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ANALYSIS OF DYNAMIC CHANGES AND ITERATIONS IN THE DEVELOPMENT PROCESS OF AN ELECTRICALLY POWERED GO-KART

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1. Introduction

Today's companies are facing numerous challenges. For decades, the importance of factors as time, costs, competition and quality for the innovation process has been emphasized. With relatively new aspects like higher frequencies of emerging new technologies, increased interdisciplinary work or new and changing markets and competitors, pressure on companies is even rising [Van de Veen et al. 2008]. Both within the innovating companies as well as in their context, preconditions, assumptions, resources etc. are changing dynamically and thus can lead to challenges like uncertainties of objectives, conflicts etc. [Van de Veen et al. 2008].
One communality of these factors and their influence on innovation processes is their dynamic behavior. According to [Lindemann 2007], these changes and variations – referred to as cycles – can be characterized as

- the repeated succession of similar occurrences and of results initiated by them like sub-processes, artifacts, developments etc.
- the succession of different occurrences within one sequence, like e.g. the innovation process

For the development process as a central element of the overall innovation process, cycles both within the process execution as well as in the context of the development process play a decisive role. These numerous external and internal parameters and their implications are not known comprehensively and, moreover, tend to be highly interdependent and dynamic. This potentially leads to deviations in the process execution and, consequently, to changes and variations in the actual development process outcome [Conrat Niemerg 1997].
Consequently, to enable the development of suitable methods for managing these cycles, a sound understanding of these complex mechanisms has to be derived. Therefore, current research is focusing on identifying triggers, objects and effects of cycles both within as well as outside of development processes. Thus a substantial basis for the subsequent development of suitable measures for a cycle-oriented design, coordination and management of development processes can be derived [Lindemann 2007].
This contribution as part of this research focuses on cyclic occurrences within development process execution. Basically, the question has to be addressed, which elements of the development process show a cyclic behavior and how this behavior can be characterized. Therefore, a development project of an electrically powered go-kart was set-up, specifically designed to offer the possibility of closely monitoring the process execution of a mechatronic development process for research reasons. Based on this, an extensive data acquisition and modeling of the process was executed. Thus, a substantial basis for subsequent analysis of cycles in development processes could be provided. Finally, as initial

analysis of the overall project, a comprehensive set of development situations with dynamic aspects was analyzed concerning the occurrence of a multitude of characteristics potentially describing features of cycles. Thus, the term “cycles” could be narrowed down by a phenomenological description.

2. Dynamic changes and iterations within innovation and development processes

2.1 The need for managing cycles in innovation processes

One of the crucial challenges for industry is the complex, dynamic and uncertain behavior of elements from both the innovation process itself as well as from its context. While dynamic changes and iterations occur within business processes (such as research & development, production, logistics, finance or service), elements outside of the innovation process are also showing dynamic temporal variations (such as evolving technologies, changing markets and competition etc.). Moreover, these diverse, dynamically changing elements and factors from the innovation process and its context are closely interconnected, thus influencing companies and their innovation processes. This can cause deficits like missing transparency, frequent changes, deficient coordination or inefficient process execution (see e.g. [Van de Veen et al. 2008] or [Murmann 2002]).

As for today, several approaches for addressing aspects of these dynamics within innovation process exist (e.g. [Suh 2001] or [Gausemeier et al. 2006]). Nonetheless, an overall approach is missing that integratedly handles these various aspects and offers a possibility for companies to cope with dynamics and changes in the course of innovation process execution. Therefore, a collaborative research centre at TU München consisting of researchers from the different fields of engineering, social, business and computer sciences transdisciplinary addresses this topic of managing cycles. The overall aim of this research project is to provide sophisticated approaches and methods for controlling and managing the collectivity of cycles and their dependencies occurring within and outside of innovation processes.

