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ONTOGENY AND TRANSFORMATION OF PRODUCT MODELS – ANALYSIS BASED ON DEVELOPMENT PROJECT DOCUMENTATION

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1. Introduction

Today's challenges for innovating companies go far beyond the classical problems of augmenting performance regarding time, cost and quality. In the context of increasing globalization and reduced product and technology life-cycles innovation processes are characterized by increasing interdependencies with products and markets. The satisfaction of market needs requires more and more complex solutions the structure of which is expected to develop from classical mechatronic products to product-service-systems i.e. integral solutions of mechatronic products and services [Bullinger und Scheer 2006], entailing the increasing importance of interdisciplinary approaches in the development of solutions.

Owing to these circumstances, constantly optimizing the efficiency and effectiveness of their innovation processes is an increasingly complex task for manufacturing companies of both consumer products and industrial goods. This becomes even more relevant taking into consideration the augmentative dynamics within and in-between sub-processes and the higher degree of uncertainty these dynamics lead to [Ulrich and Eppinger 2003].

The multitudinous external and internal parameters with a dynamic temporal behavior constitute a vital challenge for industry by considerably influencing the innovation process and thus entailing necessary adjustments within it. Consequently, what industry needs to face today's challenges is the awareness of these dynamic parameters and means to consider them integrally in their innovation processes. Therefore, it is essential to fill existing methodological gaps and – based on a holistic approach – to develop advanced analysis, modeling and measuring methods [Lindemann 2007]. In order to be able to provide industry with such methods research aims at understanding, influencing and – in the long run – partially controlling parameters with a dynamic temporal behavior as well as their interdependencies in content and time.

The research activities leading to this paper are embedded in a transdisciplinary research project referring to these parameters as "cycles" and addressing "cycle management of innovation processes". Product-related cycles constitute one central group of dynamic parameters within the development process and manifest themselves particularly in the coordination of single activities in this process thus in the exchange of information in the form of documents – subsumed as "product models" in this context. Nevertheless, the consideration of product-related cycles in the process planning for the development of products and solutions is deficient [Thomke and Fujimoto 2000]. Therefore, the central question underlying the presented research is how critical points of coordination in simultaneous engineering (SE) processes during the development of mechatronic products and – in the long run – product-service-systems can be identified.

Product models – also referred to as artifacts or intermediate product representations – are dealt with during all stages of the development process from the fuzzy front end to detail planning and production. Not only they constitute the (physical or virtual) manifestation of the thinking process of process activities but also they are the (physical or virtual) basis of information exchange. This paper outlines the analysis of the dynamic temporal behavior of product models in order to contribute to the long term goal to reduce uncertainty concerning the ideal points in time of information transfer in SE processes, still comprising a major difficulty for the management of the latter.
The following sections give further information on the general research context, the specific goals and definitions of the central terms "cycle" and "cycle management", "model ontogeny" and "model transformation". The second paragraph includes a brief literature review addressing

- established process models and procedural models and the way they consider product models and their temporal dynamic behavior
- approaches to describe and deal with temporal mechanisms e.g. iterations.

In the third paragraph research gaps identified by the merging of the analysis' results with the mentioned research goals are pointed out, leading to the derivation of requirements of new approaches of describing and modeling development processes considering product models as process-inherent factors with a temporal dynamic behavior.
The final chapter presents data collected in a student development project and results of its initial analysis. This project was set up and completely documented to identify parameters for the description of the dynamic temporal behavior of product models.

