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X-IN-THE-LOOP: A FRAMEWORK FOR SUPPORTING CENTRAL ENGINEERING ACTIVITIES AND CONTRACTING COMPLEXITY IN PRODUCT ENGINEERING PROCESSES

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ABSTRACT
Emerging complexity of vehicle development is expected not to be faced without supporting development methods, processes and tools. Extensive interactions of vehicle components and the vehicle as well as those with the driver and the environment have to be considered. Whereas the maturity level of the product and the applied models changes permanently within engineering process. The objective is to provide a new, integrative method that supports the engineering process during analysis, synthesis and validation by means of strategic resources 'information' and 'knowledge'. Thus, a related framework is regarded to be mandatory in order to be flexible and to perpetuate engineers for developing, priorizing, deciding and finally innovating. The presented XiL-Framework accommodates actual and prospective challenges of vehicle development and consequently compiles existing methods, processes and approaches. Extended by optimizing procedures recurring engineering activities can be partially automatized and carried out time-efficiently especially for complex interdependencies. XiL is based on long-term experience at IPEK and provides a perception for engineering as well as a management.

Keywords: design process, complexity, optimisation, research methodology, requirements

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1 INTRODUCTION

Individual mobility is changing and leads to more complex objectives and requirements due to increasing segmentation of the consumer profiles in automotive markets, gain in importance of the Low-Cost-Markets, increase of political restrictions and finite nature of resources (Huettenrauch and Baum, 2008). This is challenging for the automotive industry. Exemplary objectives are: energy-efficient, sustainable, individual mobility with low emissions while keeping the aim of established, vehicle category dependent development goals like NVH, comfort, driveability, reliability, quality and safety at a consumer tolerated price (Dueser, 2010; Gusig, et al., 2010, Huettenrauch and Baum, 2008; Weber, 2009). At this, economies of scale have a huge effect due to a higher lot size and a high degree of modularization as well as the electrification of the drive train, new power train configurations and alternative fuels (Winterhagen, 2012; Wallentowitz, et al., 2011; Gusig, et al., 2010; Meinheit, 2009; Huettenrauch and Baum, 2008). In order to achieve the challenging vehicle objectives and matching them with the characteristics of its parts and components as well as to convert them into an optimized and innovative vehicle, the vehicle engineering process has to be continuously holistical. Furthermore the interactions of the vehicle components and their interactions with the overall vehicle, as well as the driver and the environment have to be considered. Whereas the maturity level of the product and the applied models permanently changes within the product engineering process and as well have to be adjusted depending on the specific application. The emerging complexity however is expected not to be faced without the support of development methods, processes and tools. Especially the usage of optimization algorithms has a high potential concerning the above requirements (Beidl, et al. 2012; Kuchenbuch, 2011; Weber, 2009, Seiffert and Rainer, 2008, Krause, et al., 2007) but the qualification of such procedures are difficult and vary depending on the given boundaries (Schroeter, 2013).

The objective of the paper at hand is to introduce a new, integrative, time efficient method that is based on analyses of consumers, respectively drivers, as well as the environmental influence and which supports the engineering process during analysis, synthesis and validation by means of strategic resources ‘information’ and ‘knowledge’ in order to enable configuration and implementation of optimization procedures. Thus, a related framework is regarded to be mandatory in order to be flexible and to perpetuate engineers for developing, priorizing, deciding and finally innovating.

2 OBJECTIVES OF XIL-FRAMEWORK

A Framework for development including validation that matches with the objective has to meet various requirements as the following:

Due to the continuous interaction of the systems “Vehicle”, “Driver” and “Environment” this interaction triple has to be taken into account continuously during the analysis, synthesis, and validation stages in order to enable continuous, holistic, customer-oriented synthesis and validation of modern vehicles in spite of their complexity (Albers and Dueser, 2010).

The maturity level of the product changes permanently within the product engineering process. Applied models, respectively the level of detail have to be adjustable depending on the specific application in order to provide adequate system relevant interactions of the systems “Vehicle”, “Driver” and “Environment” (Albers and Dueser, 2010).