2.2 Dynamic changes and iterations within development processes

One aspect in this approach of managing cycles is the development process of new solutions. With the definition of cycles at hand, cyclic behavior can be seen, on the one hand, in the context of development processes. Dynamic variations of objects from the companies’ surrounding (like changing customer requirements, variations in norms and regulations etc.) can lead to changes of objects within the development process itself (like processes, artifacts etc.). On the other hand, changes and iterations occur in the course of the development process execution itself. With a focus on process tasks, [Wynn et al. 2007] point out six non-orthogonal perspectives on iterations within development processes. These viewpoints are:

- **Exploration** as the “concurrent, iterative exploration of problem and solution spaces”, that is the repeated process of divergence and convergence during synthesis and evaluation within the design process.
- **Convergence** as the iterative process of adjusting parameters of a design to meet performance objectives, especially in complex design processes.
- **Refinement** as the further optimization of secondary characteristics of designs that already fulfil primary requirements.
- **Rework** in response to problems emerging from analysis or updated process input information. This may be due to external influences, insufficient information or inefficient process structures.
- **Negotiation** between stakeholders from the development process on trade-offs between competing goals. This is perceived as being especially adequate in case of integrating contributions in highly complex products.
- **Repetition** as the execution of similar operations on different information and goals. Thus, repetition differs from the other five perspectives on iteration, which represent forms of iterations with a similar goal.

From another point of view, [Maier et al. 2008] and [Coates et al. 2004] address cycles and temporal aspects in communication processes respectively in coordination processes. Besides these examples, diverse approaches exist that consider various temporal aspects and cycles in development processes, especially in regard to complex, multi-disciplinary concurrent engineering processes.
Most of these approaches pinpoint the negative effects that changes, iterations and dynamics can imply, like increases in development times, undesired iterations, (non-conformity) costs, quality issues etc. (see e.g. [Conrat Niemerg 1997]). The missing link at this point is a comprehensive analysis and approach of characterization of potential cyclic occurrences within the development process, describing their triggers as well as the issues implied by them.

2.3 Research questions and approach selected

Consequently, the central aim in the field of development process execution is to derive an improved understanding of dynamic changes and variations within development processes, thus aiming at an enhanced coordination of activities in development processes. This leads to the overall research question to be addressed:

> *How can activities, that are relevant to be coordinated, be synchronized based on the cyclic behavior of their process objects, so that the process execution can be optimized?*

Decomposing this research question, a set of sub-questions has to be answered:

- What are the relevant process objects?
- What is the cyclic behavior of these objects?
- Which process steps (at which level of granularity) have to be coordinated, which do not?
- How can process steps be synchronized?
- Which mechanisms can lead to an "optimization" of processes?

While the first three questions concern the analysis and assessment of development processes, the last two questions address the development and assessment of measures for the actual improvement of development processes. Thus, within the scope of this paper, the first three questions are considered in order to derive a basis for discussion.

- For the **first question** ("What are the relevant process objects?"), an analysis of objects is necessary, which are subject of development processes and underlie dynamic respectively cyclic changes. Moreover, the question of relevance of these variations for the process execution has to be addressed.
- The **second question** ("What is the cyclic behavior of these objects?") necessitates the derivation of possibilities for monitoring and characterizing cycles as well as their cyclic behavior.
- The **third question** ("Which process steps (at which level of granularity) have to be coordinated, which do not?") aims at an assessment of the criticality of process coordination for the execution of specific process steps.

Subsuming, the research questions require the collection of objects from development processes that are subject to dynamic changes. Moreover, possibilities for describing and monitoring cycles are needed. Finally, an assessment of cycles, of their behavior and of their effects is needed.
Thus, for initially addressing these questions, a collection of data from development processes is executed, providing the possibility of acquiring specific information necessary for the three different fields of research.

3. Development of the eKart – an electrically powered go-kart – as basis for research

As stated in the paragraph above, an empirical observation and identification of cycles and dynamic changes in mechatronic development processes is necessary to answer the research questions at hand.

To provide the possibility of closely monitoring and observing development processes for different research reasons, a student-based mechatronic development project of an innovative, electrically powered go-kart was set up, offering the possibility for intensive data acquisition and analysis. Thus, in contrast to the data acquisition and analysis in industrial development processes, common issues with confidentiality and intensive usage of company-related resources can be avoided.
To ensure a data basis as realistic as possible, the interdisciplinary character and the high level of product and process complexity typical to car industry are considered in the planning process of the development project. Therefore, the electrical go-kart does not just aim at implementing an electrical power train into a standard go-kart (designed for a gasoline engine), but encompasses the entire development process of all components of the go-kart, with a standard framework structure as the only starting point. To increase the complexity of the development process, several challenging components like an electro-mechanical steering, an ABS-capable braking system, ESP including torque vectoring as well as all necessary controllers and sensors are developed within the project (see Figure 1 for an impression of the final CAD-model of the "eKart").