2. Research context and related work

2.1 Cycle management in innovation processes

This research is part of a transdisciplinary research project with the common long-term goal of planning, managing and controlling cycles and their interdependencies in content and time in innovation processes referred to as "cycle management". In this context, cycles are defined as the succession of occurrences of similar type (e.g. partial processes, artifacts, procedures) respectively the succession of occurrences of different type within a particular process (here: the innovation process). Not only cycles from the inside but also from the outside of the innovation process (e.g. of the market, of legislation, of production technologies, etc.) have to be addressed, since these are strongly interrelated [Lindemann 2007].
The mentioned research goal is being pursued in different closely connected sub-projects of researchers coming from engineering, social, computer and business sciences, addressing areas like life-cycle-oriented strategic product planning, requirements engineering, development process design, development of competencies, complexity management, flexible production structures, customer relationship management and customer integration.
The activities in the ongoing first of three four-year-periods are aiming at identifying and understanding the meshing of cycles, both temporally and in terms of content, and the relevant parameters proceeding dynamically (e.g. parallel, sequentially, iteratively or recursively) and/or having a dynamically varying impact on the innovation processes and/or the product. Based on a sound understanding of the specific characteristics of cycles, the long-term objective after twelve years is to systematically support industry by the development of advanced methods and sophisticated instruments of cycle management.

2.2 Understanding the dynamics of parameters influencing the development process

The sub-project the presented research is part of focuses on the development process as one central part of the innovation process. Existing approaches of the planning of SE processes will be expanded by the integrative consideration of parameters with a temporal dynamic behavior for a more efficient and more rapid process execution. These parameters can be classified into context-related (e.g. social and legal factors), strategy-related (e.g. product and technology cycles) and solution-related respectively process-inherent (e.g. artifacts and project management activities) parameters [Langer and Lindemann 2009]. The initial point of this sub-project has been the compilation of the factors and

elements describing the external context of development processes. As a result a model for the classification of external context factors had been proposed, envisaging the classification into five context fields (Environment, Market, Company interfaces, Company, Development process) and four main classes (Technology / knowledge, Socio-economics, Politics / legislation, Resources). By adding a set of classification criteria both the cyclic behavior of the external influencing factors as well as of the effects induced can be considered [Langer and Lindemann 2009].
In addition to this classification of the context factors describing the external view onto the development process, the internal view concentrates on the activities within the process and the dynamic temporal behavior of the results of these activities.

2.3 Product models as dynamic factors of the development process

The internal view onto the development process is where the focus lies in this paper, addressing the cyclic behavior of the (intermediate or partial) results of process activities, thus of product models. The specific long-term goal of the research conducted in this context is the improvement of the synchronization of the activities within SE processes and thereby an acceleration of the latter.
From a systemic point of view, product models fulfill two central functions within the development process: on the one hand they constitute the objects of manipulation of activities and on the other hand they serve as physical or virtual media for the exchange of information when coordinating tasks as they represent the product focusing on its specific characteristics or functions of interest within the respective stage of the product life cycle. This leads to the hypothesis that information about the temporal dynamic behavior of product models can be used to optimize the synchronization of activities within SE processes. The product models' temporal behaviour is thus to be considered as an indicator of critical points in time for the transfer of information in the planning and control of processes is to be used.
When investigating cycles of product models in the context of SE processes, two perspectives can be taken: the consideration of the temporal dynamic behavior of a single product model or of the interaction between various product models. For that reason the terms "model ontogeny" and "model transformation" are defined in order to prevent confusion. Stemming from the field of biological science, the term "ontogeny", also referred to as "ontogenesis", is defined as the life cycle of a single organism, thus the entire sequence of events involved in the development of an individual. On a more general level "ontogeny" can be understood as "the origin, development and evolution of a single occurrence of a type or kind of artifact" [Goossenaerts 2000]. Based on this understanding, the term "model ontogeny" is defined as the gradual changing of single product models from a simple to a more complex level. In contrast, "model transformation" stands for the transfer of information from one model into another thus for the conversion of product models. Nevertheless, both mechanisms are strongly interdependent.
Uncertainty concerning the ideal points in time for information transfer, thus for passing information in the form of product models, comprises a major difficulty for the management of development processes. Owing to the functions product models have in development processes as depicted above in this paragraph, in a first step research aims at investigating the dynamic behavior of product models in order to contribute to the central goal of deriving measures suitable for supporting the synchronization of SE processes.

2.4 Perspectives on product models and their dynamic temporal behavior in design research

For a holistic understanding of product models as dynamic factors of the development process, in a first step, established process models, procedural models and multi model spaces are analyzed in the following paragraph with regard to the role product models play in their concepts and if and how dynamic aspects like model ontogeny or model transformation are considered.

