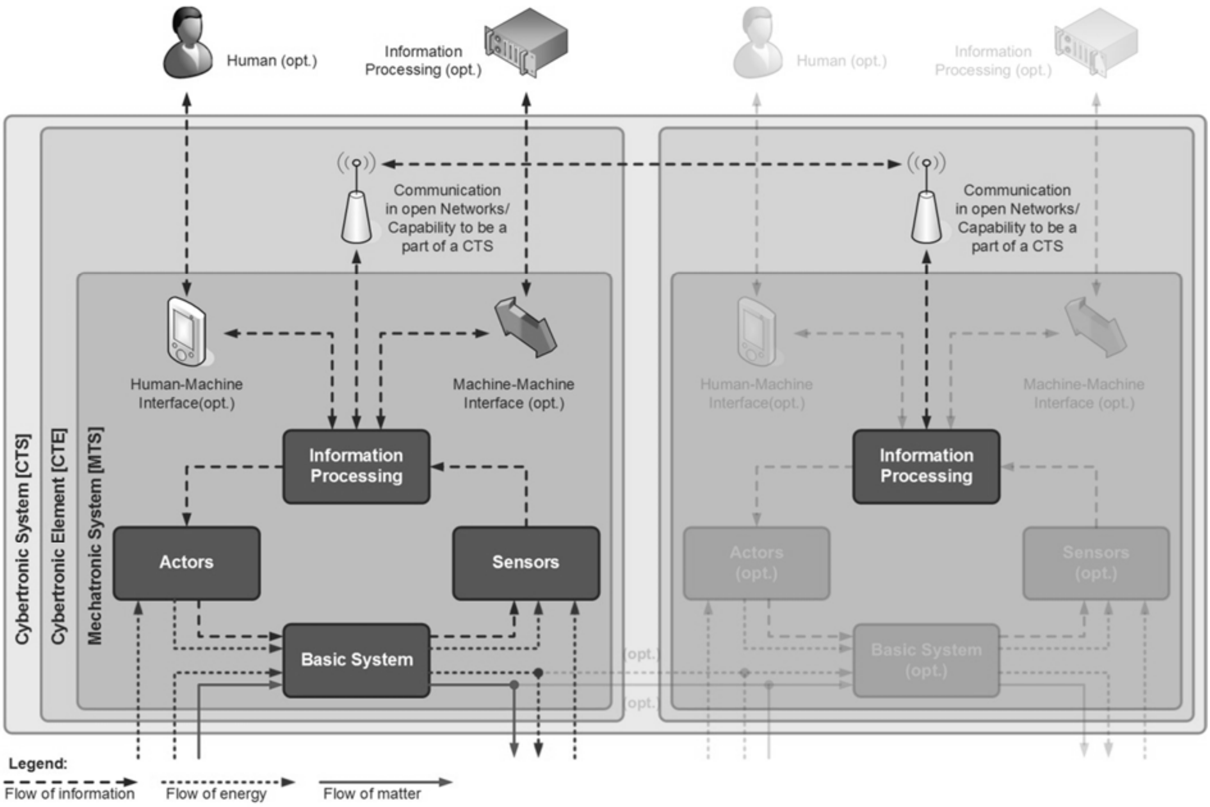

Figure 3: General Structure of a Cybertronic System

A Cybertronic System emerges out of the interconnection of at least two Cybertronic Elements (CTE). These CTEs consist in any event out of an information processing element and the abilities to act cybertronic. For the emergence of a Cybertronic System one of these Cybertronic Elements must be built up of a Mechatronic System (MTS) in the sense of the guideline VDI 2206 – Design methodology for mechatronic systems [5]. The connection between these CTEs is based on a bidirectional information exchange. Optionally there could also be a flow of material or energy. The existence of Cybertronic Systems is limited by time. They exist only for the time their elements interact with each other through this bidirectional information exchange.
In the further course of the research project mecPro² (c.f. Chapter 3) Cybertronic Systems will be subdivided in Cybertronic Products (CTP) and Cybertronic Production Systems (CTPS).