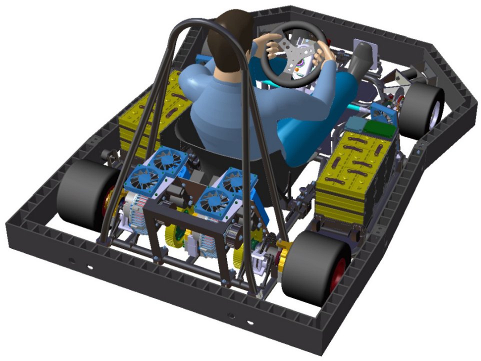

Figure 1. CAD-model of the "eKart"

Moreover, strict timelines and cost limits have to be met, thus increasing pressure in the development project. While the realization of the go-kart is limited to 9 months, the overall development phase is planned to last 6 months, lasting from April to October 2009 and encompassing all steps from requirements derivation to concept development and computer-aided design until the actual start of production. Consequently, the project plan is subdivided into five main phases, each being separated by milestone meetings of the overall project team (see Figure).

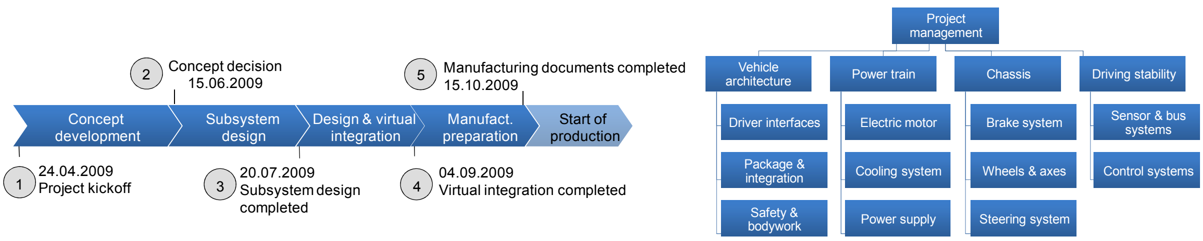

Figure 2. Operational and organizational structure of the eKart development project

The project team consists of 8 students with a background in mechanical engineering, 6 assisting researchers as well as one student focusing on the data acquisition and modeling of the development process. The team organization follows a defined organizational structure with 11 sub-projects and 4 teams (see Figure). While the students work on the different sub-projects, the assisting researchers are involved in the team coordination. This means that, due to the unequal work load within different sub-projects, three students within the process take over two sub-projects. Moreover, two of the teams are led by two researchers, and the project leader himself additionally leads one of the teams. In the course of the project, the current development status, occurring issues and next steps within the process are discussed and coordinated in regular bilateral, group and team meetings. Thus, another analogy to industrial development projects is generated.

Summarizing, the development of the electrically powered go-kart offers extensive possibilities for data acquisition and process analysis. Due to the high level of complexity of the product, the operational and organizational structure and the project constraints (as time line and cost limits), a development situation with multi-disciplinary tasks can be surveyed with significant parallels to industrial development situations. Factors deviating from industrial projects are, firstly, the homogeneous team structure, with students with the same low level of experience, but high motivation and a good level of technical and methodical education. Secondly, the concurrency of tasks for some team members and leaders is a deviation from reality as are the obligations of the students to examination periods. This leads to certain deviations of the development process at hand to industrial development processes – this is compensated by the extensive opportunity for data acquisition in comparison to industrial process observations.

4. Data acquisition and modeling of the eKart development process

4.1 Identification of the central aspects of analysis within the project

With the numerous potentials of the eKart development project at hand and with the limitations mentioned above, the central aspects of analysis within the development process have to be identified. Recapitulating the three research questions established beforehand, objects from the development process with a cyclic behavior have to be identified and possibilities for describing and monitoring these cycles have to be derived. Based on this, a possibility for assessing cycles, their behavior and their effects is needed.

To ensure the data and information acquisition to be adequate to support these objectives, an entity-relationship-diagram of the central elements of the development project and their interdependencies is set up before the start of the project. Therefore 24 types of entities and their interdependencies are modeled and subsequently transferred to a matrix representation. In this matrix, the relation between the entities can be characterized exactly (see Figure).