2.4.1 The role of product models in process modeling

The following sub-paragraphs constitute a selection of the results of a literary analysis of process models, procedural models and multi model spaces that have been scrutinized focusing on the representation of product models and their dynamic temporal behavior.

With his "generalized procedural design model" Hubka (1976) created the basis for a number of established models. He describes the developed structure as a flow diagram of the design process. The hierarchic model comprises four layers of granularity, the first being the design process, the second the main phases, the third concrete design steps and the last one specific tasks of those steps. Product models correspond to the output of each design step. Thus design steps can be interpreted as operations transforming one product model into another, each transformation raising the product's concreteness. Each main phase ends with an evaluation (dis-/approval operation) which – at non-satisfaction – can be the initial point of a setback to any other point in the same main phase. The same mechanism takes effect on the upper process layer. Thus, the possibility for iterations is implemented but there is no further information on the characteristics of the temporal behavior of the used product models.

The Three-cycle-model of Gausemeier et al. (2004) accentuates a number of important aspects of today's product development context. On the one hand it indicates the underlying sequential order of strategic product planning, product development and production system development. However, these fields being represented as three cycles arranged partially parallel point out clearly the SE environment. Though, product development and production system development are only slightly offset and proceed mainly parallel. Each of the three cycles consists of sub-processes (such as conceptual design or concretion) whereas various crosslinks between sub-processes of different cycles are indicated, which accentuates the interdependencies between the various cyclic factors. As in Hubka's model, product models constitute outputs of sub-processes (especially in the product development cycle). Therefore, iterations are not only modeled on the concretion-axis of one distinct product but also on a multi-product / multi-project layer. Again, even though product models take a central position in this model, the latter does not provide insight in the mechanisms of their ontogeny or transformation.

Rude (1998) switches the perspective of product models being linked to process steps or sub-processes of a process model or procedural model to an integrated product model as depicted in Figure 1. This provides the possibility to classify product models according to the three dimensions "degree of variation", "degree of decomposition" and "degree of concretion". The latter is subdivided into four discrete layers representing the product model groups focusing requirements, functions, principles and embodiment. The dimensions serve for the systematic arrangement of the (intermediate) results of the development process (described as condition of the final solution), thus of all types of product models produced.

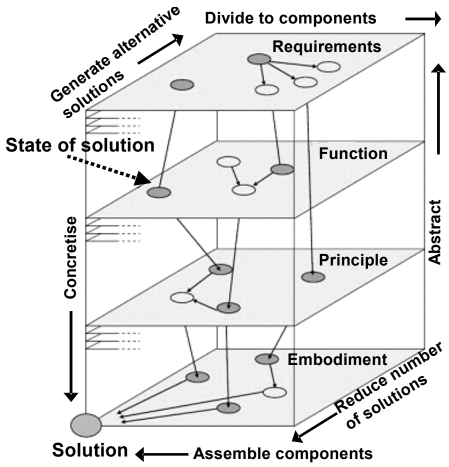

Figure 1. Level Based Three Dimensional Space of the Development Process [Rude 1998]

Rude's approach has been picked up by Lauer and Lindemann (2009) who added further functionalities and put it into a wider context. Lauer also developed a development space, but with five non-orthogonal instead of three orthogonal dimensions (Figure 2). These dimensions span a vector space and constitute parameters describing the product models, namely purpose, content, degree of cross linking, degree of concretion and development status for each of which discrete values or value intervals are defined. Applying the description of development process steps by the same parameters allows arranging them in the same vector space, whereby the link between product models and the development process is established. The calculated distance between product models and process steps inside the vector space is referred to as the relevance distance and allows an automatic allocation. Since product models evaluate during the design process the relevance distance is dynamic and the allocation of product models is automatically adapted after parameters are updated at the end of a process step, thus after manipulation of a product model. Thereby, and by the existence of a threshold value, the respective process steps can be provided with the documents of highest relevance at all times.