Moreover it has to provide an open architecture which integrates the general possibilities of cross-domain interconnection of established tools, the access to standardized maneuvers and test cases for validation and process models for application-specific configuration of the validation environment (Albers and Dueser, 2010; Dueser, 2010).

By developing E-vehicle concepts or dimensioning components and operating strategies it becomes obvious, that there is always the need to regard several real and virtual components simultaneously because of the interaction of the (sub-)systems. Otherwise it’s impossible to optimize the entire system “Vehicle” effectively. The simultaneous monitoring has to be possible throughout the whole analysis-, synthesis- and validation process (Albers and Schroeter, 2011; Albers and Schroeter, 2011b; Kuchenbuch, 2011).

Benchmark results, customer profiles, cross-domain tools and their simulation models, appropriate optimization procedures, (sub-)systems of objectives, increasing (sub-)systems of objects, contact persons, etc. build valuable elements of the product engineering process. Their use within the context of the company can gain effectiveness through a central and interdepartmental deposit. In that sense a company-central Framework with global accessibility is crucial (Schroeter, 2013).

The level of complexity increases rapidly due to the rising variety of options and models, new powertrain topologies, higher modularization in combination with Systems Engineering and virtual development methods and tools. Thus, methodological approaches have to be provided supporting the designer during the vehicle development process. This includes as well appropriate optimization procedures that allow deriving global optima. For an appropriate corresponding optimization task they have to work as automatically and time efficiently as possible. Therefore the Framework has to be linked to optionally used optimization modules that meaningfully connect optimization algorithms to other systems of the framework via unified interfaces (Beidl, et al., 2012; Winterhagen, 2012; Albers and Schroeter, 2011; Kuchenbuch, 2011; Wallentowitz, et al., 2011; Gusig, et al., 2010; Kluin, et al. 2010; Denger, et al., 2009; Meinheit, 2009; Huettenrauch and Baum, 2008, Seiffert and Rainer, 2008).
For providing a comprehensive operation system with a productive, effective and continuous practicability it must be able to be integrated into a product engineering process.

3 XIL-FRAMEWORK IN CONTEXT OF ENGINEERING PROCESS

Due to competitive and innovational pressure in the automotive industry information and knowledge concerning the building of cars has to be gained and used efficiently, fast and goal oriented. For a company the product development is one of the divisions with the highest needs of information and knowledge. Customer profiles, benchmark-results, simulation- and testing-environment, tools, appropriate optimization procedures, precise (sub-)systems of objectives, expanding (sub-)systems of objects, contact person etc. are very useful elements of product engineering if they are captured and maintained in the correct way. They have to be accessible by the developer in a structured and clear manner during the present activity.
The research presented in this paper is based on the system triple of product engineering (Albers, 2010). It describes product engineering as a continuous interaction of three systems: the operation system, the system of objectives and the system of objects (Albers, 2010). Discussing human aspects, knowledge aspects and process aspects of the system triple approach has revealed that the role of the operation system within the co-evolutionary and iterative process of complex product engineering has to be specified (Albers, 2010). This leads to the Advanced System Triple Approach (s. Figure 1). The advanced system triple describes the two central activities of product engineering. The combination of analyzing objectives and synthesizing objects can be understood as creation, whereas the combination of analyzing objects and synthesizing objectives can be seen as validation (Albers and Behrendt, 2010). Thus, valid objects as well as objectives can be methodologically generated.

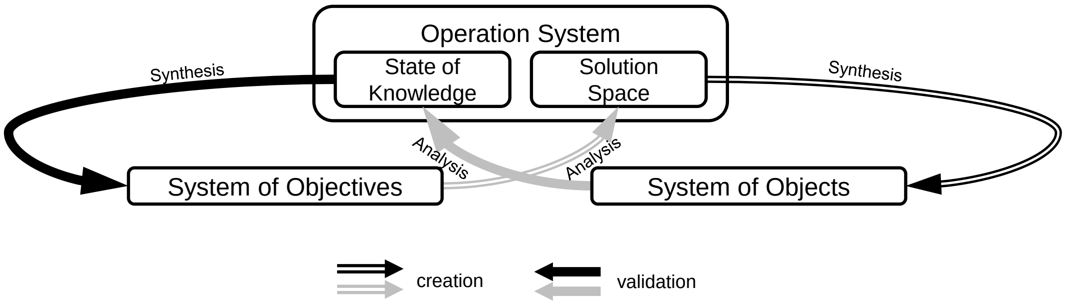

Figure 1: Advanced System Triple Approach (acc. to Albers and Lohmeyer, 2012)

