INTEGRATED SYSTEM AND CONTEXT MODELING OF ITERATIONS AND CHANGES IN DEVELOPMENT PROCESSES

Stefan Langer[1], Arne Herberg[1], Klaus Körber[1] and Udo Lindemann[1]
(1) Technische Universität München, Germany

ABSTRACT
Cycles play a decisive role in innovation and development processes. Iterations and engineering changes as one perspective on cycles have a major influence on both value generation as well as resource consumption within the process. While several initiatives are addressing this field of research, methods for coping with iterations and engineering changes more effectively and efficiently are still needed. This research contributes an explorative model of cycles, iterations and changes that integrates both a system perspective and a context perspective on the development process. The modeling concept is evaluated by modeling examples from the development process of a SAE Formula student race car. The results show that the model allows for (1) a more precise analysis of iterations and changes, (2) for the derivation of hypotheses for handling iterations and changes and (3) for a subsequent operationalization.

Keywords: Cycles, iterations, engineering change, development processes, process modeling

1 INTRODUCTION

One of the most intensely discussed challenges innovating companies from the field of consumer as well as capital goods are facing is the highly dynamic behavior of the diverse external and internal influencing factors on their innovation processes. Aspects from the companies' context, as for example market demands, competitors, availability of technologies or legislation, are changing with varying speed and frequency, moreover being highly interdependent and thus forming a complex, dynamic network of influences. Equivalently, company-internal aspects show a both dynamic and highly interdependent behavior, such as iterations within processes, changes of employees and resources or adaptations of the product portfolio. This can lead to numerous issues like uncertainties of objectives, conflicts, changes due to insufficient coordination etc., consequently putting the achievement of temporal, quality-related and economic targets at risk (see e.g. [1-3]). These diverse dynamics and the involved challenges have been part of research with diverse, yet specific foci (see e.g. [4-7]).

The aim of this research is to support academia and industry in understanding, managing and controlling reoccurring patterns – cycles – within development processes and their context as well as their interdependencies in order to improve overall innovation processes in terms of efficiency and effectiveness.

One of the most challenging aspects in this regard is the field of engineering changes and iterations in development processes. While extensive research has been conducted within this field (see e.g. [8]), yet research and industry call for more efficient and effective models and methods to deal with this challenge.

As a contribution to this field of research, this paper aims at providing a modeling approach capable of depicting the constituents of cycles, iterations and changes within development processes as well as the related mechanisms. Therefore, the paper (1) depicts the different perspectives on cycles in development processes and elaborates on the necessity of addressing iterations and engineering changes. Subsequently (2), an explorative model of cycles in development processes is developed, integrating both a system and a context perspective on development processes. Finally (3), the modeling approach is evaluated by modeling cyclic examples from the development process of a Formula SAE race car.

2 THEORETICAL FOUNDATION / RELATED WORK: PERSPECTIVES ON CYCLES, CHANGES AND ITERATIONS IN DEVELOPMENT PROCESSES

2.1 Perspectives on cycles within development processes

As stated initially, cycles within development processes as well as in their context play a decisive role for the competitiveness of today's innovation processes. For this research, cycles are defined as reoccurring patterns of temporal or structural nature that can be subdivided into phases. Their constituting elements are:

- Repetition
- Phases
- Duration
- Triggers
- Effects

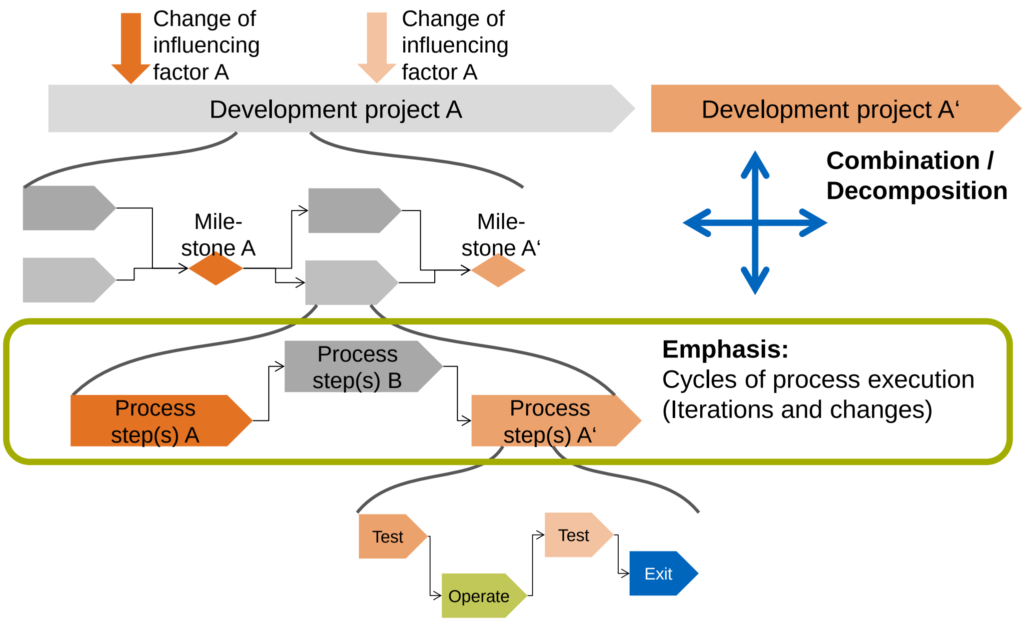

Figure 1: Perspectives on cycles in development processes

As depicted in Figure 1, a horizontal as well as a vertical decomposition of the development process can be conducted (as e.g. stated by [9]). This shows the variety of cycles occuring within development processes, being interrelated with numerous other types of cycles at the same time. Namely, potential cycles can be:

- Execution of development projects (as addressed for example by [6] and [7])
- Change of influencing factors from the development context (see e.g. [10])
- Milestones within development projects (e.g. [11])
- Iterations of process steps, e.g. as a consequence of necessary engineering changes (e.g. [12])
- Repetition of elementary processes on action level (e.g. [13])

These examples just show a fragment of the possible perspectives on cycles in development processes. For example, the cyclicity of information flows has been part of research (e.g. [14]) as well as changes of organizational structures, employees or tools. Each of these aspects represents a different perspective on development processes and the cycles within. These perspectives again differ in various aspects, mainly regarding:

- coverage of the development process (e.g. overall project vs. single process steps)
- objects of consideration (e.g. process steps, decision points, information flows, objects of development)
- purpose of perspective (e.g. project planning, process optimization etc.)
- interdependencies with other perspectives (e.g. dependency between decision points and process steps)

For this research, following the definition of relevancy provided by [15], those cycles from development processes and their context shall be addressed that

- significantly add value within the development process and/or
- significantly consume resources within the development process and/or
- initiate, by their effects, relevant cycles (in terms of the above-mentioned definitions), thus being linked causally

Based on this focus, the field of iteration and engineering change research can be emphasized, as the repetition of process steps provides a direct link to the aspects of value creation as well as resource consumption in development processes. Moreover, the closer analysis of iterations and changes allows for the identification of related cycles both within development processes as well as in their context.

2.2 Theoretical foundation in the field of iteration and engineering change research

As stated in paragraph 2.1, research on engineering changes and iterations provides one vital perspective on cycles in development processes. A comprehensive overview of engineering change literature is provided by [8]. The authors categorize the existing field of literature according to the three following perspectives, depicting the specific interests being tackled:

- Process perspective
    - general characterization of engineering change (e.g. definitions)
    - engineering change in the context of related activities (e.g. life-cycle, configuration management)
    - deriving generic processes for engineering change
    - specific nature of change processes (e.g. reasons, prioritization, effects / impacts, efficiency, change propagation) and arising challenges
- Product perspective
    - Influencing the flexibility and/or robustness of products towards change (e.g. via product complexity, system architecture, degree of innovation)
- Tool perspective
    - Tools to address the needs of designers in change processes (e.g. work flow / documentation, decision support)

Yet, the authors point out that these perspectives are difficult to separate in practice and that numerous publications contribute to more than one of these areas. This applies especially to general methods and strategies that aim at providing support and improvement in the following areas [8]:

- Prevention – reduce and eliminate the number of emergent changes
- Front-loading – detect and execute changes in early phases
- Effectiveness – identify the necessary changes by analyzing effort versus benefit
- Efficiency – implement changes by efficient use of resources
- Learning – improve products and processes based on analyses of the executed changes

For this research, the motivation stems from enabling companies to better coordinate both their development and their engineering change processes. The focus is neither on improving system architecture and layout as part of ideas like design for changeability (as e.g. suggested by [16]), nor is it on the development of supporting tools as described above. Consequently, the focus of this research is on providing models, methods and strategies from a process-oriented perspective to improve the management of cycles, iterations and changes.

