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CONCEPT FOR A SIMULATION MODEL TO ANALYZE KNOWLEDGE CONVERSIONS WITHIN THE PRODUCT DEVELOPMENT PROCESS

Laukemann, Alexander; Binz, Hansgeorg; Roth, Daniel
University of Stuttgart, Germany

Abstract

Business Process Management (BPM) has been established in industrial environments for decades. In the course of progressive information technology support, the research of BPM benefits from the advantages of digital process modeling and its tools. The results are complex and unclear process models, which should rather increase process transparency and be analyzable. Nevertheless, digital process models remain indispensable, particularly when information and knowledge-intensive processes are to be analyzed. The modeling language "Knowledge Modeling and Description Language" provides different views and objects to establish a valid digital process model. The advantage as well as disadvantage – is the modeling of information flows and knowledge conversions, which are interlinked and complex. The presented concept for a simulation model aims to overcome this contradiction and provide quantitative analyses of digital process models. The analytical results can be compared with existing qualitative analyses and used for a holistic investigation of the simulated process. In this way, target-oriented support from suitable knowledge management solutions can be purposefully compiled.

Keywords: Knowledge management, Process modelling, Simulation, Design process

Contact:
Alexander Laukemann
University of Stuttgart
IKTD
Germany
alexander.laukemann@iktd.uni-stuttgart.de

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1 INTRODUCTION

The simulation of technical processes, in particular production and logistics processes, has proven its effectiveness in practice. Comprehensive analytical methods of simulation are established in many branches and support decision-making when process-relevant decisions have major impacts on the company (Rabe, 2008). In order to save investment costs or reduce processing time, digital factory layouts or entire virtual production process chains are simulated using process models. Simulations are performed when there is a particular risk, if implementation of a prototype would consume too many company resources and/or conventional analytical methods cannot map the complexity of the object to be investigated.

In the course of digitalization, the currently available information systems and their supporting tools serve to ensure further improved, high-accuracy digital process models which are necessary to conduct simulations. On this basis, process modeling approaches such as Business Process Management (BPM), Unified Modeling Language (UML), Event-Driven Process Chains (EPC) or Systems Modeling Language (SysML) are becoming increasingly important in business environments (Freund and Rücker, 2014). Each modeling approach has its own advantages and disadvantages, but the primary and overarching objectives – such as improving process transparency, increasing productivity through continuous processes or clear and easily usable documentation – apply for all process management approaches (Wagner and Patzak, 2015).

As already indicated, simulations are mostly used to analyze alleged value-added processes like the production or logistics process. However, it must be taken into account that structural change is leading industrial nations away from capital- and labor-intensive activities and toward information- and knowledge-intensive activities. Viewed from this perspective, huge potential is offered by modeling and simulating information and knowledge-intensive business processes such as product development, which Eppler (Eppler et al., 2008) describes as one of the most knowledge-intensive and complex business processes. In attempting to exploit this potential, conventional modeling languages which mainly pursue the objective of coordinating the activities involved in business processes reach their limits and need to be extended or adapted in order to model and simulate the new focal points. However, several modeling languages such as PROMOTE (Hinkelmann et al., 2002), ARIS (Scheer, 2000) or KMDL (Gronau and Maasdorp, 2016) include objects for precisely describing information flows. The basic rule is that the more precise the digital process model, the more accurately the simulation provides quantitatively analyzed results. With the Knowledge Modeling and Description Language (KMDL) information flows, knowledge transformations and personal knowledge of a business process can be described in detail and provide the basis for further simulations. KMDL includes several pattern-based qualitative analyses of knowledge-intensive business processes and shows how different process patterns may be used to redesign and improve processes (Gronau, 2009). Conversely, the quantitative analyses of a KMDL process model (which are important for further recommendations) are not possible with the qualitative analyses instruments (process patterns).

A valid simulation model of KMDL process models is necessary for this purpose (Fröming, 2009). A simulation model in the context of product-development-specific activities has not been considered yet and will comprise the content of this paper. In the next section, the problem statement and goals of this paper will be presented.