3. RESEARCH PROJECT mecPro²

The research project mecPro² (Model Based Engineering of Cybertronic Products and Production Systems) [15] runs inside the field of "Industrie 4.0" which is a project in the high-tech strategy of the German government. Industrie 4.0 promotes the computerization of traditional industries such as manufacturing and claims to develop and support the vision of the forth industrial revolution. The revolution consists of the enhancement from automated production to intelligent production, which is one part of a fully connected world (c.f. Internet-of-things). Therefore the German Government invests around 200 million Euro in research activities all around Industrie 4.0.
During a project duration of three years, in mecPro² an overall concept including the usage of SysLM, MBSE and of the extended V-model will be developed and validated which allows the integrative planning and development of Cybertronic Systems and the management of corresponding accumulating information along the system lifecycle. The processing, transfer and integration of system data should be made possible by the use of an integrated approach

which includes methods, processes and IT-tools as well, already beginning from the early phases of the system lifecycle. As a result of the project, a reference process as well as a data schema for meeting the requirements of the development of highly complex systems like Cybertronic Systems will be provided by the project consortium consisting of companies and research facilities.

3.1 Project Goal

The goal of the project is to increase efficiency in Cybertronic Systems development efforts through the use of Model Based Systems Engineering. Hereby, the focus lies on the improvement of the quality of development results and on an earlier start of production (SOP). Main targets are a reduction of error of up to 25% and a shift of SOP by about 20-25%.
The resulting goal of the project is to understand the complex dependencies between departments, to capture and to optimize design processes and data, as well as to accelerate the exchange of information. Media breaks often represent obstacles for an efficient data transfer between design tools. In order to achieve a central description of a Cybertronic System at the early stages of design, such media breaks should be reduced. This should be done through integrated model-based development processes and hence enable an acceleration of the exchange of information. Furthermore, an integrative contemplation of the development processes of products and production systems is necessary for the earlier shift of SOP.
In summary, the processing, distribution and integration of product and production system information in the early phases of the product life cycle should be made possible in this research project with the help of an integrated process and IT-tool approach. This approach should allow to develop intelligent, highly cross-linked Cybertronic Products and Production Systems in relation with each other (see Figure 4).

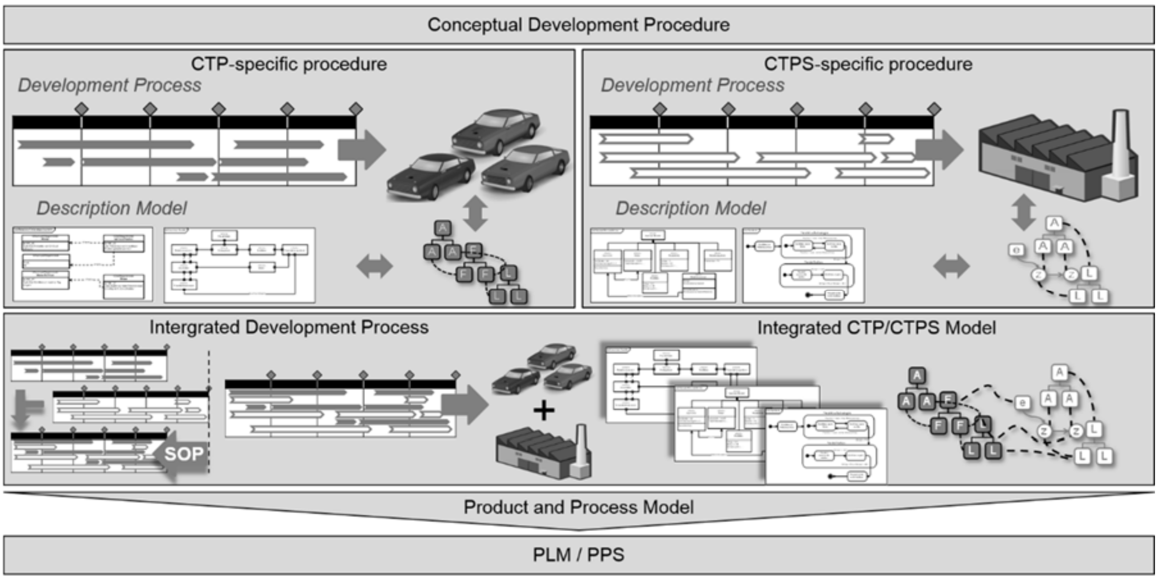

Figure 4: Integrated and model-based Development of CTP and CTPS

The most important partial results of this collaborative project are:

- An integrated reference process with IT tools and resulting models to be used.
- A product and process model as a neutral representation for mapping to company-specific PLM solutions.

These two results are indispensable preconditions for the future development process of highly complex Cybertronic Systems at industrial partners that participate in this project.