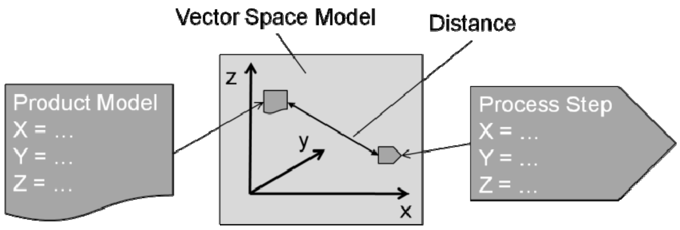

Figure 2. Linking product models to development process steps applying the principle of a Vector Space Model (according to [Lauer and Lindemann 2009])

2.4.2 Dealing with iterations in processes

This sub-paragraph is to provide insight in current approaches to formalize knowledge about dynamic temporal behavior by outlining two representatives of actual literature. As we could already see in the above mentioned examples, one particularity of product models compared to most other context factors is the existence of a targeted dynamic behavior – otherwise development would not exist. Though lacking a specification of this targeted dynamic or cyclic behavior, literature provides various approaches to characterize and classify deviations thereof. Iterations are omnipresent in design processes and by far the most mentioned type of deviation from a targeted dynamic behavior [Wynn et al. 2007, Krehmer et al. 2009]. Therefore, they are given special attention to in this research. Another prevalent approach to deal with the existence of the temporal dynamic behavior is to control processes through a degree of maturity as determining parameter.

To increase the utility of New Product Development process simulation Wynn et al. (2007) examine the modeling of design iteration and proposes a classification framework of six perspectives of iteration, namely exploration, convergence, refinement, rework, negotiation and repetition. For example conversion constitutes an optimization process when relations between requirements are complex and different methods are applied at different stages of a project to solve existing conflicts of goals towards a most satisfying solution. Negotiation as another example occurs when high product complexity requires a number of experts for the solution of versatile specific problems who cannot have the complete overview of the project. The basic statement that iteration is too complex to be captured by one single model and that it is dependent of situation-specific factors leads to the approach of a categorization by “perspectives”. The latter are non-orthogonal and depend i.a. on a person's perception and/or position, which can even be decisive for iteration being detected or not. The generation of product models is referred to as a central task in design but the description of the key challenges of, and thereby the requirements to modeling iteration, is limited to activities.

A further categorization is made by Krehmer et al. (2009) who distinguishes between advantageous and unnecessary iterations. Advantageous iterations representing useful approximation towards an optimal solution are to be promoted, whereas unnecessary iterations representing a setback in the development process (e.g. due to requirements being concretized too late) are to be averted. Furthermore, he describes the effects of design iterations on the product's degree of maturity which he defines as relevant measurement for the fulfillment of customers' requirements. By means of a holistic method of monitoring and securing of the product's degree of maturity, decision making is supported, whether or not an iteration can be expected to be efficient, meaning that the degree of maturity after iteration is higher than before iteration. The holistic approach comprises i.a. the integration of the dimensions product, process and participants, the latter playing a role similar to Wynn's “perception”.

2.5 Recapitulation of the state of the art

The overview won by the literature review, parts of which are presented in the previous paragraphs, leads to the following conclusions:

- In most process or procedural models product models hold a central position but predominantly their consideration is limited to static results of (sub-)processes or process steps. The three cycle model proposed by Gausemeier et al. (2004) depicts dynamics and interdependencies within the overall development process, but product models exist only as one final completed model. Earlier stages or (rejected) variants cannot be integrated.
- This deficit is removed in case of approaches providing a development space allowing that multiple product models and their potential stages during development process are represented in as in the models of Rude (1998) and Lauer and Lindemann (2009). However, the shortcoming of these models is the loss of a process-related character – specifications of temporal dynamic behavior cannot be depicted for lack of time-reference.
- The described approaches to classify or to cope with iterations and degrees of maturity provide important information in this field. Nevertheless, due to the chosen degree of abstraction it is not apparent if the described mechanisms are effective also in the temporal dynamic behavior of product models.

3. A new approach of analyzing the dynamic temporal behavior of product models in order to support cycle management

Regarding the aims of the research project, it becomes obvious, that none of the existing modeling approaches depicts the necessary elements in their integrality. The following paragraph outlines the requirements on research arising from these gaps and presents first results of the initial analysis of a student development project having been documented for this purpose.