2 PROBLEM STATEMENT AND GOALS

In general, regardless of which modeling language is used, digital process models attempt to emulate real processes with high accuracy. A modeling language generally consists of the components vocabulary, syntax and related semantics. The syntax and related semantics often offer a variety of modeling objects and associated links. However, the number of objects adversely affects the clarity and transparency of a process model. Yet comprehensive modeling languages are required in order to support information and knowledge-intensive activities within business process steps. KMDL is able to model product development process steps and their supporting methods with the necessary level of detail (Laukemann et al., 2015). The latest version of KMDL (KMDL 2.2 (Gronau, 2009)) provides three different views to differentiate between the superior process view, the detailed activity view and the additional communication view. The activity view visualizes knowledge transformations and information flows, which are the most important factors concerning further analyses and simulations.

The activities in product development steps are complex and involve comprehensive expertise in engineering design (Pahl, 1994). On the one hand, the digital process model should be as accurate as possible and, on the other hand, it should be clear and transparent in order to facilitate further analyses. New analytical methods and tools are required to overcome this contradiction. Related to the underlying business process, specific simulation models support the analysis of complex and knowledge-intensive KMDL activity views. The focus of this paper is a product-development-specific simulation model to quantitatively analyze a digital process model.
The main research question of this paper is as follows: *"How must a simulation model be structured in order to simulate product-development-specific activities and optimize information flows and knowledge conversions based on the simulation results?"*
This research question leads to additional questions about the influence of information flows and knowledge conversions for product-development-specific activities. In order to give an initial answer to the main research question, an explicit assumption has to be formulated in the form of a hypothesis: *"With a suitable simulation model, it is possible to simulate and optimize product-development-specific activities."*
The objective of this paper is to present a simulation model, which the contradiction of process complexity and simple analytical possibilities can be overcome. Furthermore, the result of analysis of the simulation allows recommendations for action to be derived. Finally, the simulation model will be embedded in a holistic framework of a product-development-specific knowledge management approach. Figure 1 represents roughly the contradiction between process complexity (on the left-hand side) and quantitative process analysis (on the right-hand side).

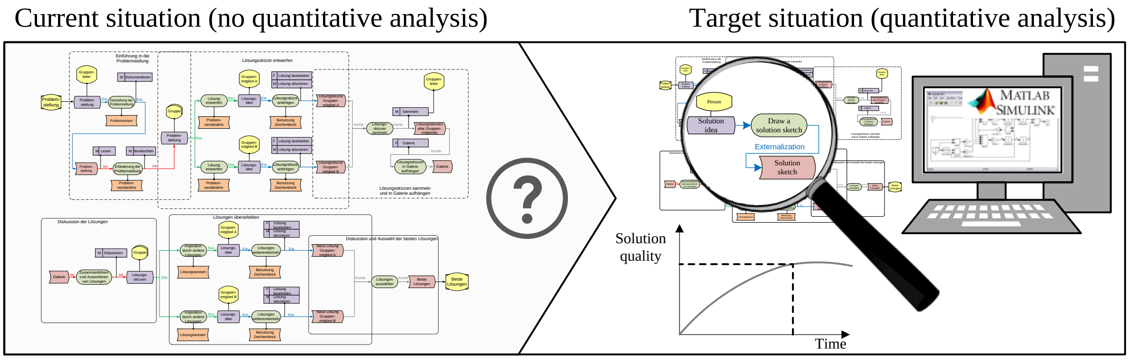

Figure 1. Contradiction between process complexity and quantitative process analysis

3 STATE OF THE ART

In this chapter, the three main topics related to this paper will be briefly presented. Firstly, the theoretical principles of process-oriented knowledge management for describing the underlying product development process with a link to knowledge management are presented. In accordance with this, the Knowledge Modeling and Description Language (KMDL) is shown to understand the digital process model of the product development activities. With the knowledge gained from the previous sections, explanation is given of the simulation method "System Dynamics" for following interdependencies between the digital process model and the results obtained from the analysis.

3.1 Process-oriented knowledge management

Successful products are the result of well-structured business processes and many other impact factors. The organizational structures and workflows are often enhanced through company-specific continuous improvement processes. In spite of every effort, current studies show that organizational knowledge and information are not used productively, although knowledge management indicates a close reference to business processes (Allweyer, 1998; Haufe, 2014). Remus (Remus, 2002) comprehensively analyzed process-oriented knowledge management approaches regarding the modeling of processes and their differing levels of intervention. Finally, Remus concludes that the high potential of process modeling is not yet exhausted and recommends applying process modeling as a powerful tool to establish knowledge management support. Figure 2 shows the connection and interaction between business process management and knowledge management (Abecker et al., 2002).