3.2 Conceptual Procedure

In order to achieve the overall goal of an integrated and model-based design, the extended version of the V-model [7] [8] according to the guideline VDI 2206 [5] is used as a basis (see Figure 2) in the elaboration of the project. It describes the procedure and the arising results during the development of a Cybertronic System. The focus lies on the early phases of design (left wing of the V-model). Furthermore, the differences in the V-models for Cybertronic Products (CTP) and Cybertronic Production Systems (CTPS) as well as their interdependencies will be examined and transferred to an integrated development process. The conceptual procedure of this research project is based on this extended V-model and is subdivided into eight work packages (see Figure 5). Parallel to this, three application scenarios from the industrial environment provide requirements and information from practice.

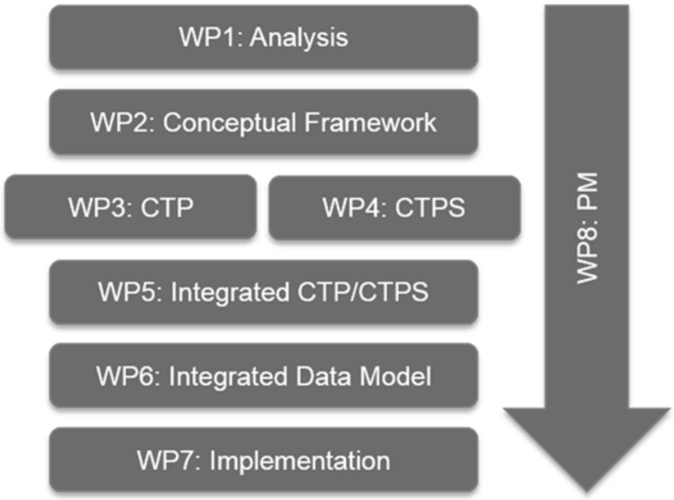

Figure 5: Overview of the Work Packages

The aim in the first work package is to identify and document the special features that distinguish a Cybertronic System from a Mechatronic System as well as the three application scenarios. Resulting from this, the specific problems that arise within the development process of Cybertronic Systems will be derived.

The second work package revolves around the conceptual framework for the development of CTS. In a first step, there will be a process analysis in which actual development processes from the industrial environment will be documented. After this, in two parallel sub packages a process framework and a systematic specification concept for CTS will be prepared. The following sub package will merge the developed results in an integrated concept for model management.

In the following two work packages the Cybertronic System will be individually considered from the viewpoint of products and production systems. In parallel, the special requirements of CTP and CTPS on the development process will be examined and specified more in detail. For this purpose, the systematic specification concept will be extended by their specific aspects. During the further progress of the project, these specific aspects as well as their impact and requirements regarding an early simulation will examined more closely.

In the fifth work package, the merge and the parallel development of CTP and CTPS is considered more in detail. No fundamentally new findings should be explored here but rather the common information intersections should be highlighted. The development processes of CTP and CTPS should be analyzed in terms of synchronization points in which an information exchange should ideally take place.

Work package six summarizes the results from the packages three, four and five. In work package seven, correlations between CTP- and CTPS-specific solutions are examined parallel to the implementation. The three application scenarios, as well as the systematic specification concept derived from them will be checked for consistency. A shared data model will be defined-, which then is implemented in work package seven. As a further objective, the availability of standards for the exchange of information in the development process should be identified and supplied to the implementation work.
The seventh and final operational work package is used to implement the preliminary results in a new System Lifecycle Management solution. The data and process model will be implemented in an IT solution to validate the usefulness of the research work on the existing three application scenarios. Another component of the work package is the programming of required interfaces and the expansion of authoring tools used to validate the application scenarios for the systematic specification concept. The project is concluded with a successful validation. Subsequently, now the scientific and economic exploitations can begin.
The project management, standardization activities and the transfer of knowledge from the project will be done in work package eight and parallel to the operational work packages.

3.3 Application Scenarios

The usefulness of the research work will be validated in the following three application scenarios:

- AS1: "Autonomous parking in the car park".
- AS2: "Cybertronic Production Systems".
- AS3: "Integrated design process of a Cybertronic Product and the associated production system."

