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The Semantic Interaction of Knowledge, Data and Processes within the Product Development Process

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Abstract

Multidisciplinary and holistic integration in today's heterogeneous PLM environments is crucial in all development phases. It is seen as the key factor for multidisciplinary product development within a cross domain enterprise and a complex supply chain network. This paper describes and discusses a new approach how to integrate different development disciplines, lifecycle stages and IT systems as well as associated information, data and processes along the product creation process.
A concept for a generic PLM integration platform is developed that contains fundamental components all for complex product development. These components include powerful solutions for requirement, program, process and product structure handling. The interaction of these solutions, especially the interdependencies of processes and shared data is in the foreground of this paper. Business processes are composed by the capabilities of the platform services and respectively the platform processing logic is controlled by the modeled processes.
Research results of developed server and client architecture, functionalities and semantic integration aspects that are out of scope of today's solutions are explained. The data model and core concepts for the integration platform are shown with an outlook for the extension of heterogeneous application integration up to the design of knowledge structures through the extended enterprise.

Keywords: Product Lifecycle Management, Process, Semantic, Metagraph, Integration

1 Introduction

Today's increasing product complexity and the associated high quality demands that interfere with shortened development cycles and reduced development costs make it seem obvious that intelligent solutions for today's and tomorrow's demands are necessary.
Besides the expansion according to integration of real data (from test, after sales, etc.) and knowledge transfer out of previous product generations, full lifecycle integration has to be considered. Additionally, globalization and multi site development – bringing together big OEMs with the smallest supplier (Tier 1, 2…n) – demands future engineering network

solutions. In this context especially the ever increasing amount of data and information needs to be organized in terms of structured availability.

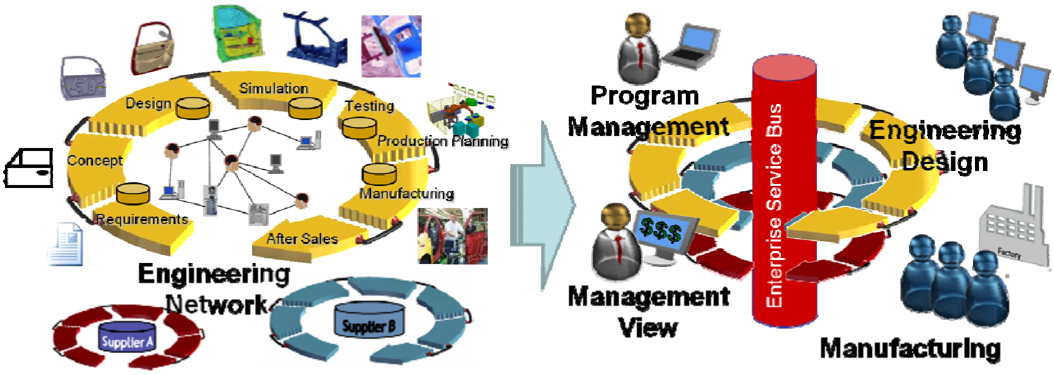

Figure 1: PLM related Tendency within Complex Product Development

Unfortunately today's solutions (systems, applications, etc.) with their different data formats are - in spite of endeavor's like interchange standards (e.g. STEP AP214, AP 212, etc.) - not really useful in terms of interdisciplinary collaboration. Therefore the strong need for more intelligent solutions is mandatory. Such a solution is seen in a semantic future PLM approach that brings together all lifecycle phases as well as the supply chain network and related disciplines as shown in Figure 1.

This paper summarizes related research efforts to get closer to that goal. Integration aspects of PLM are discussed and an accordingly appropriate state of the art IT approach is described to close the gaps within today's complex world of product development.

2 Product Lifecycle Management –Approaches and Challenges

The term *Product Lifecycle Management (PLM)* emerged in late 1990's after nearly twenty years of market and technological evolution. With the advent of Computer Aided Design (CAD) solutions, as the means of creating the geometric model of the products, engineering design entered a new era. Product Data Management (PDM) systems appeared during 1980s which originally focused on solving the problems of CAD file management by providing a data vaulting facility, and were typically limited to the engineering aspects of product.
PLM is not a tool or a system such as PDM. It is a development and management strategy focusing on all aspects related to product development [1]. CIMdata defines PLM as a strategic business approach that applies a consistent set of business solutions in support of collaborative creation, management, dissemination, and use of product definition information across the extended enterprise, from concept to end-of-life, integrating people, processes, business systems, and information [2].

Today's biggest challenge according to PLM can be summarized as challenges for *Cross Enterprise Engineering*. This term describes the challenge of not only closing the gap between the different stages of the product development process (*cross lifecycle*) but also introducing a set of integrated activities to incorporate *cross domain* and *cross enterprise* integration (i.e. the supply chain network). Here it has to be distinguished between reference processes to be developed (e.g. for certain business areas or collaboration scenarios) and the according IT aspects that allow the integration of such processes on a level that is generic enough to fit in everybody's development strategy without high effort of customization.