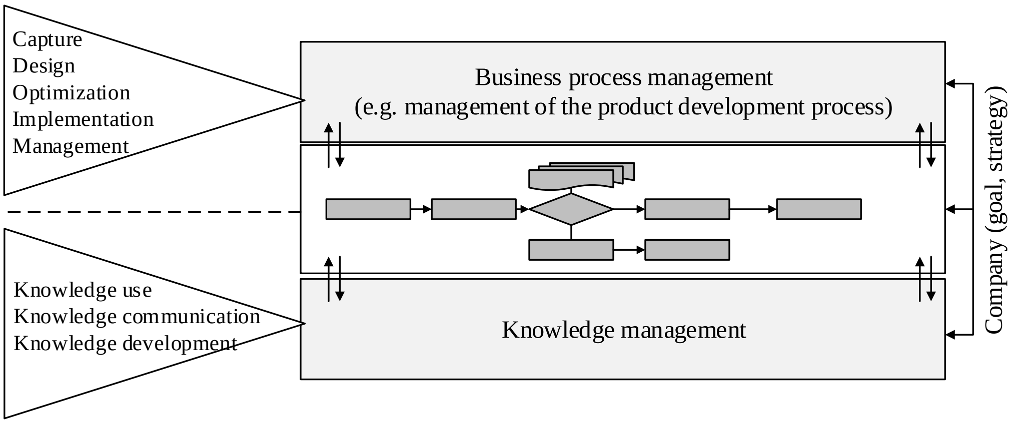

Figure 2. Interaction between business process management and knowledge management (Abecker et al., 2002)

3.2 Knowledge Modeling and Description Language (KMDL)

The "Knowledge Modeling and Description Language" (KMDL) constitutes a semi-formal and graphic modeling language. The language provides a defined set of symbols and a given syntax. The distinction between three different views (process view, activity view and communication view) allows complex process steps to be modeled in a clear structure. The superordinate process view contains objects such as "process interfaces", "tasks", "roles", "information systems" and different "joint operators". The most important object of the process view is represented by the "task" object, which describes a general stage of the examined business process. In the context of the product development process, the object "task" includes a set of product-development-specific activities such as "task clarification", "concept development" or "idea evaluation" (Pahl, 1994). Each task may be connected with the object "role", which comprises one or more persons involved from the same area of responsibility. An "information system" constitutes information or communication technology that is used in business processes and determines the requirements for conversions (see object "conversion". "Process interfaces" are designed to connect sub-processes to process chains. The individual "joint operators" manage the control flow and display the possible paths. On the basis of the modeled process view, the more detailed activity view can be derived in the next step. The objects of the activity view, such as employee-related objects like the "person", "undefined person", "team" and "knowledge object", "information object", "conversion", "requirement" are required to develop a precise activity view (see Figure 3). For example, the knowledge object "Knowledge about the current market situation" of an experienced employee is transformed through the conversion object "carry out a market analysis" into the information object "product market matrix". This process describes an externalisation of knowledge (Nonaka and Takeuchi, 1995).

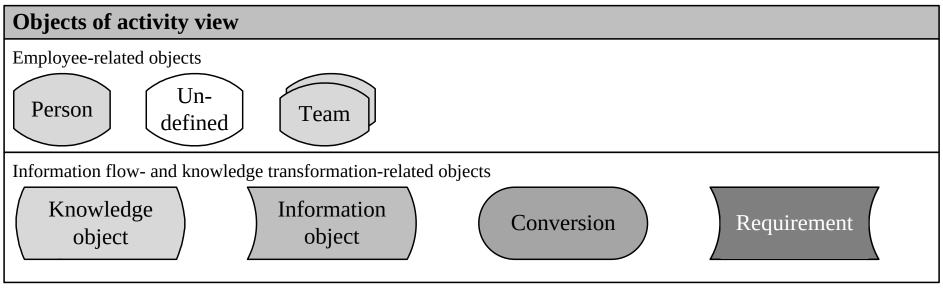

Figure 3. KMDL objects of the activity view (Gronau, 2009)