In order to describe and model the product engineering process the integrated product engineering Model – iPeM is considered the most suitable because it represents a highly flexible and general meta-model of the product engineering process (Albers, 2010). Based on its generalized approach iPeM allows consideration of every specific product engineering process based on a problem solving process with related knowledge in a holistic manner (Figure 2).
The operation system of the iPeM is based on a meta-model of interlinked activities. These are divided into "Activities of Product Engineering" (also called macro-activities) and the "Activities of Problem Solving" (also called micro-activities). Albers (2010) derives them from the lifecycle-model. In the iPeM they don't have to be completed sequentially. Their placement is done through a specific phase model which provides three model levels (Albers, 2010). Validation is considered to be the central activity with respect to the interdependencies of the Advanced System Triple Approach (Albers, 2010). In the context of iPeM validation balances the system of objectives with the system of objects

and is of great importance for the success of the engineering process as only thereby knowledge can be generated (Albers and Behrendt, 2010). This valuable knowledge solidifies and expands the system of objectives and allows a successful synthesis in case of a goal-oriented return of knowledge in other activities (Albers and Schroeter, 2011; Albers, 2010).

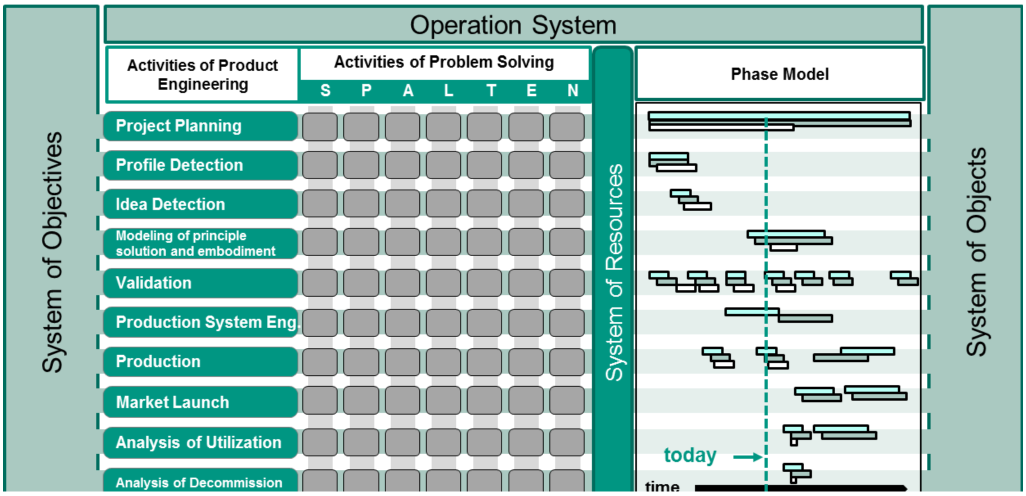

Figure 2: Integrated Product Engineering Model – iPeM (Albers, 2010)

The application of the XiL-Framework within the development process mainly addresses the interaction of the activities “Modeling of principle solution & embodiment” and “Validation”. Extended by the activity „Project planning” an application-related realization of the XiL-Framework is enabled. This relates to strategy, concept determination and series development according to the Stage-Gate-Model. In case of applied optimization procedures within the product engineering process it is necessary to closely interlink the activities “Modeling of principle solution & embodiment” and “Validation” as they are assumed to be combined and carried out automatically as far as possible. Thus, an ideal and validated “System of Objects” occurs in terms of the present “System of Objectives” after every successful optimization procedure (Schroeter, 2013).

The XiL-Framework represents a continuously useable and process applicable method from the “Operation System” of product engineering which allows the analyzing of the three interacting systems “Driver”, “Vehicle” and “Environment” with a changing focus (Albers and Behrendt, 2012). The optional integration of the optimization procedures helps to find the optima, for example at vehicle operating modes, design of the components and the topology of the powertrain. This has to be implemented into the product engineering process and the knowledge management system to ensure a holistic and efficient utilization and exploitation of the results (Schroeter, 2013).