Taking a closer look on research in this field, various valuable contributions have been made, as with regard to the causes and effects of engineering changes (e.g. [17]), the evaluation of the (positive and negative) impact of iterations (e.g. [18]) or the differentiation between forms of iterations and their relation to engineering change ([12]).

Approaches from e.g. [19] appear as being promising by tackling changes and iterations from a system perspective. Nonetheless, models and methods for a detailed description, modeling and analysis of changes and iterations are missing. Or, as [8] point out, while suggestions and strategies exist, more profound methods for supporting companies within the field of change management are needed.

"To date, there is no consensus on how engineering changes can be handled most effectively and efficiently. The literature overwhelmingly points to the need for such methods."

2.3 Research motivation and approach selected

With regard to the challenges within the field of research on iterations and engineering changes and with the depicted goals at hand, this contribution aims at developing an explorative model of cycles, iterations and changes within development processes. Thus, research and industry shall be supported with an improved possibility for modeling and analyzing these cycles, iterations and changes. This model is intended to provide the basis for a subsequent derivation of hypotheses and development of improved methods and strategies for handling these challenges.

To address these aims, this paper is aligned to the research model proposed in Figure 2. This model decomposes changes and iterations in five main aspects (adapted from [20]), this being:

- Causes for iterations / changes
- Target deviation
- Decision on iteration / change execution
- Options for action
- Effects of iteration / change execution

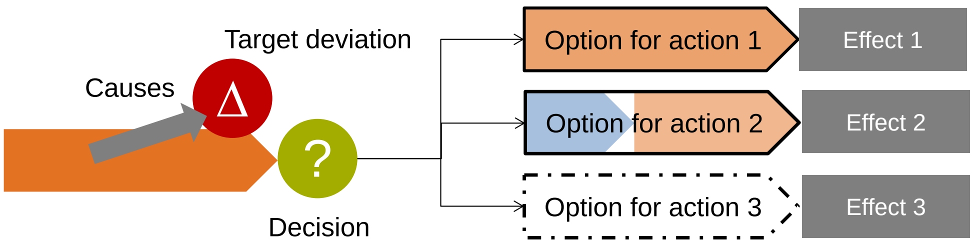

Figure 2: Research model of changes and iterations in development processes

The decomposition of the occurring changes and deviations allows for addressing these different interdependent aspects in detail. The main challenge arises from the heterogeneity of the different aspects of cycles as well as from their interdependencies and thus constitutes one of the main areas for further application of the explorative model.

To develop the explorative model, initially the requirements on the model have to be derived based on the literature review depicted in paragraph 2.2. With these requirements at hand, the modeling approach will be developed by iteratively modeling and refining cyclic examples derived from development process analysis of the eKart project (as described in [21]) as well as from the process analysis of a SAE Formula Student Team. The final explorative model can be validated by modeling these examples at hand, thus providing possibilities for further development.

3 AN EXPLORATIVE MODEL OF CYCLES WITHIN DEVELOPMENT PROCESSES BY INTEGRATING SYSTEM AND CONTEXT PERSPECTIVE

3.1 Requirements on an explorative model of cycles in development processes

With regard to the motivation of this research – supporting research and industry in better handling cycles, iterations and changes in development processes – a set of requirements regarding the explorative model is set up. Accordingly, the explorative model should:

- allow for the modeling and decomposition of cycles via precise syntax and semantics
- clearly depict the execution of iterations and changes on a given time line
- include relevant aspects of iteration and change management theory
    - sources of triggers / causes for cycles
    - deviations (Δ's) as reasons for cycles
    - decisions regarding cycle execution
    - areas of influence of cycles
- illustrate the dependencies within cycles
- be capable of showing chains of cycles (e.g. iterations caused by iterations in other processes)
- allow for the derivation of hypotheses on optimized process planning and execution

3.2 Basic structure and constituents of the explorative model

Browning et al. [22] discuss the need of modeling development projects from a system perspective, themselves proposing to model development projects based on five different, yet interdependent systems as depicted in Figure 3.