KMDL is not just a modeling language, but rather a holistic approach for analyzing knowledge-intensive process steps. For this purpose, KMDL provides different process patterns as options for analysis. The predefined process patterns are derived from practical projects and aim to map the informal transfer of knowledge (Gronau, 2009). Compared to other modeling languages, KMDL describes the transformation of tacit knowledge into explicit knowledge and the inverse transformation of explicit knowledge into tacit knowledge with the object "conversion", which is an advantageous and unique feature. This takes the SECI (Socialization, Externalization, Combination, Internalization) model of knowledge dimensions developed by (Nonaka and Takeuchi, 1995) into account. In addition to this, the main activities of knowledge management (identification, acquisition, development, transfer, storage and use) can be addressed with KMDL. These are significant facts for the selection of KMDL as a modeling language to establish valid process models (Laukemann et al., 2015).

3.3 System Dynamics

System Dynamics is a methodology for the analysis and simulation of dynamic systems. System Dynamics was developed by Jay W. Forrester in the 1950s when he was confronted by the occupancy problems of a General Electric plant (Forrester, 1977). System Dynamics is based on the assumption that every system contains a feedback ratio. This means that each event affects a subsequent event and can be visualized as a "closed loop" in contrast to an "open loop", where the activity chain ends with a result. "Accumulation of flows into stocks" and "time delays" are two further elements which are required in order to create a System Dynamics model.

The following steps should be considered in order to establish a System Dynamics model (adapted from Forrester) (Forrester, 1977):

1. **Textual description** of the system with an initial theory about system behavior.
2. Preparation of a **causal loop diagram** with all its elements and their interactions to represent the system behavior in a qualitative way.
3. Creation of a **stock and flow diagram,** which is derived from the causal loop diagram, in order to characterize the system behavior in a quantitative way.
4. Determining of the **equations** which describe the flows mathematically.
5. **Simulation** of the model.

The causal loop diagram represents a simple map of the system to be simulated. There are different feedback loops between the system elements. The positive reinforcement loop (see Figure 4, left) is defined as a positive loop gain around a closed loop of cause and effect (Karl and Ibbs, 2016).

Positive feedbacks are related directly to the input and make the input larger. Contrary to this, the negative feedback loops (see Figure 4, right) occur when elements of the system return to reduce variations in the output, whether caused by changes in the input or by other external circumstances. Unlike positive feedbacks, negative feedbacks tend to balance a system and reduce disorder (Karl and Ibbs, 2016).

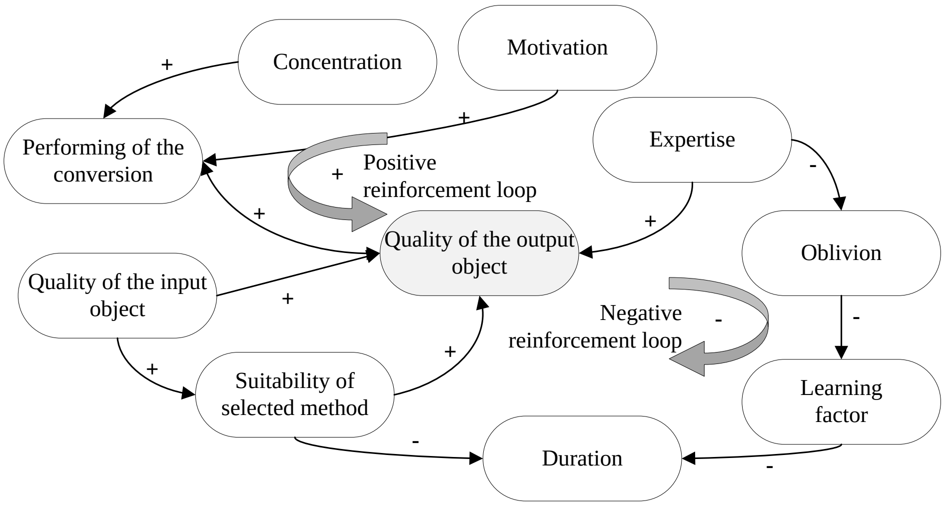

Figure 4. Causal loop diagram of a KMDL activity view output object (for example an information object)

The stock and flow diagram includes elements and interdependencies of the causal loop diagram. The stock and flow diagram is the most important part of System Dynamics for conducting further quantitative simulations due to the mathematical correlations of stock variables and flow variables (Karl and Ibbs, 2016). In this way, complex system connections are described by means of equations of stocks and flows (see Figure 5).