4 XIL-FRAMEWORK WITH RESPECT TO OPTIMIZATION

The XiL-Framework is based on long-term research at IPEK – Institute of Product Engineering started in 1996 and integrates consequently simulation and test in the product engineering process. It covers the requirements listed above and therefore provides the prerequisite of a continuous, holistic, customer oriented synthesis and validation of modern vehicles with complex functionality with respect to environmental interactions (Albers and Dueser, 2010, Dueser, 2010, Figure 3). The „X“ of the XiL-Frameworks represents the Unit-Under-Test (UUT) respectively the Unit-Under-Development (UUD). UUT and UUD are considered equivalently but in the following UUT is used representatively. The UUT represents a (sub-) system of the system “Vehicle”. Dependent on its characteristics, the UUT is capable to be validated task-specifically on different system detail layers (XiL-Layers): beginning with the “working surface pair”-layer followed by different levels of the subsystem-layer up to the analysis of the entire system. This enables “Closed loop” investigations by integrating the Rest-Vehicle and the systems “Driver” and “Environment” for modeling respectively simulating. The level of detail of the Rest-Vehicle which consists of virtual and/or real subsystems respectively the interaction of the driver with the environment has to be adjusted depending on the specific application in an appropriate way (Albers and Dueser, 2010). Furthermore the IPEK XiL-Framework offers the possibility to take the system “Driver”, the system “Environment” or their subsystems as an explicit UUT itself (Schroeter, 2013; Albers and Dueser, 2010; Dueser, 2010).

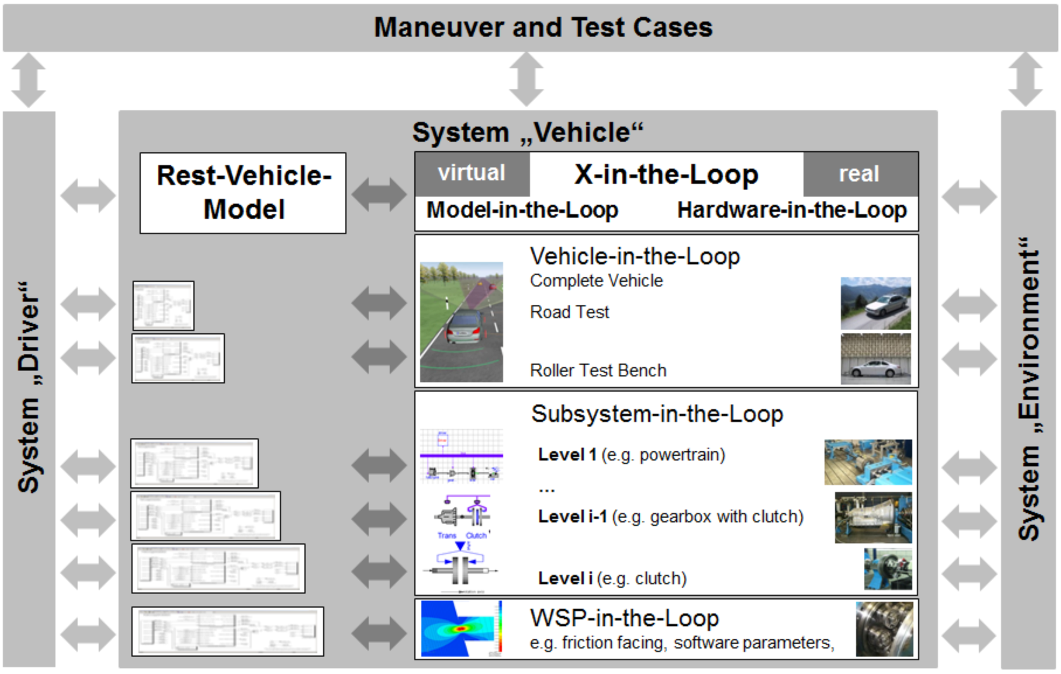

Figure 3: IPEK X-in-the-Loop-Framework (Albers and Dueser, 2010)