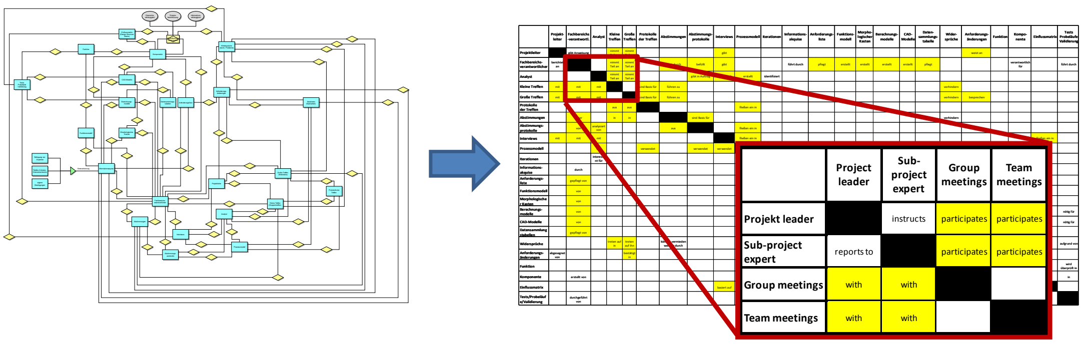

Figure 3. Entity-relationship-diagram and matrix representation of central elements in the eKart development

The analysis of the entity-relationship-diagram shows three distinguishable groups of entities:

- Elements, which can not be influenced directly by the project management, but that mainly depend on the approach of the process participants (e.g. CAD models, components etc.)
- Elements, which describe negative effects occurring in the course of a suboptimal process execution (like contradictions, iterations etc.)
- Elements, which are of specific interest for the subsequent analysis (e.g. meetings, information flows, interviews etc.)

From this analysis of the dependencies of the different entities of the process, the central aspects of analysis can be derived. In order to address the research questions depicted, the acquisition of information on process steps, communication flows and occurring issues as well as decisions taken within the process turn out to be of central importance. With these objects of analysis, both information on typical issues in process and project execution as well as data on process objects and their cyclic behavior can be extracted from the development process.

4.2 Data acquisition – objects, premises and methods

As stated in the paragraph above, the central objects of monitoring and data acquisition in the development project are the occurring communication flows and decision points. To ensure a high quality of the data acquired, firstly the premise of a high effectiveness of the data acquisition is focused, aiming at a high level of completeness and accuracy. Secondly, a high efficiency of acquisition both for the observer and for the process participants is aspired. Thus, a high amount of information can be derived with a relatively low effort for both parties. Thirdly, a high consistency in the data acquired is aspired (especially a similar level of abstraction) to enable the comparability of data from different participants and process steps.

To acquire the relevant aspects of information, all occurring activities as well as all interfaces and coordination and synchronization processes within the development process are captured. This information acquisition is conducted through multiple methods. Firstly, the development process steps are captured through individual interviews with the participants involved. Secondly, the data acquisition of information and coordination flows is achieved through "coordination transcripts", in which the participants record all information shared between the sub-projects. For each sub-project, a dedicated coordination transcript is stored on a central server. In these transcripts, for each information exchange, the date, the communication partner, the content of communication, eventually occurring issues and the actions taken (next steps / decisions) are queried (see Figure for an example).

Date	Communication with	Content of communication	Occuring issues	Next steps / decision
13/05	PI	E-mail request concerning preliminary estimations of package	Lacking decision for drivetrain concept	Invitation to next powertrain meeting (22/05), as precise information will be available then
14/05	ES	Initial performance characteristics for the dimensioning of the energy storage	Precise performance characteristics not possible due to numerous assumptions	Replacement of roughly estimated values with preferably precise values

Figure 4. Exemplary section of a "coordination transcript" used for data acquisition

As information is acquired from each process participant individually, a verification of the information flow is possible. Additionally, information on the process execution is extracted from sample observations of the development process as well as from minutes of the different meetings.

Besides the monitoring of the actual process execution, the data generated in the course of the different process steps is stored and versioned on a central server. Thus, additional information is available on the time points and frequencies of generation of process outputs. Finally, the eKart itself is modeled regarding the mechanical, energetical and informational dependencies of its components.

Summarizing, an extensive set of information from the development process execution itself as well as from the product structure and its models is available for the subsequent modeling and analysis.

4.3 Process modeling – premises, methods and results

To ensure clarity, consistency and quality of the process model, the subsequent process modeling is executed according to the guidelines of modeling introduced by [Becker et al 2003]. These guidelines focus on correctness, relevance, economic efficiency, clarity, comparability and systematic design of the modeling process and of the process model generated.