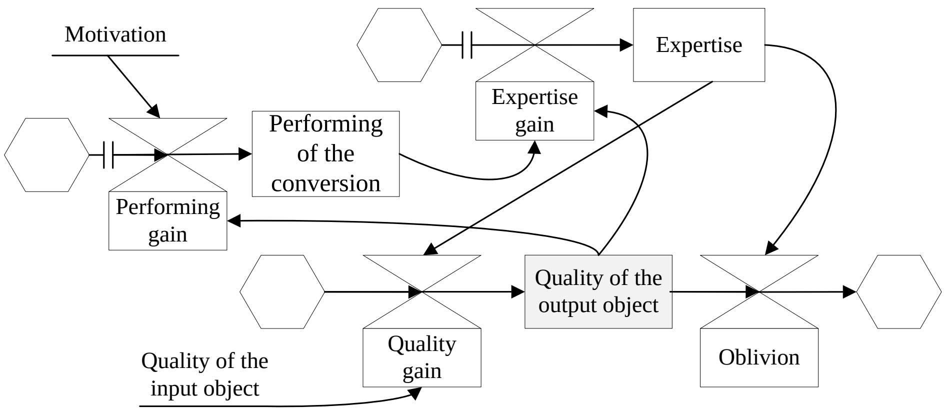

Figure 5. Stock and flow diagram of a KMDL activity view output object (for example an information object)

In contrast to other simulation methods, the consideration of dynamic and social aspects through specific elements of System Dynamics is necessary to simulate knowledge-intensive processes (Fröming, 2009). The simulation results depend on the simulation goal, but a complex and unclear process with many interrelated elements can generally be analyzed by means of System Dynamics. In particular, the impact of each element of further activities can be analyzed with a sensitivity analysis by means of System Dynamics.

Conclusion regarding the state of the art

The process-oriented knowledge management approach is suitable for formally describing the product development process. Using KMDL, it is possible to map the "living product development process" as a digital process model, which additionally reveals knowledge transformations and information flows (Laukemann et al., 2015).

This digital process model is complex and unclear, just like the underlying business process. The System Dynamics simulation method provides a set of instruments to simulate complex process models. The simulation results permit product-development-specific and target-oriented support options to be recommended based on different sensitivity analyses.

4 CONCEPT FOR A SIMULATION MODEL TO ANALYZE KNOWLEDGE CONVERSIONS WITHIN THE PRODUCT DEVELOPMENT PROCESS

With the findings from process-oriented knowledge management, the KMDL modeling language and the System Dynamics simulation method, it is possible to derive a concept for a simulation model to analyze knowledge conversions within the product development process. First, however, the term "conversion" in this context needs to be clarified further. As stated in section 3.2, the transformation of knowledge or information is termed "conversion". The types of conversion are represented through the SECI model (Nonaka and Takeuchi, 1995). Each type of conversion provides a set of methods to transfer knowledge or information (see Table 1).

The different methods of conversion can be assigned to the attributes "level factor" and "time factor". With these factors, the conversions can be additionally characterized by their duration and quality level (Fröming, 2009). For instance, the drafting of a sketch does not consume much time (time factor), but the level of information (level factor) is limited compared to document which includes text and diagrams. Another example would be the comparison between sorting and categorizing given information. The conversion type "combination" does not change the level of information, but the related methods differ considerably from the time factor, e.g. simple sorting of an excel sheet takes half the time of categorizing the information of this excel sheet.

Dealing with the KMDL object conversion can be divided into three sections. The input object(s), the conversion itself and the output object(s). A conversion has at least one input and one output object. These objects vary between knowledge or information objects according to the type of conversion.