The first application scenario "autonomous parking in the car park" considers the case that several Cybertronic System Elements have to communicate with each other. For the development process it is necessary that all system elements are explicitly described and the behavior definitions of the participating elements fit together. The application scenario regards especially the first and second level of the extended V-model. Here, in order to use the system's requirements, functions and behavior for later simulations, they are represented by the systematic specification concept. For the later stages of the product development process of a CTP, the systematic specification concept also provides a framework, which supports a multi-disciplinary product development process. The application scenario should fulfill the requirements so that the complexity, which results from the various system elements of the individual interaction partners, is still manageable.
In the second application scenario the focus lies on the design of Cybertronic Production Systems including their elements, as well as their special properties. At the second modeling level of the extended V-model material flow simulations will be derived from the functions and behavior of the production systems that have been specified at the first modeling level. The application scenario should show (a) how production in general could be made more flexible through Cybertronic Production Systems and (b) the enhanced involvement of production with engineering and simulation.
The third application scenario combines the results of AS1 and AS2. The aim is to show that a model-based product design process is able to provide information for developing a model-based design process of an associated production system in a very early phase of development. In this application scenario, the benefit of the common data model and the unified reference development process for CTP and CTPS will be demonstrated.
Figure 6 shows where the three different application scenarios will be mapped within the development process.

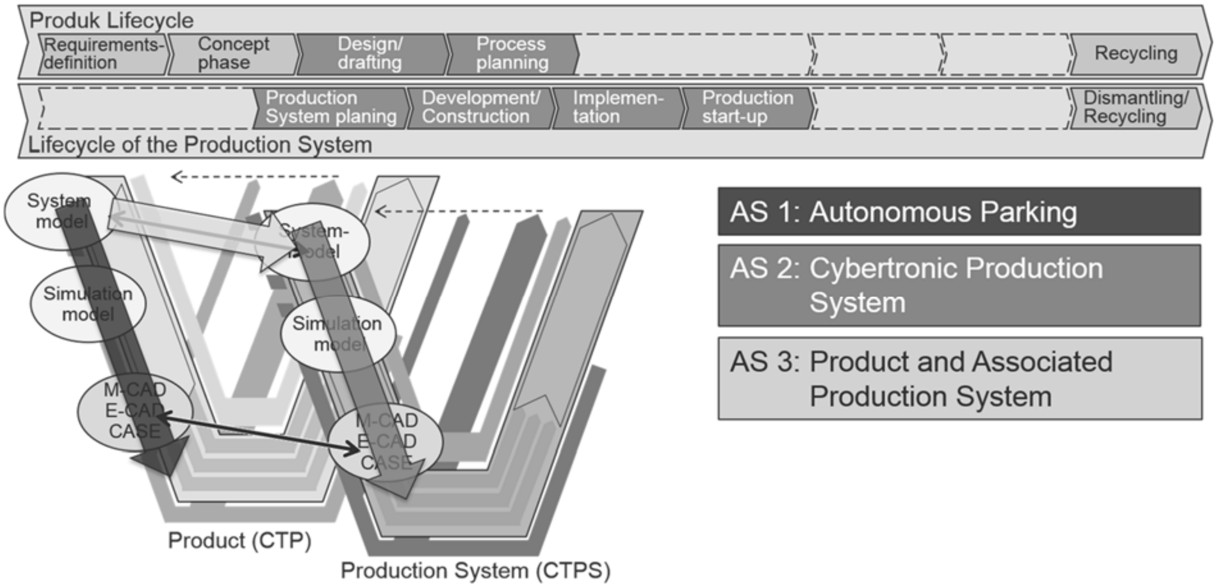

Figure 6: Application Scenarios along the Development Process

3.4 Project partners

To guarantee a comprehensive and application-oriented realization of the goals of the project, the partners from industry are composed of three different groups: Manufacturing industry, process experts and distributors of information management software. In addition, there are four scientific partners, three from the Technical University of Kaiserslautern and one of the Technical University of Berlin.