3 Concept for Holistic PLM Integration Approach

The major benefit of PLM lies in the seamless integration with other fields of product development. This is done by bringing together e.g. product data, functions, requirements, processes, projects tasks, costs etc. (i.e. *PLM objects*) in direct correlation with other related PLM objects. These objects may be authored and managed in e.g. different PDM systems and other software tools used in product development. Thus for an efficient product development strategy, they must be integrated with all fields of product development.

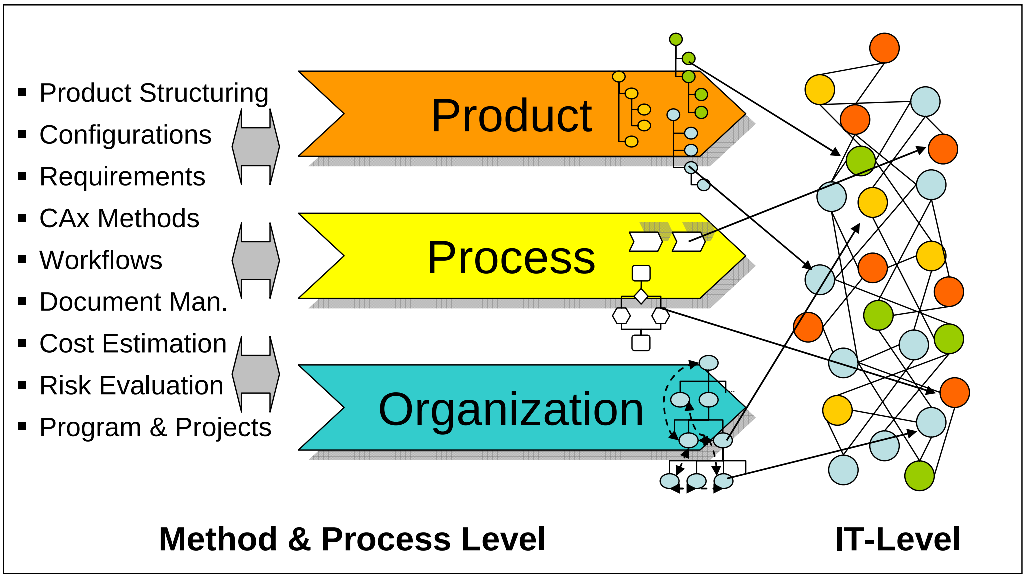

Figure 2: Overview Integration Models within PLM

Communication to be generated between all fields of product development allows a smoother flow of information between the various phases of product development in a more structured manner. This ensures that a product is developed following fully documented state of the art procedures. All of this considerably accelerates development time and ensures that the product satisfies all customer requirements and quality standards.
Stand alone solutions need to be integrated in engineering and management software landscape's. This takes also in consideration that the supply chain network has to be fully integrated in such activities (depending on the level of involvement in the product development activities).

Three integration models which supplement each other were developed and are subject of discussion. They represent the described integration approaches as a widening of today's PLM scope. An overview of the specific models is shown in Figure 2.
Some of the integration aspects are not new in terms of science and industry, however the method of integrating such aspects on a semantic level that is out of scope of today's solution is in the foreground of this research. Such a semantic integration includes pre-defined, flexible and open structuring concepts based on experience, rules etc. defined in appropriate domain ontologies.

This chapter describes the methodical approach of the different integration models. Here the focus is on process integration. Product and organizational integration aspects are only summarized within the scope of this paper (for more detailed information see [3] [4] [5]). Chapter 5 focuses on the semantics introduced and realized within the IT aspects.

3.1 Product Integration Model

Within the product integration model aspects related to product structuring, configuration management, requirements and functional modeling as well as CAx integration is discussed.
The methodical approach is to cross link different structures used within the development process. Depending on in what phase of the product creation process we are, according structures are in use. In early phases when product properties are generated usually requirements and functional structures are used. Including the product structure in these phases is often based on generic product structures which can have different occurrences (e.g. functional, modularized etc.) depending on business domain, experience etc. [6].
Further on in the development process product properties get more detailed, functions get broken down into systems and sub-systems including detailed generation of product data (usually in form of CAx data). All structures are undergoing a constant process of improvement. Different views on the product and according structures are in use. Examples of such structures are design, simulation, testing or manufacturing structures. For more details how to derive such structures out of a semantic net of PLM objects see [4].