Table 1. Types and methods of conversion including level and time factor (Fröming, 2009)

Types of conversion	Methods of conversion	Level factor	Time factor
Internalization	Read	0.02	0.6
	Listen	0.03	0.3
	See	0.05	0.1
Externalization	Draft	0.1	0.05
	Document	0.2	0.1
	Model	0.3	0.25
	Digitize	0.4	0.6
Combination	Sort	0.1	0.05
	Categorize	0.1	0.1
	Add/Delete	0.1	0.25
	Integrate	0.1	0.6
Socialization	Observe	0.01	0.01
	Communicate	0.02	0.09
	Self-study	0.03	0.2
	Practice	0.04	0.7

The quality of the output object depends on the quality of the input object as well as the personality profile of the person involved in the conversion (see Figure 6).

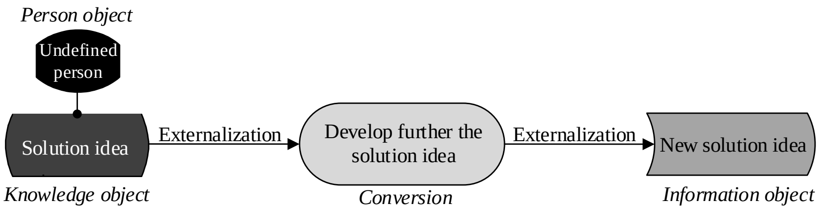

Figure 6. KMDL objects involved in a conversion

The main factor that influences the output quality is the knowledge of the person(s) involved in the conversion. In terms of this knowledge, a distinction can be made between application knowledge or expertise in a certain subject area. In the course of a conversion, the application knowledge used and the expertise of the person(s) involved increase depending on the type and method of conversion. The knowledge used within the conversion is described as a KMDL knowledge object. The next quality-critical factor is the personality of the person involved in the conversion process. Each person has a certain range of attributes related to personality, competence and condition. These personal attributes – in addition to the type and method of the conversion – result in the quality of the output object. A further quality-critical factor is the performing of the conversion. The quality of the performing and the duration of the conversion depend on the person-specific skills for conversion. Some conversions have a certain duration within which the task must be processed (e.g. the brainwriting method 635). The performing of the conversion becomes better and faster the more frequently the person performs the same type of conversion (learning effect). The derivation of personal attributes is necessary to describe the personality and the role of the person in the simulation model. The notation of KMDL does not consider the personal attributes or skills which must be added to be able to create the simulation model. The following personal attributes and skills are derived from the personality psychology approaches "BigFive" (Fehr, 2006) in combination with the Myers-Briggs Type Indicator (MBTI) (Achouri, 2015):

- **Social competence**: Distinction between extroversion and introversion
- **Creativity**: "Openness to experiences" (inventive and curious vs. consistent and cautious)
- **Independence**: Conscientiousness (organized vs. negligent)
- **Motivation**: "Energizing preferences" (motivated employees provide better results)
- **Concentration**: Conscious focus of attention on a work task

The listed attributes describe the personality of the persons involved in the product development process, but they do not reveal anything about their competencies. In order to take the personal competencies and the learning progress into account, (Fröming, 2009) introduced the attributes "use explicit", "use tacit", "write tacit" und "learn explicit" to attain the capability to perform individual conversion types (see Table 1). Activities within the product development process are characterized by progress in knowledge and method competency. The personal attributes "capacity" and "integration capacity" have been added, in contrast to other simulation approaches. After each influencing object and its specific attributes have been presented, the factors of the attributes must be converted into mathematical relationships with a certain range of values (equations). Each variable is thus assigned to a value between 0 (0%) and 1 (100%). SimuLink was chosen as a tool for modeling in order to implement the simulation model. SimuLink is an object-oriented software for modeling mathematical and other technical systems that provides various discrete and continuous blocks. The flow of data between the individual blocks is visualized by means of connection lines. SimuLink is an add-on to Matlab and therefore allows the integration of familiar Matlab functions. The digital KMDL process model serves as a blueprint for the simulation model. For this purpose, the respective KMDL objects are created as partial models and the mathematical relationships and interdependencies are integrated according to System Dynamics (see Figure 7).