Latest Research brought up a suggestion for an enhancement of the XiL-Framework in order to implement optimization procedures in the product engineering process by consequently analyzing and synthesizing using the C&C²-approach (Contact & Channel approach). The generalized C&C²-approach combines function, effect and embodiment continuously. Consequently technical systems and the description of processes of the virtual product development and validation can be analyzed and synthesized much better on a more abstract level. This generalized approach supports the development and selection of an appropriate simulation- and/or optimization-model and therefore has a significant impact (Schroeter, 2013; Matthiesen, et al., 2012; Albers, et al., 2011). As a result the “enhanced XiL-Framework for a continuous integration of optimization” is shown in Figure 3 (Schroeter, 2013).

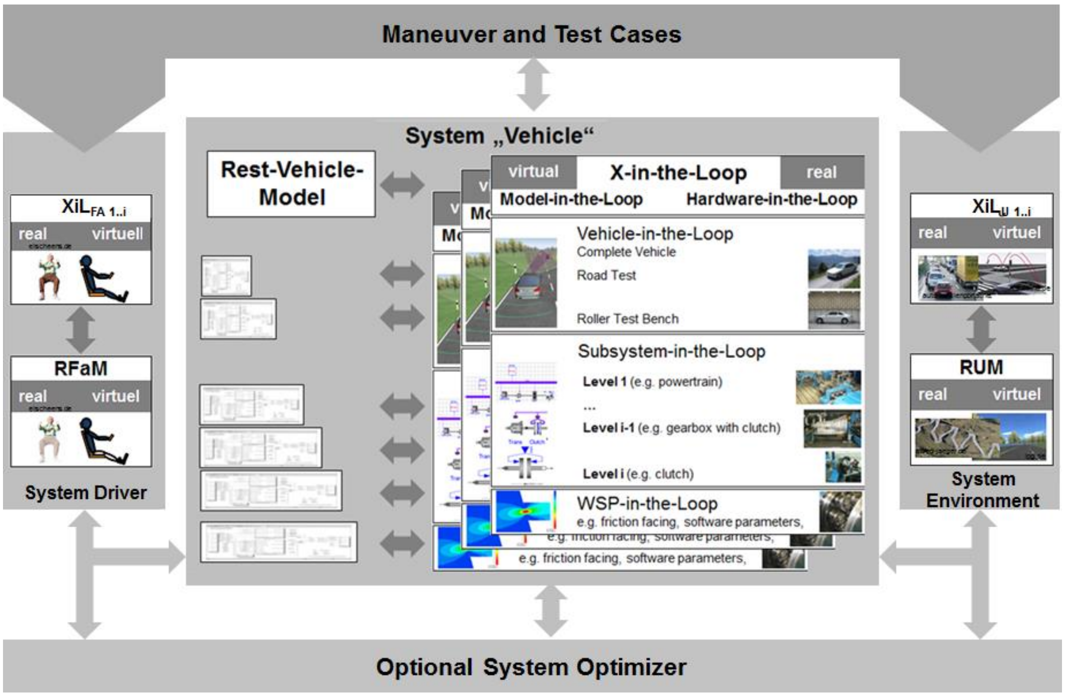

Figure 4: Enhanced X-in-the-Loop-Framework for continuous integration of optimization procedures into the product engineering process (Schroeter, 2013)

The previous systems “Driver”, “Vehicle” and “Environment” of the XiL-Framework are still mandatory but by now extendable by the optional system “Optimizer”. The “X” substitutes the respective UUT or multiple, simultaneous UUTs from the systems “Driver”, “Vehicle” and “Environment” simultaneously that can be completed by rest-models according to the requirements. With the help of the corresponding assignment of tasks the XiL-Framework can be specified and transferred into a specific function oriented structure. For a better understanding, the systems will be explained in the following. (Schroeter, 2013)

4.1 The System Driver

The system “Driver” consists of the UUT (virtual/real) and the “Rest-Driver-Model” (virtual/real). If the focus of the examination is not on the system “Driver” the system is reduced to the entire structure “Driver” according to Figure 3 (Schroeter, 2013).