3.2 Process Integration Model

The approach for process integration differs in the process origin. Basically two different process aspects are taken into consideration – *core* and *support processes*. Core processes are value adding processes in various phases along the product creation process. Examples are design, simulation or manufacturing processes. They are within the core competence of an enterprise and therefore the key to successful product development.
Support processes are essential for reaching the goal of successful and efficient product development. They are the binding factor between different core processes and organizational aspects, along the supply chain network as well as across the product lifecycle.
Processes are not equal to workflows. The similarity of a process and a workflow is that both describe repeating activities. The major difference between processes and workflows however lies in the different application level. A workflow is usually on a detailed task level whereas processes are kept on a highly generic level of detail.

Within this paper process and workflow integration is discussed in more details. Aspects how to integrate processes within the proposed IT concept is here in the foreground of discussions. Therefore mathematical concepts have been studied in detail in order to find similarities that could potentially be used with the scope of future PLM systems. A method found capable of handing such demanded needs was found in graph theory, especially metagraphs.

3.2.1 Metagraphs and Workflow Analysis

Graphs play an important role in the design of many information processing systems. In its simplest form, a graph is an ordered pair $G = < V,E >$ consisting of a set V of vertices (nodes) and a set E of edges (links). The elements of E are pairs of vertices, which are either all unordered, when G is a simple graph, or ordered, when G a directed graph. There are several diagrammatic system design tools whose construction is based on the graph concept, such as e.g. functional dependency diagrams, data flow diagrams, petri nets, semantic nets, etc. Most of the above mentioned tools are representational, not analytical.
One of our goals is to enhance the data model introduced in chapter 5.1 to an analytical level in order to improve the machine processibility.

Another disadvantage of the above mentioned graphical structures is that they usually associate individual elements, while in many applications it is necessary to associate sets of elements, e.g. multiple attributes in data relations, multiple variables in decision models, multiple documents in workflow systems, etc. Hypergraphs are a generalization of graphs, where each edge comprises two or more vertices. A further step in the development of graph theoretic structures is reached by metagraphs.

Metagraphs generalize on one hand directed graphs (by allowing vertices to consist of more than one element) and on the other hand hypergraphs (by the directionality of edges). They are structures that represent directed relationships between sets of elements and are more “natural” as models for modern information systems than the graph theoretic structures mentioned above. A metagraph is an ordered pair $S =< X,E >$ consisting of a generating set $X = \{x_1, . . . ,x_n\}$ and the set of edges $E = \{e_1, . . ., e_m\}$. The generating set contains all elements in the metagraph, while the edges represent directed relationships between sets of elements. In metagraphs, vertices may contain one or more elements of the generating set.
There are algorithms that deal with metagraphs which are suitable for different applications such as workflow management. It is important that, by using matrices, one can work with metagraphs algebraically, not just graphically. This is essential for the applications and makes the metagraphs “nice to handle”. For more detailed information on metagraphs see [7].
Figure 3 illustrates a simple example of a metagraph with 9 generating elements and 5 edges.

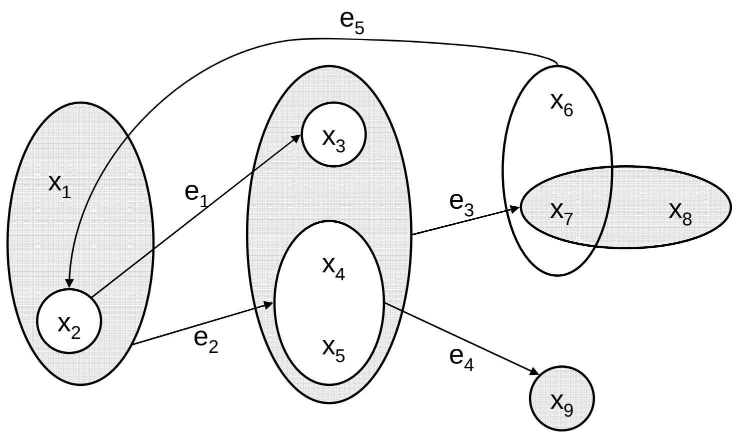

Figure 3: A simple Metagraph Example

In the context of this paper nodes may represent PLM objects or sets of PLM objects. Edges represent the corresponding dependencies between these objects.

Processes and their associated workflows can be modeled in different ways, based on different tools. There are four perspectives commonly used in process representation. *Informational modeling* focuses on the structure and interactions of the informational entities involved in the process. *Functional modeling* focuses on the tasks performed in the process and the informational entities involved in these tasks. *Organizational modeling* focuses on which agents/resources are involved in each task, where information entities are stored and what communication is needed between agents/resources. *Transactional modeling* analyzes issues of timing and control, within and between tasks involved in the process. For more details on those aspects see [7] [8] [9]. As a process is composed of a set of tasks that connect a source set of information elements to a target set of information elements, each workflow can be represented by a metapath from the underlying process source to its target.