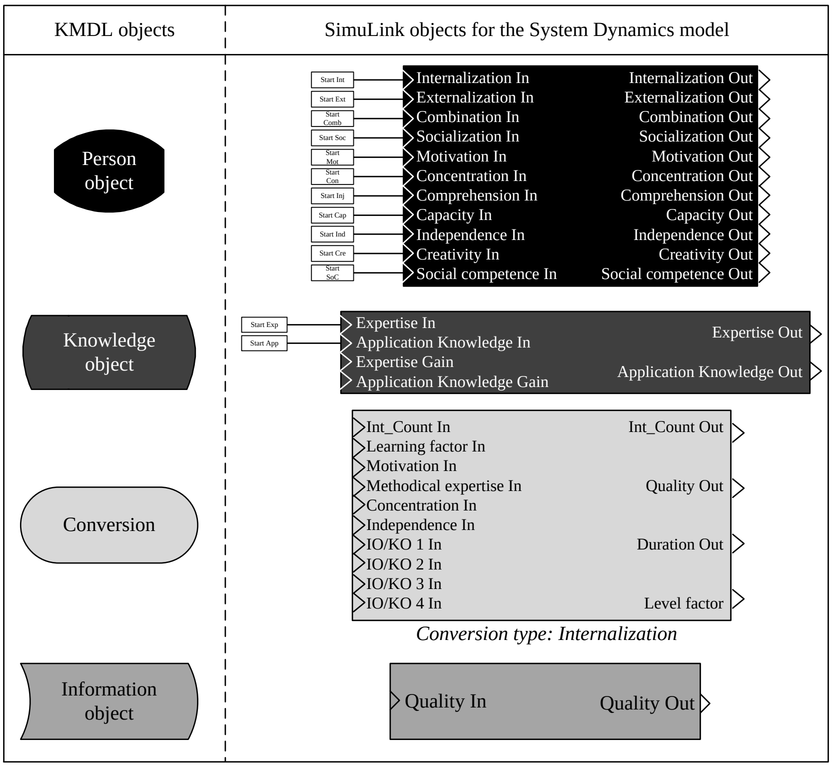

Figure 7. Comparison between KMDL objects and SimuLink objects

The simulation process is event-driven (see EPC, Chapter 1). Each conversion comprises one event. Only by means of the conversion event are knowledge or information objects created or changed. As stated previously, the person object is very important for the simulation model and must be extended with the personal attributes and skills (see Figure 8).

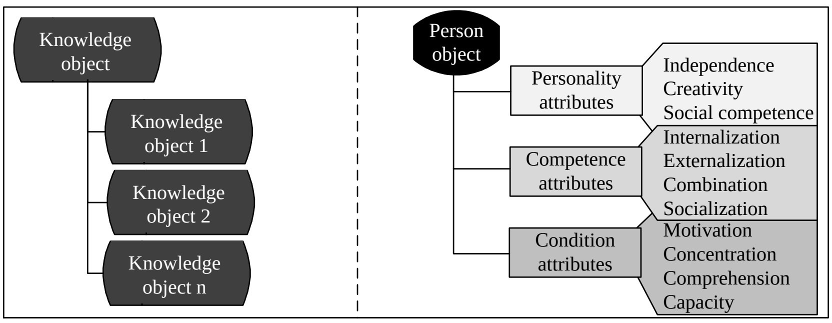

Figure 8. Person model in the System Dynamics model related to the KMDL objects

The SimuLink objects provide a great deal of meta-information in comparison to the KMDL objects. Each SimuLink object represents a partial model consisting of mathematical equations and control tools for measurement and control technology. Figure 7 shows a selection of the SimuLink objects compared to the KMDL objects. The SimuLink objects have different connectors, which are required to combine them with other objects or input variables. In order to properly simulate a product development activity or a product development process step (series of successive activities), role models for persons involved in the product development process are still missing. The simulation model therefore provides various role models derived from the findings of (Pahl, 1994). The presented simulation model has been validated by simulating the "gallery method" creativity technique, which can be applied in the early phases of the product development process. This method combines the benefits of individual work and group discussions. The method is usually implemented in the form of a workshop on a specific problem with five or more persons. In the course of this, suggestions for solutions are elaborated and prepared and concretized in the form of sketches, tables, drawings or other forms of presentation. An interdisciplinary team composition promotes the search for solutions. The contents – in addition to the process of this method – are representative for many product-development-specific activities. Figure 9 shows an overview of the KMDL process model (activity view), the System Dynamics model established with SimuLink and some quantitative analysis results presented as diagrams. For example, using the new quantitative analysis results, the impact of the expertise of an experienced employee can be mapped with the solution quality. Furthermore, different role models can be varied (teamwork simulation), as can their influence on the solution quality. It is difficult to simulate human behavior and the model presented has no claim to completeness, but the analytical results reveal a more purposeful support in the form of problem-oriented knowledge management solutions. One major advantage of the simulation model is the traceability of various factors and their impact on further knowledge development or information quality.