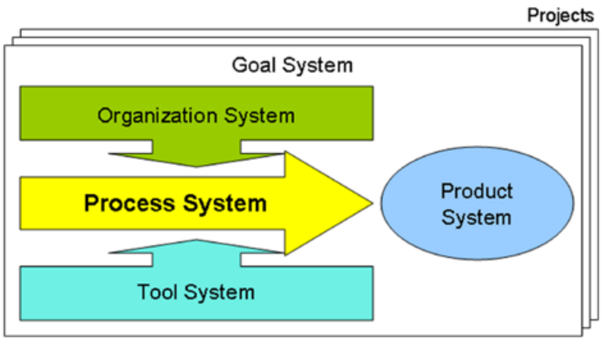

Figure 3: System perspective on development projects as proposed by [22]

The motivation behind this perspective and its predecessors (e.g. [23]) is to support and improve the design, management and improvement of either one of these sub-systems. To do so, integrated models of the different sub-systems of product development as well as of their interdependencies are necessary.

For this research, we pick up this aspect and adapt the suggested model to correspond with the specific needs in analysis of iterations and changes. In our interpretation, the perspective on the overall development system consists of the four sub-systems:

- Goal system
- Object system
- Process system
- Organization system

Furthermore, we adapt and incorporate a context perspective on development processes as e.g. provided by [10] and [24]. This incorporation can also be interpreted as the additional integration of a “context” system consisting of the sub-layers:

- Environment
- Market
- Company

Thus, influencing factors on the development system can be classified and modeled with regard to their influence on specific elements of the overall development system. The result of the combination of the system and context perspective is depicted in Figure 4. With regard to the requirements stated in paragraph 3.2, one central aspect to be solved is the decomposition of the model for a meaningful modeling of specific examples. Figure 4 illustrates the approach to derive an “example perspective” out of the overall system and context perspective.

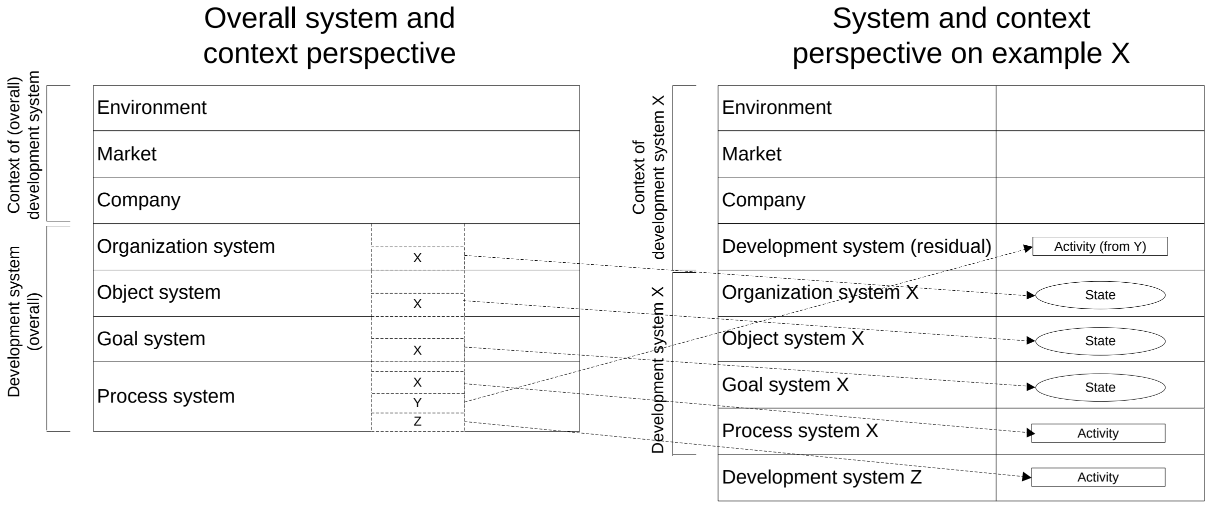

Figure 4: System and context perspectives on the overall development system (left) and derivation of the example perspective (right)

Therefore, the relevant aspects of the overall development system (initially consisting of the complete sub-systems) have to be identified and "cut out" to focus the relevant "development system X". This is done to reduce the necessary amount of modeling, both in terms of temporal coverage and of content-related coverage. To clarify the necessity for this, the example of a simple engineering change within the development of a complex mechatronic system is suitable: to understand the relevant constituents and influencing factors in this example it is neither necessary to model the overall development processes (both in its duration and its elements) nor to do so with the related organization, object or goal systems.