3.1 Research gap and derivation of research questions

As shown above, current process models and procedural models as well as models formalizing dynamic mechanisms of processes are not satisfactory with regard to the defined research goals. The central research goal being the identification of critical points in time of coordination between different activities of SE processes, existing models lack in the integrability of the depiction of the dynamic temporal behavior of multiple product models and their interrelationships as determining factors of the progress of the development process.

This leads to the question how to identify parameters characterizing the development process accommodating the existence of numerous potential points of coordination. On the one hand, the necessary consideration of several discrete stages of product models during their development requires the characterization of the product models' ontogeny, on the other hand parameters describing the different ways of transformation between the involved product models must be integrated.

On a more concrete level, questions to be answered are which parts of the information formalized in a product model find expression in other models and what about non- transformed, thus information being potentially independent or even superfluous.

Several criteria for an initial classification of the mentioned parameters appear to be appropriate in this context, e.g. a differentiation between universal and product model specific parameters or a differentiation between parameters being influenceable or not.

The latter lead to further requirements deriving from the overall research aim constituting the identification of effects, external factors of the development process have on the parameters of the models' ontogeny and transformation. This information is considered obligatory to reach the long-term goal to enable the manipulation of the process in order to ideally make the coordination of product models reacting either stable or flexible on external influences, thus to use knowledge on cyclic interrelationships in planning and controlling of development processes.

To acquire information helping to answer these questions, a phenomenological approach has been chosen. To identify characteristics of critical points of coordination of SE processes, a development project has been completely documented as described in the next paragraph, including numerous subversions of all generated product models, allowing their analysis with regard to their ontogeny as well as their transformation.

3.2 Analysis of a fully documented development project

In order to address the research gaps mentioned in the previous paragraph, a student development project has been initialized for the purpose to generate a data base which allows analyzing the dynamic temporal behavior of product models dealt with during the development of a mechatronic product and other addressed coherences in the overall research project.
The object of this development project being a fully electric-powered go-kart, the interdisciplinary character of typical projects of the car industry as well as a sophisticated degree of product complexity have been considered for the data base being as realistic as possible. The challenge for the students has been to run a complete development process for all subsystems of the entire vehicle being restrained by strict boundary conditions with regard to time, cost, weight and the utilization context. The project group has been composed of eight mechanical engineering students organized in four teams and six research assistants as team leaders or with a coaching function (Table 1 shows the assignment of the eleven sub-systems to the four teams). During the project duration of six months the teams were in charge of the clarification of the requirements, the development, evaluation and selection of solutions as well as for their configuration and implementation. Two other students have been responsible for the documentation of the process attending the team meetings, running interviews with the teams (mainly on occurring problems) and capturing the project's complete information exchange by means of protocols. The data thereby acquired has been modeled with the ARIS toolset for process modeling.

3.2.1 Specification of the data basis

The technical basis for generating a relevant data base has been the utilization of a subversion software – thus a collectively used repository including a version control system – which allows maintaining current and historical versions of files. Therefore, not only final versions or released stages of product models are accessible for analysis, but also any saved intermediate stage. Table 1 provides an overview which product models have been worked on by the team during the development of the different subsystems. Each of the 77 crosses provides the information that a certain type of model has been used for the respective subsystem and that all saved intermediate versions of this model – rejected versions included – are available for analysis.

Table 1. Overview of the product models used during the documented development process

	subsystem	used models										
		requirements models	functional models	models of partial solutions	calculation models	electric circuit diagrams	concept models	evaluation models	CAD-models	mechanic simulation models	manufacturing drawings	electronic simulation models
vehicle architecture	driver interfaces	x	x	x	x			x	x	x	x	
	package & integration	x	x		x		x		x			
	safety & bodywork	x	x	x	x		x	x	x	x	x	
power train	electric motor	x	x		x		x	x	x		x	
	cooling system	x	x	x	x		x	x	x		x	
	power supply	x	x	x	x	x			x	x	x	
chassis	brake system	x	x	x	x		x	x	x			
	wheels & axes	x	x	x	x		x	x	x		x	
	steering system	x	x	x	x		x	x	x		x	
driving stability	sensor & bus systems	x	x		x							
	control systems	x	x	x			x					x