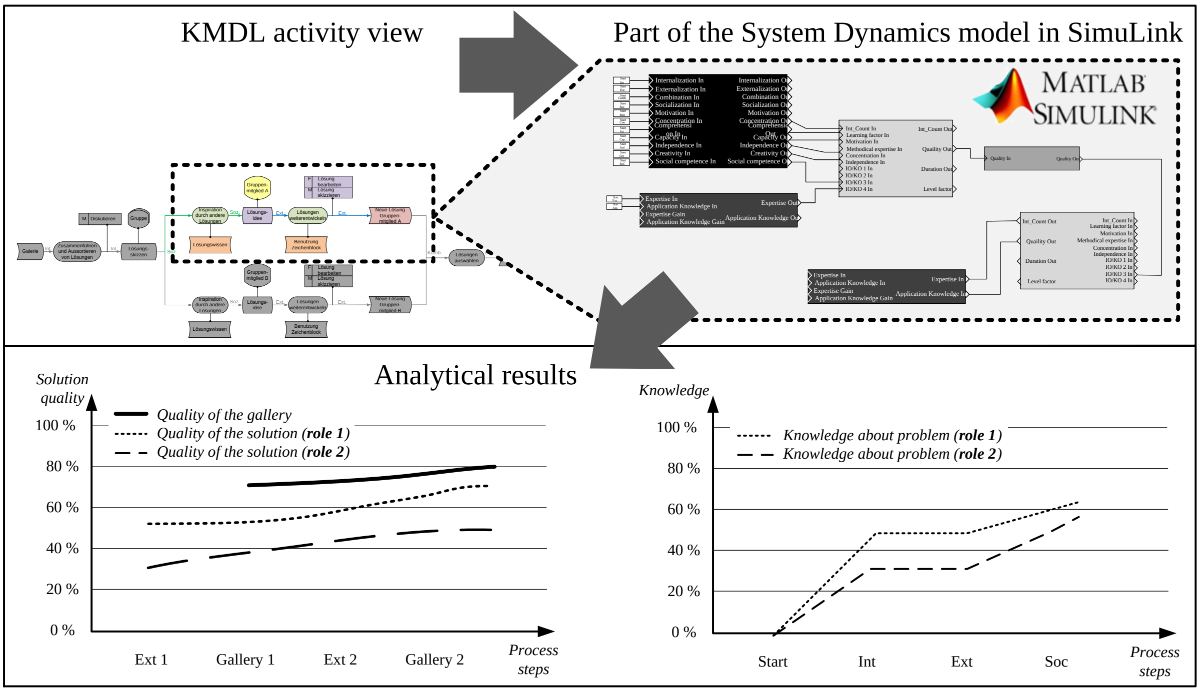

Figure 9. Overview of the essential components of the concept

5 DISCUSSION OF THE RESULTS

An initial critique would be that simulation models never precisely map the real process, regardless of which modeling language or business process serves as the basis. The reason for this is that many assumptions which directly influence the analytical results must be made in order to establish the simulation model, particularly if a simulation model claims to be able to simulate human behavior. The preliminary works of (Fröming, 2009) and (Wynn et al., 2006) were incrementally improved in some cases (e.g. extension of objects), yet the innovative link between product-development-specific activities and their involved persons with specific attributes as well as skills (Pahl, 1994) has been presented in this paper and represents current research into product-development-specific knowledge management. Even though the analytical results are based on assumptions, the qualitative analysis options can be compared with them to improve knowledge management support for the analyzed activity or process step.

6 CONCLUSION AND OUTLOOK

The presented concept for the simulation model is able to simulate knowledge conversions of a product development process. The analytical results provide targeted support of individual activities or extensive process steps by means of knowledge management solutions. A considerable advantage compared to other approaches is that the personal attributes and skills of persons involved in product development have been taken into account. The main focus of further research will be the handling of the analytical results and their connection to a catalog in particular, which provides suitable solutions for the identified problem.

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