4.1.1 The Unit-Under-Test$_{Driver}$ (UUT$_{Fa}$)

In the initial activities of the vehicle development process the target customer profile in the context of interaction as a base for the “System of Objectives” has to be worked out precisely. Therefore investigations in driving simulators or drives in a real vehicle are used (Albers, et al., 2012b; Herrtwich, 2012; Albers and Schroeter, et al., 2009; Kassner, 2007). For such research, as an example the HMI layout, a real driver forms the UUT_{Fa}. If the focus is on the human steering behavior with respect of automatic longitudinal-controlled assistant-systems the UUT_{Fa} contains only parts of the capabilities concerning the vehicle handling. In order to build up the XiL system’s interactions completely the system “Driver” has to be replaced by a “Rest-Driver-Model” (Schroeter, 2013; Lewandowitz, 2011; Albers und Schroeter, et al., 2009).

4.1.2 The Rest-Driver-Model (RFaM)

In the example of the analysis of the steering behavior the “Rest-Driver-Model” has to adopt the handling of the remaining vehicle controls (breaks, clutch, throttle, shift). If the investigation takes place in a driving simulator it can be accomplished by a virtual Rest-Driver-Model. Whereas, in test drives this can be performed by the use of an appropriate real driving robot. With respect of maximum effectivity the accuracy of the “Rest-Driver-Model” should be as low as task-specifically possible (Herrtwich, 2012; Albers und Schroeter, et al., 2009). If the UUT_{Fa} describes the system completely the Rest-Driver-Model can be vanished (Schroeter, 2013).

4.2 The System Environment

The system “Environment” consists of the UUT (virtual/real) and the “Rest-Environment-Model” "(virtual/real). If the focus is not on the system “Environment” the system is being reduced to the entire structure “Environment” according to Figure 3 (Schroeter, 2013).

4.2.1 The Unit-Under-Test$_{Environment}$ (UUT$_U$)

Environmental conditions like temperature, visibility of the track or traffic density have a huge influence on the vehicle and/or the driving behavior and therefore have to be considered during vehicle development. They have to be reproducible virtually or in reality. In order to ensure the reproducibility of relevant environmental conditions their influence has to be analyzed methodically in the entire system context (Roth, et al., 2011). For the development of predictive energy saving driver assistance systems, route data has to be supplied and the backlash of the system to the following traffic (UUT_U is following traffic) has to be considered. This prevents inconvenient or even dangerous interactions between vehicles applied with driver assistance systems and following vehicles in real life situations. Depending on the requirement models for following behavior or real tests can be used. Additionally even more environmental conditions $UUT_{U2...x}$ can be applied simultaneously (Schroeter, 2013; Roth, et al. 2011, Meinheit, 2009, Grein, et al., 2009).

4.2.2 The Rest-Environment-Model (RUM)

To ensure a holistic approach during the examination of sub-elements of the system “Environment” a “Rest-Environment-Model” completes the system “Environment”. This can either be simulative (e.g. via Augmented Reality) and/or with the help of real content (e.g. test track). If the UUT describes the system “Environment” completely the RUM can be vanished (Schroeter, 2013; Herrtwich, 2012; Bock, 2008).

4.3 The System Vehicle

The entire vehicle consists of many subsystems (e.g. powertrain, clutch, combination of the clutch facing, etc.) that are in extensive interaction and influence each other. Therefore the simultaneous examination of several real and/or virtual UUTs is essential and the prerequisite of an effective optimization of the entire system in order to cover all interactions for analysis, synthesis and validation process (Albers und Schroeter, 2011). Thus, the XiL-Framework has to allow the simultaneous examination of several UUTs. The exact amount depends on the particular assignment of tasks. If it's about developing of a new vehicle component (e.g. UUT_{F1} power steering pump) and a driving strategy of an energy-efficient predictive driver assistance system (UUT_{F2} vehicle without steering pump) simultaneously, two UUT_F have to be provided for an ideal dimensioning (Albers und Schroeter, 2011b). If necessary the Rest-Vehicle-Model has to be used for describing the system „Vehicle" entirely or for allowing the interactions between the systems „Environment" and „Driver" (Dueser, 2010).