3.2.2 Strengths and weak points of the data access

The chosen approach of documentation of the set up development project for this research – a common repository including a version control system – resolves severe deficits of most data access available in projects with partners from industry, where uncertain data isn't being passed on or released, in order to avoid further tasks being carried out on an uncertain base. Hence, relevant indicators are not accessible or too vague [Krehmer et al. 2009]. Through the accessibility of all saved subversions of the project's product models, the extensive analysis of their complete development in time is possible – a fact scarcely to implement in industrial projects owing to prevailing measures of secrecy.

A disadvantage of the accessible data must be seen in the homogeneity of the development team consisting of students with approximately the same (low) level of experience. Due to the team members' parallel activities of different intenseness, certain conclusions – e.g. concerning the comparison of product models with regard to the necessary effort for their generation – can only be drawn considering a certain adulteration.

3.3 Results of the initial analysis

At the current stage of the project, the electric-powered go-kart is being assembled. Hence, the development phase and its documentation have just been finalized. The analysis process being yet at the beginning, an extract of results is presented to demonstrate the data quality and first ideas of derivable causal relationships. For this initial analysis, the representation of quantitative data has been chosen. Nevertheless, other relevant parameters are yet to be identified. Table 2 shows the development in time of quantitative data extracted from certain repository states of the project's initial phase of the product models having been generated for the power train subsystem.

From the represented numbers of the models' elements it is apparent which time offset the modeling of the products' functions starts with compared to the modeling of the products requirements. Furthermore, the comparison of the development in time of the two product models (their respective model ontogeny) indicates different intensities of activities proceeding parallel. This leads to the assumption of different types of partial mutual influences: The initial phase of the functional modeling e.g. is run through without important quantitative changes of the requirements model's elements (version numbers 6 to 8), whereas version numbers 12 to 14 show significant changes of both, the requirements model's and the functional model's elements. In this case, direct interrelationships between the two models' ontogeny could be retraced by means of the ARIS process documentation (see additional information in the bottom row of Table 2).

Table 2. Extract of quantified results of the analysis of the project history (power train subsystem)

	version number of repository state	…	5	6	7	8	…	11	12	13	14	…
	time span since previous date [workingdays]		0,5	0	1	0,5	…	0,5	0	0,5	1	
product model	parameters											
Requirements model	total number of requirements	…	14	14	15	15	…	15	26	26	26	…
	categories of requirements	…	6	6	7	7	…	7	8	8	8	…
	number of replaced requirements*	…	1	0	0	0	…	0	6	2	0	…
	number of deleted requirements*	…	0	0	0	0	…	0	0	0	0	…
	number of new requirements*	…	0	0	1	1	…	1	11	0	0	…
	…	…	…	…	…	…	…	…	…	…	…	…
Functional model (relation oriented)	total number of modelled functions	…	0	42	52	59	…	61	61	46	62	…
	number of useful functions		0	18	22	26		27	27	19	22	
	number of bad functions	…	0	24	30	33	…	34	34	27	30	…
	number of relations	…	0	61	70	74	…	69	69	60	68	…
	number of replaced useful functions*	…	0	0	4	1	…	1	1	0	2	…
	number of deleted useful functions*	…	0	0	1	0	…	0	0	3	1	…
	number of new useful functions*	…	0	0	5	4	…	0	0	0	9	…
…	…	…	…	…	…	…	…	…	…	…	…	…
	…	…	…	…	…	…	…	…	…	…	…	…
additional information / comment	* --> since the last date		C)	D)	E)	F)			G)			

C) replacement of a wrong data sheet
D) beginning of the functional modelling
E) detailing of 3 functional groups
F) detailing of 2 other functional groups
G) integration of additional req. coming from subsystem *chassis*

In this context, version numbers 12 and 13 show the most significant and momentous coherence of occurrences within the represented data, since the integration of additional requirements coming from the chassis subsystem required the modification – and thus a setback – of the functional model. Consequently, in the discussed example there is no discrete moment of transformation from the requirements model into the functional model, but there is at least a certain phase of simultaneous development.