With the identified "development system X" at hand, the relevant elements in the four sub-systems can be modeled. The remaining development system (indicated as "development system (residual)" resp. "development system Z" in Figure 4) can be modeled besides the focused "development system X" as well to illustrate dependencies in the overall development system. As Figure 4 shows, the residual development (sub-)systems can be modeled both in the context field of development system X (as done for "part Y" of the generic example) and as separate development system (as done with "part Z" of the generic example, with the possibility to decompose it to its sub-systems equivalently to development system X). Thus, the basic modeling structure allows for a maximum of flexibility for modeling specific examples.

With this system decomposition at hand, development process examples can be modeled in the necessary level of detail and, as well, be further decomposed or integrated. Yet, for a meaningful modeling of iterations and changes, the basic structure of the development system and context model has to be refined with regard to the specific aspects of iterations and changes.

Therefore, we incorporate the central aspects of the research model – as described in paragraph 3.1 – both in the basic structure of the model as well as in the elements for modeling. The left side of Figure 5 shows the enhanced basic structure of the explorative model. The process system has been additionally subdivided into three layers:

- process step layer
- cycle decision layer
- Deviation (Δ) checking layer

Thereby, the activities and steps of development process execution as well as the specific states reached can be modeled in a dedicated field, while the central aspects of (1) checking for and identifying deviations between IS-states and TO-BE-states and (2) deciding on the form of iteration can be modeled in separate fields as well.

One aspect of the model is the time line depicted in the basic structure. This leads to the modeling of cycles, iterations and changes with regard to their temporal sequences – an aspect that would be lost in a structural model of the activities and processes.

Moreover, Figure 5 illustrates specific notations for four different fields:

- Main elements of the explorative model: activities (with a specific duration), states, deviations (Δ's) and logical operators

- Semantics for modeling temporal aspects: succession, time lags, down time, specific points in time
- Semantics for modeling interdependencies of elements
- Semantics for modeling reactive and prescriptive cycles