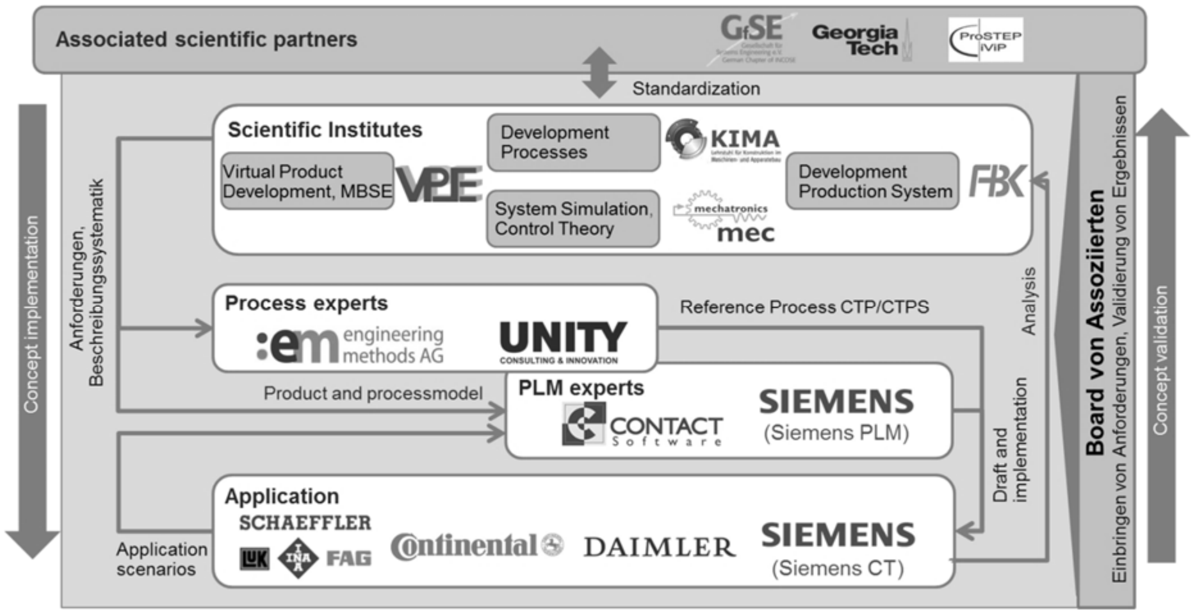

Figure 7: Overview of Project Partners

3.5 Usage of findings

The results of the project will be turned into account by the scientific partners as well as commercialized by the industrial partners.

3.5.1 Industrial usage

The industrial partners will use the findings of the project to meet the requirements of a flexible, customer-oriented production, like it is demanded in the fourth revolution of industrialization ("Industrie 4.0"). One of the challenging goals of Industrie 4.0 is the possibility to produce similar but customer-specific products ("Losgröße 1" – "lot-size one") in combination with high quantity. This means for the development of these products that semantic-rich models are needed which guarantee a high potential of reusability as well as the flexibility to meet customer-specific requirements.

3.5.2 Scientific usage

The universities will bring the results into their teaching activities. As it is expected that products get more and more complex and interdisciplinary, the universities have to react on the need of cross-disciplinary education of future engineers by setting up new programs for studies as well as updating and expanding existing lessons. Of course the results will be used in future research projects in the field of product and production process development as well. Especially by using the findings from the early phases of a development process in new projects which focus more on the later lifecycle phases.

3.5.3 Standardization

All partners are interested in the standardization of the research results. The findings of the project mecPro² can be input for several standardization groups. On the one hand for the development of Systems Engineering standards led by the INCOSE, especially the MBSE section. The collaboration and data exchange between different tools in the lifecycle can support standardization efforts like OSLC hosted by OASIS. Collaboration and model exchange processes between OEM supplier relations are one of the goals of the Smart Systems Engineering group of the ProSTEP iViP e.V..

4. CONCLUSION AND OUTLOOK

Modeling a complex product system requires the integration of various authoring systems and the product structure with related processes. Following this way, full traceability can be achieved. The paper introduces System Lifecycle Management as key concept integrating these two layers. The model-based approach being pursued within the project offers a solution to manage the complexity which is a consequence of the needs of multi-disciplinary systems development. This can be realized through the representation of a system by formal, digital system models. The implementation of the introduced approach will be provided within a new System Lifecycle Management backbone. Finally, at the end of the research project the partners from industry should be able to develop Cybertronic Systems in less time, in better quality and, moreover, in consideration of traceability.

While writing this paper, the research project has ended the tasks of exploring and working out scientific fundamentals and the capturing of classic mechanical of development processes at the the industrial partners.

The scientific fundamentals have been captured by finding several characteristics of CTS as well as by the comparison and assessment of numerous engineering methodologies and will be an input for a new interdisciplinary reference process for CTS in later working packages. Additionally the working package which will develop a classification for describing CTS by the language of SysML has been started. Both, the reference process and a first proposal of the classification, should be finished in the end of 2014. In the year 2015, the use cases will be processed by using the results of the early work packages of the project. In 2016 all results will be wrapped up and implemented in IT-solutions like PLM software and some plugins for discipline-specific software tools in order to support the flow of information within the engineering processes.

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