4.4 The optional System Optimizer

The simultaneous examination of several UUTs in order to optimize the complex system „Vehicle" in the context of interactions of the systems "Environment" and "Driver" is only manageable effectively with help of the continuous use of optimization procedures (Albers und Schroeter, 2011b). That is why the enhanced XiL-Framework integrates the optional optimizer structure which contains several optimization procedures, as for example with less calculating time (reinforcement learning) or lower expectations to the description of the optimization problem (evolutionary algorithm) (Schroeter, 2013). This allows the selection of carry-over parts and the determination of possible driving strategies simultaneously and effectively during the activity "Idea detection" (Albers und Schroeter, 2011b). Furthermore these listed algorithms can be used as a subcomponent of the UUT being developed. This increases the performance significantly. This becomes particularly obvious when predictive driver assistance systems instruct the driver to drive fuel-economic and increases the profit of the new system even more. If any optimization problem occurs (e.g. analysis of the driving behavior) the system "Optimizer" is not applicable (Schroeter, 2013, Roth, et al. 2011).

4.5 Interactions between the XiL-Framework, iPeM and Knowledge Management Systems

For a company the product engineering is one of the divisions with the highest needs of information and knowledge. Both have to be captured and maintained in the correct manner and as well accessible by the designer in a structured and clear manner during the present activity (Arrow 1 in Figure 5).
Current, holistic and continuous concepts for knowledge-management e.g. "FuturePLM" and "Engineering Data Backbone" which include the levels processes, human and organization during the product engineering process accommodate and allow an important interdivisional transfer of knowledge, data and information. Within the processes the use of resources can be optimized, mistakes can be prevented, time can be saved and expenses can be reduced due to the holistic and corporate use of knowledge-management systems. This offers an ideal set-up for a company-wide use of the enhanced XiL-Framework in iPeM's context because its usability is not bound to one discipline or division (Albers, 2010; Albers, et al. 2010; Virtual Vehicle, 2010; Meboldt, 2008; Gausemeier, 2006).
The Framework can be used as part of the "Operation System" throughout the product engineering process of the mechatronic product "Vehicle" in order to support the engineer as good as possible in terms of interdependencies and complexity by keeping the engineer's decision priority. The particular, specific application case and its specifications (which UUT should be analyzed in what environment) results from the context of the development process (Arrow 2 in Figure 5; Schroeter, 2013). For the task specific realization the simulation model, the hardware components and test benches from different disciplines (mechanics, software, electrics, …) have to be chosen and combined from the company's resource pool. This is anything but simple (Arrow 3 in Figure 5; Albers, et al, 2012; Virtual Vehicle, 2010).
With the help of a central storage providing all deployed models, carry-over parts, vehicle modules, proven optimization algorithms and central co-simulation-platforms for cross-domain linking of simulation models, hardware and optimization procedures the specific application case of the enhanced XiL-Framework can easily be carried out throughout an user interface – with or without optimization procedures. Therefore new tools have not to be developed but approved tools are being connected by

the use of appropriate interfaces. By logical coupling of established tools the usability is ensured with respect of engineer's work load whereat the IT complexity is hidden from the user (Albers, et al. 2010). By this, the user is expected to gain easy access to additional and relevant information by the interface as for example model's degree of maturity by the use of linked Wikis and contacts in kind of yellow pages analogous to Meiwald (2002) and Suchomel (2006). As well, defined input options for the knowledge return based on the results are considered. The corporate idea storage enables standardization of maneuvers as well as test scenarios that have to be carried out during development and validation with respect to complete vehicle interactions. This significantly supports the result's reliability and transferability (Dueser, 2010) with time and cost related benefits.