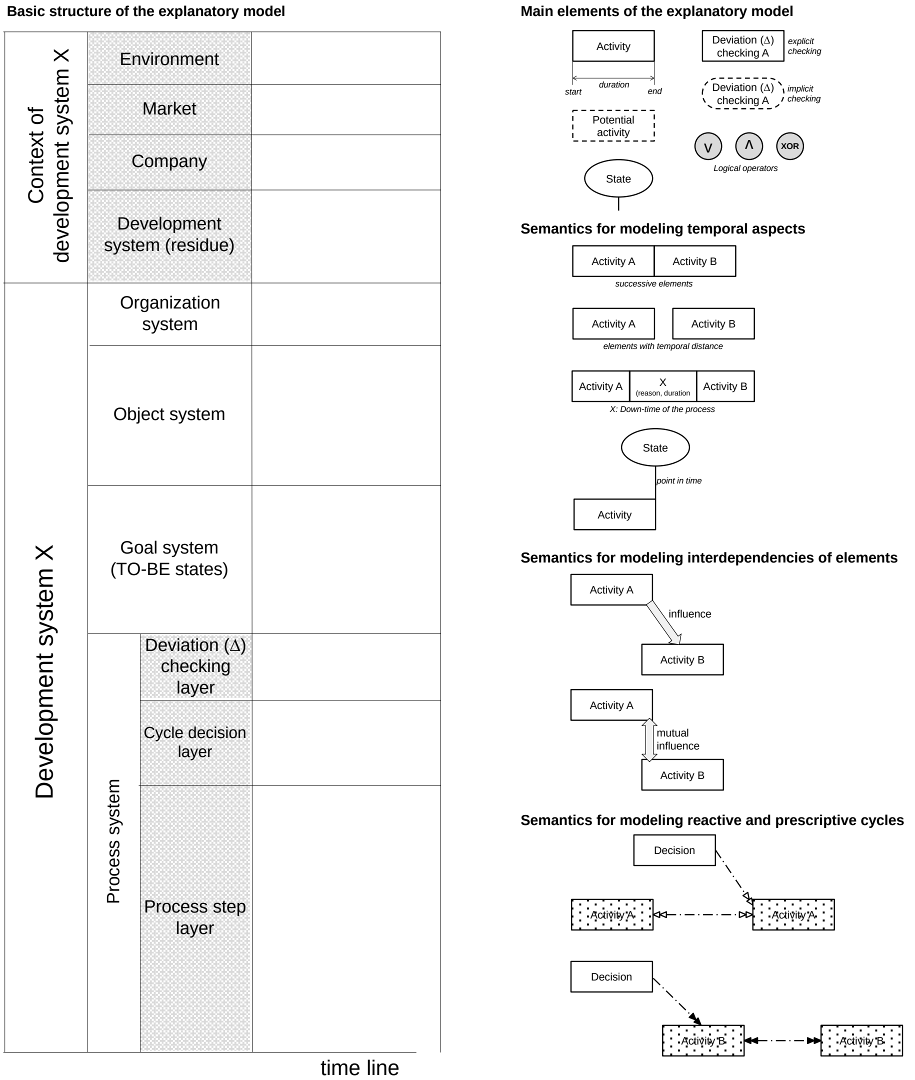

Figure 5: Structure and elements of the generic context and development system model

The proposed structure and the related elements and notations of the model have been generated, evaluated and improved iteratively by modeling examples of cycles, iterations and changes from development projects. The following paragraph 4 shows one of these examples.

4 EXEMPLARY APPLICATION OF THE EXPLORATIVE MODEL WITHIN THE CONCEPT PHASE OF A RACE CAR

4.1 Modeling cycles within the concept phase of a SAE Formula Student race car

With the explorative model, as described in paragraph 3.3, examples from process execution can be modeled. Figure 6 shows an example from the development process of a SAE Formula Student race car. The example addresses the causes, issues (deviations), decisions, iterations and effects from the concept phase of the crash nose of the vehicle. The main challenge in the example arises from both a co-worker quitting the project team and an insufficient concept for manufacturing. This leads to the necessity of major rework. As can be seen, various cyclic examples can be identified, including the causes, deviations, decisions, effects and interdependencies. Thus, the applicability of the modeling approach can be verified.