Based on the extensive data acquired as described in the paragraph above, an EPC-based modeling is conducted. Therefore, a specific notation is used, modeling the process steps of each sub-project within a dedicated swim lane and their duration by the length of the objects used. Thus the model adapts to representations in Gantt-charts. The temporal resolution is broken down to a daily basis. As one of the main focuses is on the coordination and information processes, specific notations are introduced for bilateral communication as well as for information exchanges within group, team and special meetings or in case of "major happenings" that are affecting the development process (such as changing requirements etc.). For all information flows, meetings and happenings, a duplicate is introduced for each sub-project affected. Thus, each swim-lane contains all relevant information for the later analysis of the respective sub-project. By assigning attributes to all objects of the process model, the information from data acquisition is allocated to the respective entities of the process. This signifies, that all information from the coordination transcripts (as described in paragraph 4.2) is available within the process model. Thus, all issues occurring within the process as well as the decisions taken and information shared are directly available for identifying cycles and their possible triggers and effects. Figure shows an overview of the overall process model, a section from one swim lane and the notations and attributes used for modeling.

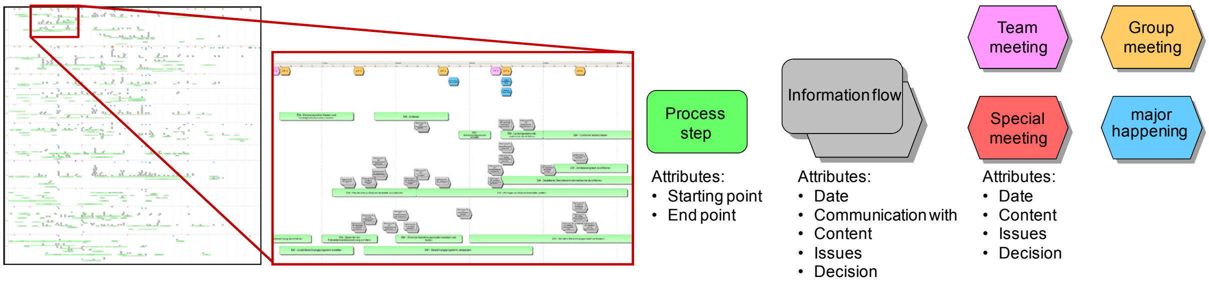

Figure 5. Overview of the eKart development process model and the notations used

The overall process model consists of 978 symbols (595 distinguishable, due to the duplicates in the model), representing 286 activities, 68 events and 241 communication flows. The events mentioned can be sub-divided into 16 group meetings, 6 team meetings, 2 special meetings and 44 “major happenings” (mainly new or changing information from the process’ external context).

Subsuming, the overall aims of generating a sound, objective representation of the actual process can be achieved by a customized modeling approach. By using attributes for the different objects in the model, not only the different process steps and durations as well as the communication flows can be captured, moreover, specific information on communication contents and dates, induced effects and decisions made can be recorded. Thus, extensive, detailed information on the process execution is available. Shortcomings of the model are the lacking conjunction of process steps with the objects generated by them and the missing communication flows with manufacturing, which to the time of submission of this contribution still are being captured.

5. Initial analysis of the eKart development process

5.1 Narrowing down the term “cycles” – objectives, methods and aspired results

Referring to the research questions established in paragraph 2.2, the initial analysis of the development process at hand focuses on the first two questions:

- What are the relevant process objects?
- What is the cyclic behavior of these objects?

Therefore, the captured data and the process model are, on the one hand, analyzed regarding the identification of the process objects showing cyclic behavior, and on the other hand concerning possibilities for identifying and describing this cyclic behavior.

Thus, initially a preliminary definition is developed within the research team to encompass all relevant dynamic changes and variations occurring in the course of the process execution. This definition is:

A cycle is a reoccurring (temporal or structural) pattern.