As we could see, the represented ontogenies are not independent from each other. Instead, by analyzing and comparing the captured model ontogenies, information on the model transformation can be derived. Nevertheless, by this simple data example it is not possible to derive clearly which of the two model ontogenies exerts a higher influence on the other one.

In the project's context, it is one of the aims to analyze if e.g. effects of iterative type as depicted in the example constitute an avoidable effort if information would be better coordinated. With regard to the quality and quantity of the documented and accessible data (see above), these elementary results of the example deriving from a very small part of this data suggest further important conclusions from the complete analysis concerning the temporal dynamic behavior of product models and their interrelationships.

4. Conclusion and outlook

The objective of this paper has been the depiction of research activities on the analysis of the dynamic temporal behavior of product models during the development process as part of the innovation process. The research context is an interdisciplinary project aiming at the development of advanced methods and sophisticated instruments of cycle management, that means to systematically support industry in planning, managing and controlling cycles and their interdependencies in the diverse aspects of innovation processes. In this context cycles are defined as the succession of occurrences of similar type or the succession of occurrences of different type within a particular process, and exist inside and outside of the innovation process.

The research activities presented are focusing on the development process. Existing approaches of the planning of SE processes will be expended by the integrative consideration of parameters with a temporal dynamic behavior for enabling the process to be conducted more efficiently and more rapidly. Product models constituting the output of development (sub-)processes or activities are part of these – in this case internal – parameters. Their temporal dynamic behavior is being addressed in this paper, the goals of this part of the research project being to identify potentials how this behavior can be used to accelerate the synchronization between those models and to make it more flexible. The central research question in this context is how critical points of coordination in SE processes during the determination of the product's specification can be identified.

Established process models and procedural models have been analyzed for their suitability of representing the dynamic temporal behavior of product models and their interdependencies both among themselves and with other context factors. The outcome of this literary state of the art analysis has not been satisfactory with regard to the research aims – essentially they depict product models as static final results of sub-processes but lack the representation of dynamics. Hence, requirements to a new model have been formulated, referring to parameters being able to describe dynamic temporal behavior of product models and allowing classification.

For supporting the differentiation between the dynamic temporal behavior of one distinct product model on the one hand and of two or more product models and the possibility, that one bases on information of the other on the other hand, two terms have been defined: "model ontogeny" is described by the parameters of one distinct product model, "model transformation" by those of two or more product models.

For the phenomenological analysis of product models in order to gather information on their dynamic temporal behavior a student project – the development of a fully electric-powered go-kart, restrained by conditions as close as possible to those in car industry – has been run and completely documented in terms of information flow (problems, decisions) and the utilization of a collectively used repository including a version control system which allows analyzing the complete history of the development in time of the generated product models.

The development phase and its documentation just having been finalized, the quality of the extracted data and its initial analysis has been presented including first ideas of derivable coherences. Despite the low amount of data provided in the example, it yet allowed the derivation of first observations e.g. that there is no discrete moment of transformation from the requirements model into the functional model of the regarded sub-system, but there is at least a certain phase of simultaneous development.
Nevertheless, other further parameters are yet to be identified and described. With this ongoing analysis, interdependencies between the product models used during the development process are to be identified and classified. Additionally, conclusions concerning efforts in terms of time and money relating to ontogeny and transformation of product models are striven for in order to enable product model-related evaluations of certain mechanisms of temporal behavior, e.g. iterations.
As all versions of the history of the repository can easily be connected to the data of the documentation of information flow and problems, coherences to external factors like e.g. new requirements can be analyzed, which will constitute one of the activities of integrating the internal and external view of the sub-project (see paragraph 2.2.).
As the overall research project in the long run addresses the development of integral solutions of mechatronic products and services (product-service-systems), future research will include the analysis of the artifacts worked with in computer science and services and the collaboration with researchers of the respective disciplines.

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