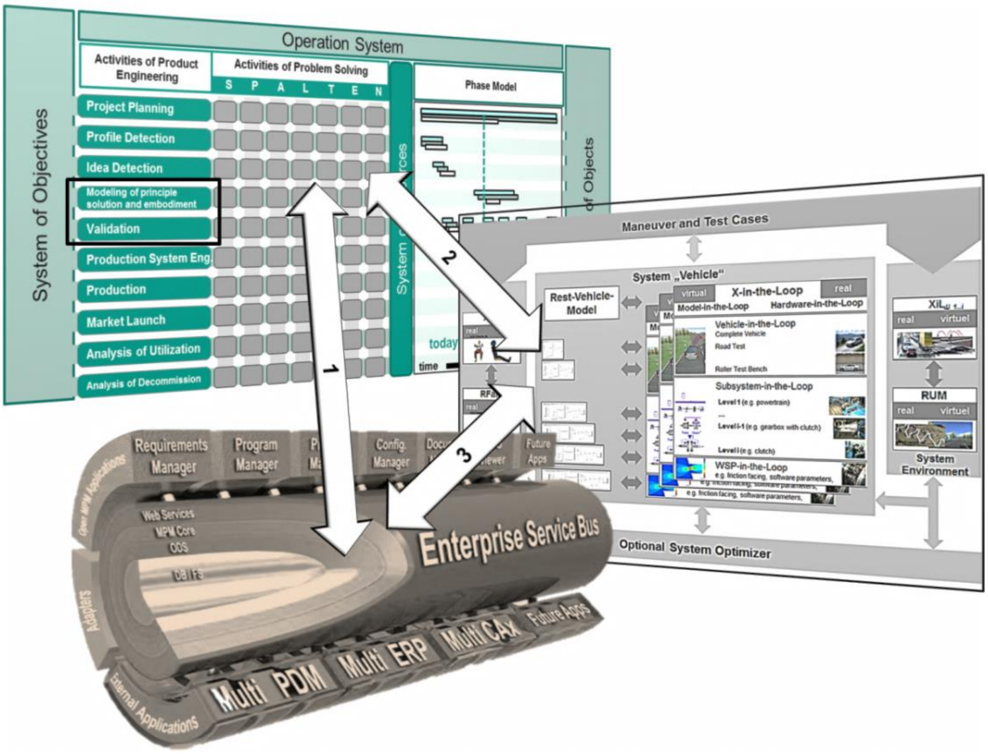

Figure 5: cross-disciplinary interactions of iPeM, XiL and „Enterprise Service Bus" in terms of corporate knowledge management (Schroeter, 2013; Albers, 2010; acc. to Virtual Vehicle, 2010; acc. to Zamazal, et al., 2007)

The holistic knowledge management system approach as well integrates all necessary process elements as for example the change management or innovation management and the System of Objectives and the System of Objects. The continuous availability, quality and integration of virtual methods and tools throughout the engineering process that are regarded as decisive competitive factors for the development of vehicles are thereby enabled (Schroeter, 2013; Virtual Vehicle, 2010; Zamazal, et al. 2007).

5 CONCLUSION AND OUTLOOK

In this article the XiL-Framework for continuous integration of simulation and test in the product engineering process has been presented considering the interacting systems "Driver", "Vehicle" "environment". The obligatory virtual or real "Rest-System-Models" that are specifically detailed for their current task allow to completely represent the systems relevant interactions. The optional system "Optimizer" allows a continuous integration of optimization processes in order to find global optima in the context of system-interaction, either offline or even online. The recurring activities like "modeling of principle solution & embodiment" and "validation" during the engineering process can be partially automatized and carried out time-efficient based on the different system-detail-layers from "working-surface-pairs"-layer up to the entire "system"-layer.

The XiL-Framework accommodates the actual and prospective challenges of vehicle development concerning analysis, synthesis and validation and consequently combines existing methods, processes and approaches, independent from the focused power train configuration. Although it provides closed-loop and open-loop maneuvers, an open and flexible architecture, integration of established methods and tools, integration of models, maneuvers (test cases) and automation routines, it is compatible with existing engineering processes. By applying XiL there is always an engineering and management view on the engineering activities.

XiL is based on long-term experience at IPEK since 1996 and it was and will be transferred, applied and validated in many industrial and fundamental research projects. Meanwhile the XiL-Framework became major approach for structured research on “Mobility Systems” at Karlsruhe Institute of Technology (KIT). Actual research aims for globally distributed development and validation approaches based on the XiL-Framework. But for IPEK it is even more as XiL is considered as a research philosophy for vehicle and powertrain research and development.

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