This definition considers the aspect of repetition, as it is part of the six perspectives on iteration proposed by [Wynn et al. 2007], but furthermore encompasses the reoccurrence of miscellaneous other aspects within process execution besides process steps and communication, such as repeated changes and influences on the process execution from within or outside the development process. This constitutes the central difference to the concept of iteration as it is perceived in process

As the analysis is aiming at identifying objects of cycles as well as their cyclic behavior, firstly, a set of potential aspects and criteria to characterize cycles is developed. Secondly, cyclic occurrences from the process execution are identified applying the preliminary definition introduced above. With this information, finally an analysis is conducted, deriving objects of cycles from the occurrences identified as well as applying the description criteria to these occurrences. Hence, a compilation of objects of cycles as well as a frequency distribution of aspects describing cycles is generated. Thus, the term cycles is further narrowed down. The approaches for the single steps and their specific results are described in detail in the following paragraphs.

5.2 Criteria and definitions for the phenomenological description of cycles

In order to narrow down the term cycles, as described, initially a set of definitions is derived in a team. The team itself consists of four researchers involved in the overall research project. Starting from examples from industry derived from prior interviews, experiences from industrial projects and from the development process modeling itself, aspects and potential criteria of description of cycles within development processes are collected. Aiming at a phenomenological description of cycles, these criteria are subsequently defined by adapting lexical definitions (mainly from [Brockhaus 2005]) to the specific field of cycles. Consequently, the definitions applied are described below. For an enhanced clarity, these 30 criteria are grouped in three different classes:

- characteristics of cycles
- analyzability of cycles and
- controllability of cycles.

Characteristics of cycles

Point in time: Cycles possess one or multiple defined points in time, if a certain moment in the temporal course of a specific cycle can be characterized unambiguously based on specifically defined criteria of description within a temporal frame of reference. The definitions of starting and end points hence signify special cases of points in time.

Duration: A cycle can be characterized by the criterion “duration”, if there exist attribute levels of the cycle, which last over a finite time span of definite length. The time span thereby is defined as the temporal distance between two specific points in time (→ see definition). A duration resulting from the subtraction of an end point and a starting point of a cycle represents a special case.

Starting point: A cycle possesses a starting point, if the start of a temporal course of a specific cycle (of arbitrary attribute) can be characterized / described unambiguously by a specific set of description criteria.

End point: A cycle possesses an end point, if the end of the temporal course of a specific cycle (of arbitrary attribute) can be characterized / described unambiguously by a specific set of description criteria.

Variability: The term variability characterizes the change of one or multiple attributes and / or attribute levels of cycles (regarding dimensions, form or in any other manner) over time.

Poly-dimensionality: A cycle is poly-dimensional, if it possesses more than one attributes.

Bandwidth of attribute levels: The bandwidth describes the area of values respectively the area of variation of attribute levels of cycles.

Frequency: Frequency of cycles describes the frequency of the occurrence of specific attribute levels of cycle characteristics in the course of time.

Rhythm: A cycle possesses a rhythm, if the temporal course of the attribute levels of one or multiple of its constituting characteristics possesses a pattern that is repeated sequentially.

Periodicity: Cycles are periodic, if they possess attribute levels, which occur in regularly returning temporal sequence.

Trigger: A trigger is an intentional or unintentional, yet abstractable event initiating a cycle / a cyclic course.

Effect: A cycle possesses an effect, if it is capable of triggering / inducing one or multiple effects (or cycles) within elements being influenced, or if it is able to affect them in another arbitrary way.

Dependency from other cycles: A cycles is dependent from one or more cycles, if it is connected with this or these cycles through specific correlations or coherences and can be influenced by their behavior. Thus, this definition is a special-case of the definition of “trigger”.

Uniformity: The term uniformity describes attribute levels of cycles without changes or alterations over a longer period of time.

Iteration: A cycle represents an iteration, if to a subsequent point in time the similar object (e.g. action, situation etc.) occurs in a similar or equivalent context.

Recursion: A cycle is recursive, if the course of a cycle initiates the identical cycle as a prerequisite for the termination of its own cycle.

Analyzability of cycles

Observability: A cycle is defined as observable, if it can be identified through suitable measures and thereby be mentally perceived by an observer.

Uncertainty: A degree of uncertainty can be allocated to a cycle, if one or multiple of its current or future attributes and attribute levels can not be described unambiguously.

Abstractability: Abstractability defines the possibility of concretely, theoretically and terminologically describing cycles respectively the attribute levels of cycles.

Divisibility (in phases): The term divisibility describes the possibility of dividing a cycle in different sections or phases of its temporal course.

Measurability / quantifiability: The attribute level of a cycle is measurable and quantifiable, if a principle for measuring exists – that is if it can be defined meaningfully within the chosen approach and therefore especially can be quantified.