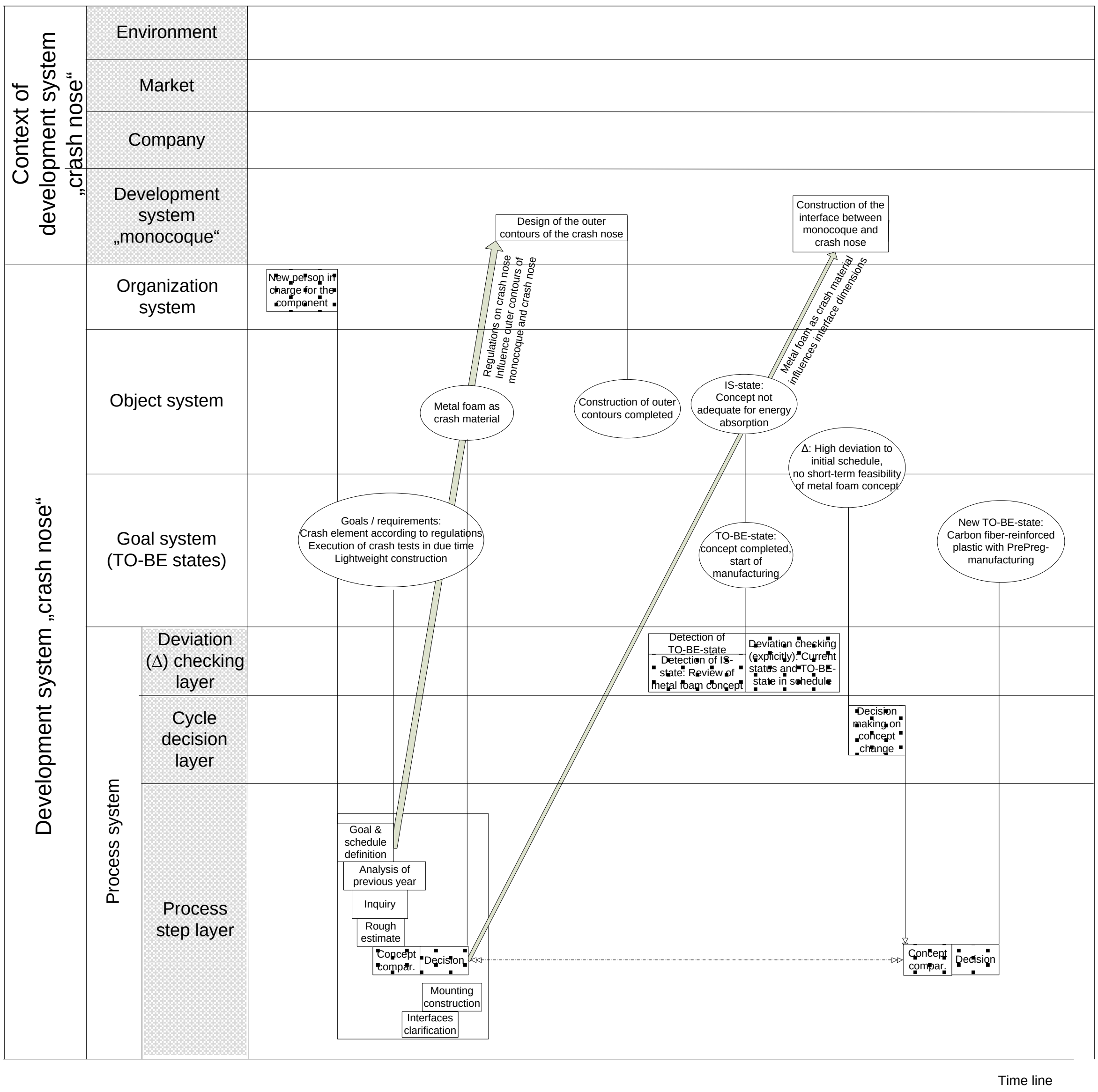

Figure 6: Modeling of cycles within the concept phase of the crash structure of a SAE Formula Student race car

4.2 Findings from the analysis of cycles in development processes with the explorative model

Reflecting on the results of modeling the exemplary cycles, following benefits and shortcomings of the modeling approach can be identified. The integrated modeling of cyclic aspects of activities as well as deviation checking and decision making regarding change execution provides different fields for process optimization. On the one hand, process planning could be supported through an optimized scheduling of deviation checking and decision making (in regard to the overall process efficiency). On the other hand, different approaches for either preventative avoidance of iterations and changes or reactive support in case of occurring deviations can be derived.

This is related to an enhanced understanding of causes, deviations, decision bases and effects, which can be provided by modeling examples with the suggested approach. Thus, company-specific analyses of relevant cycles can be conducted, allowing for the derivation of individually adequate measures.

Current shortcomings of the explorative model are the high effort necessary for modeling examples, which can be solved by tool support. Moreover, the operationalization of the cyclic examples (in terms of actual resource and time consumption etc.) would allow for more profound analyses.

5 CONCLUSIONS AND OUTLOOK

The motivation for this contribution stems from the challenges arising from dynamic changes and variations – cycles – both within and outside of innovating companies. With a focus on supporting iteration and engineering change management, an explorative model of cycles, iterations and changes was developed that integrates both a system perspective and a context perspective on the development process. The modeling concept was evaluated by modeling an example from the development process of a SAE Formula student race car. The results show that the model allows for (1) a more precise analysis of iterations and changes, (2) for the derivation of hypotheses for handling iterations and changes and (3) for a subsequent operationalization.

The next steps should encompass the development of a modeling tool to reduce the effort for modeling, the operationalization of the model and the modeled examples in terms of e.g. resource and time consumption as well as the usage of the model for deriving hypotheses for an optimized handling of cycles, changes and iterations.

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Contact: Stefan Langer
Technische Universität München
Institute of Product Development
80469 München
Germany
Tel: Int +49 89 289 15137
Fax: Int +49 89 289 15144
Email: stefan.langer@pe.mw.tum.de
URL: http://www.pe.mw.tum.de

Stefan Langer is a doctoral student at the Institute of Product Development, Technische Universität München, Germany. He received his diploma degree in mechanical engineering at the RWTH Aachen, Germany, and joined the Institute of Product Development in January 2008. His main research interest is in cycle-oriented planning and coordination of development processes.

Arne Herberg is a doctoral student at the Institute of Product Development, Technische Universität München, Germany. He received his diploma degree in mechanical engineering at Universität Karlsruhe (TH), Germany, and joined the Institute of Product Development in June 2009. His main research interest is in the efficiency-oriented analysis and improvement of processes.

Klaus Körber is a student in mechanical engineering at Technische Universität München, Germany. He was project manager of the Formula SAE racing team TUFAST and conducted a semester thesis in the field of analyzing and modeling cycles within development project execution.

Udo Lindemann is a full professor at the Technische Universität München, Germany, and has been the head of the Institute of Product Development since 1995, having published several books and papers on engineering design. He is committed in multiple institutions, among others as Vice President of the Design Society and as an active member of the German Academy of Science and Engineering.