Assessability: Cycles are assessable, if an evaluation of cycles by value and / or meaning is possible. The assessment is particularly related to the effect of cycles. A possible assessment of a cycle regarding a positive, a neutral or a negative effect is sufficient in order to characterize a cycle as assessable.

Interpretability: Cycles are interpretable if they can be explained regarding content or if indications can be drawn from them.

Predictability: A cycle can be predicted, if a substantiated statement on the probable future course of its attribute levels can be made.

Noise of attribute levels: Noise describes a permanent, random fluctuation or variation of attribute levels of cycles, which is not considered for the description of the cycles in focus.

Controllability of cycles (from the viewpoint of the innovation process)

Possibility of active influence: The possibility of actively influencing cycles describes the characteristic of cycles respectively attribute levels of cycles to be able to be modified, changed or manipulated by a certain, intended influence from participants of the innovation process.

Scalability: A cycle is scalable, if its attribute levels can be changed in their dimensions by suitable measures.

Interruptibility: The term interruptibility describes the possibility of actively ending a cycle by participants of the innovation process.

Invertibility: A cycle is invertible, if its attribute levels and attribute level courses can be inverted by suitable measures.

Reversibility: A cycle is reversible, if it can be inverted formally, that is if it can be inverted in its course, in its triggers and its effects.

Subsuming, these definitions offer an initial possibility of characterizing cycles in the development process context. An important restriction of this set of criteria is the derivation of its factors from the current state of experience in this field. Thus, the set can neither be complete nor terminatory – moreover not all of the criteria necessarily have to be appropriate for the definition of cycles. Contrarily, the descriptional set is intended as basis for narrowing down the meaning and the possibilities for describing the multitude of cycles occurring within development processes. Consequently, for optimized efficiency and relevancy to practice, the overall aim has to be to derive a set with a minimal number of descriptional parameters that is capable of generating the maximum significance and relevance in the field of actual industrial development processes.

5.3 Analysis of exemplary cyclic occurrences from the development process

As described in paragraph 5.1., simultaneously examples for cyclic occurrences within the course of the eKart development are collected. These examples are derived from an initial analysis of the process model as well as from information on process execution issues and suggestions for improvement extracted from interviews with the process participants. Thus, a total number of 49 exemplary cyclic occurrences can be identified that corresponded to the preliminary definition of cycles set up previously. These examples are analyzed concerning the aspect of process execution they address as well as their relation to the preliminary definition of cycles. Moreover, the object of cyclic behavior is identified and collected in a data sheet. Based on this, the examples are analyzed whether the 30 descriptive criteria are applying for the specific occurrence at hand. Figure shows an example of this analysis.

Analysis of exemplary cyclic occurences within the eKart development process

Aspect of process execution	Relation to the preliminary definition of cycles	Specific example	Objects of cyclic behavior	Characteristics of cycles	Point in time	Duration	Starting point	End point	Variability	Poly-dimensionality	Bandwidth of attribute levels	Frequency	Rhythm	Periodicity	Trigger	Effect	Dependency from other cy	Uniformity	Iteration	
			Counter:		48	39	39	39	48	48	13	48	3	1	47	48	43	4	10	0
Postponing of decision	Delay Follow-up	Postponement of decision on powertrain layout	Decision		1				1	1		1			1	1	1		1	

Figure 6. Example of the analysis of cyclic occurrences within the eKart development process

By conducting the analysis as described, a more accurate characterization of the term "cycles" can be achieved:

- As the results in Figure show, a set of 9 **objects of cyclic behavior** can be derived: decisions, communication, knowledge / competencies, product (elements), process, documents, resources, process participants and organization.
- Moreover, the main **characteristics of cycles** can be narrowed down to a set of criteria most frequently being applicable for the description of cyclic behavior (framed in Figure). While the criteria "point in time", "variability", "poly-dimensionality" and "frequency" characterize the behavior and "shape" of a specific cycle, the criteria "trigger", "effect" and "dependency from other cycles" show the interdependencies of cycles with their context.
- Concerning the **analyzability of cycles**, again, the most frequently applicable criteria are framed in Figure . While only approximately one half of the exemplary cycles seems to be measurable, most of them show to be observable, abstractable, assessable and interpretable.
- Finally, the aspect of **controllability of cycles** suggests for 34 out of 49 cyclic occurrences a possibility for actively taking influence, while at least 21 of the occurrences seem to be interruptible.

Objects of cycles	Characteristics of cycles	Quantity	Analyzability of cycles	Quantity	Controllability of cycles	Quantity
Decisions	Point in time	49	Observability	44	Possibility of active influence	34
Communication	Duration	39	Uncertainty	18	Scalability	3
Knowledge / competencies	Starting point	39	Abstractability	49	Interruptability	21
Product (elements)	End point	39	Divisibility (in phases)	34	Invertibility	0
Process	Variability	49	Measurability / quantifiability	28	Reversibility	0
Documents	Poly-dimensionality	49	Assessability	49		
Ressources	Bandwidth of attribute levels	13	Interpretability	49		
Process participants	Frequency	49	Predictability	12		
Organization	Rhythm	3	Noise of attribute levels	3		
	Periodicity	1				
	Trigger	48				
	Effect	49				
	Dependency from other cycles	44				
	Uniformity	4				
	Iteration	11				
	Recursion	0				

Figure 7. Result of the analysis of exemplary cyclic occurrences within the eKart development process (high-frequent results marked with frames)

Subsuming, these results allow for a more precise description of the term “cycles”, as the different aspects of objects of cycles, their characteristics, their analyzability and their controllability can be assessed more profound based on empirical data. Nonetheless, a set of constraints has to be considered. Primarily, the results of analysis are highly dependent from the data acquisition and modeling conducted within a student project as well as from the process of identifying the applicability of the criteria. Thus, the results should not be perceived as a conclusive definition of characteristics of cycles, but as a basis for narrowing down the term cycles in the context of process execution. To derive a more thorough definition, a wider set of data, also from different development processes is necessary.
Therefore, the next steps necessary are the extension of the data basis for analysis, primarily by intensely analyzing the process model at hand, but also by observing other development processes. Moreover, as the initial analysis indicates the close interdependencies of cycles with other cycles as well as with their triggers and effects, further steps of analysis of these correlations will be conducted.

6. Conclusion and outlook

6.1 Conclusion

Dynamic changes and iterations – referred to as cycles – play a decisive role in today’s innovation and development processes. To enable a sophisticated control and management of these cycles, current research is aiming at developing adequate models and methods. In the specific field of development process execution and coordination, firstly, a sound understanding of the actual forms of cyclic occurrences in the course of the processes is necessary.
Consequently, this contribution aims at identifying, analyzing and characterizing the cycles within development processes as well as their behavior. Therefore, a development project for an electrically-powered go-kart (“eKart”) is surveyed intensely, offering the possibility of acquiring detailed data and information on the process execution. Based on these results, a process model is generated, adapted to the specific focus of describing and analyzing cycles and temporally related aspects. In the last step of this contribution, an initial analysis is conducted, aiming at narrowing down the term “cycles” in the context of development process execution. Therefore, on the one hand, a set of cyclic occurrences is derived from the process model as well as from interviews. On the other hand, potential criteria for describing cycles are compiled and defined precisely. Finally, the cyclic occurrences are checked for the applicability of the descriptive criteria. This leads to an empirically based, more precise description of the term “cycles”. In detail, the results describe the frequency of applicability of the different descriptive aspects regarding objects, characteristics, analyzability and controllability of cycles. While these results do not represent a terminatory definition of the term cycles in development processes, they provide a sound basis for further discussion.

6.2 Outlook

In the next steps, the analysis conducted has to be continued with an expanded set of data, both from the eKart development process as well as from other development processes. Therefore, information from the manufacturing process of the eKart has to be acquired and fed into the process model. Moreover, an intensive analysis of the process model has to be conducted to extract a wider set of cycles from the process. With this information, a quantitative analysis of the frequency of occurrences of different cyclic objects in the development process can be conducted.
Moreover, not only an identification of the applicability of different descriptive criteria is possible – rather, the actual description of cycles is possible by analyzing the attribute levels of the different criteria. Utilizing the closer analysis of the process model, triggers and effects of cycles as well as their correlation with other cycles can be identified. Furthermore, with this information on dependencies, cycles can be linked to chain of effects that occur within the process execution. Thus, the duration, value, dynamic, criticality etc. of these chains of effects can be determined.
With these analyses, the research questions on the relevant process objects underlying cyclic behavior, on the characterization of cyclic behavior and on the criticality of this behavior can be answered.

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