For a given source and target, a metagraph can be used to identify the possible workflows for the process with the help of algorithms. Thus, a metapath search can help to determine whether a process is functionally complete or not. Moreover, if there is more than one workflow possible for a given source and a given target, then the concept of dominant metapath can be applied. On one hand to facilitate the choice among them and on the other hand to determine whether a chosen workflow is efficient or whether alternative workflows may be preferred.

The same concepts and operations can be used regardless of which aspects of workflow systems are analyzed. The metagraph approach has the advantage that it uses a single representational construct, which can also be used for traditional system modeling of system components such as data, models and rules [10]. Moreover, the correspondence between the visualization and the algebraic capabilities of metagraphs give the possibility to use algebraic operators not only in order to supplement or even to substitute visualization, but also to form a foundation for the construction of computer-based tools that support workflow management in controlling PLM platform business logic. Through that a direct relation between PLM objects and workflow systems can be established.

3.3 Organizational Integration

The organizational aspect of integration is mainly related to issues of program and project management. A project in this context is a snapshot of neutral objects (e.g. structures related to the product integration model and/or process templates related to process integration model) “filled” with specific data and information. This put’s organizational integration aspects into an important position. The main aspects here are also depending on where one stands in the development lifecycle. In early stages, such as feasibility or offering, the challenge lies in the estimation of development effort – essentially costs [11]. Question if compromising on functionality or quality is here in the foreground of discussion. None of them are usually popular to renounce. In later stages aspects e.g. product maturity monitoring (quality issues), cost tracking or risk estimation and the compliance of deadlines are in the foreground.

The integration of project management, realized as an engineering management cockpit, where all important and relevant product and process data and information are available is within the scope of this research. Methods how to semi-automatically generate project and resource plans based on requirements specification documents have been developed and described [5]. A solution seen in order to use all cross linked information again lies in a semantic net of PLM objects mentioned earlier. The related IT concept is described in following chapters. The challenge however is to include the supply chain network in an appropriate manner. From the IT point of view that seems to be realized much easier then from organization aspects. The organizational aspect includes the development of collaborative reference processes (as approached by ProStep iViP - CPM Group [12]) and information exchange scenarios.

4 Generic Concept for a PLM Framework

In order to offer the necessary flexibility to integrate the before discussed issues in an efficient and effective manner, future PLM systems need to have generic PLM integration hubs with embedded and predefined neutral process and product models. They will support cross domain, cross lifecycle and cross enterprise integration. Product & process diversity is essential to such generic models and will be embedded in a business logic layer. Such business layers include semantic knowledge of e.g. a domain, a product or other aspects of an enterprise. However adoptions to those models are indispensable. This additional semantic layer will enrich PLM integration hubs in order to reinitialize product, process and organizational know-how. Agents will support the learning process by processing rules and automatically notify foreseen conflicts arising though data and object changes though the entire lifecycle.

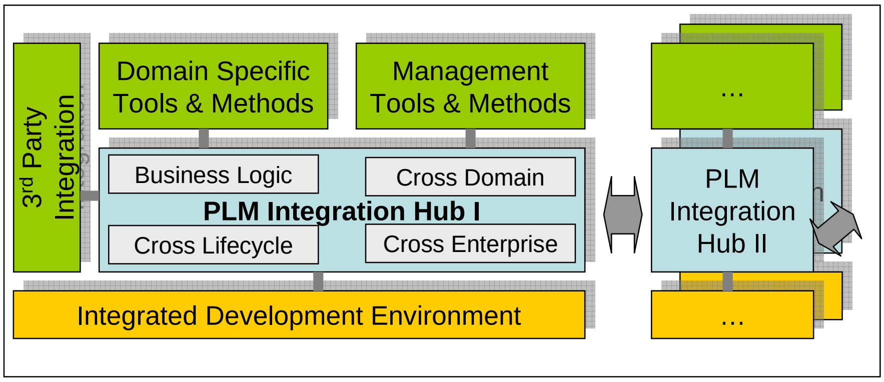

Figure 4: Future PLM Architecture

From the methodical and tool point of view, the need is to offer frameworks in domain specific areas as well as management cockpits as basis for decision support and optimization. 3rd party solutions will be capable of "plug & play" integration (see Figure 4). Administration and IT effort on the other side will be reduced to a minimum.
In order to handle the increasing amount of data and interdependencies scalability is an important issue. Scalability is seen to be offered to add different locations along the supply chain network as well as quantitative measures to counteract to the flood of data and information.

Communication will be based on implemented reference processes through the PLM integration hub. Since very specific solution will always be needed, a PLM integrated development environment (PLM-IDE) as a basis for customization (in form of configuration) of existing solution will be established. The development of individual and specific solution will then be automatically embedded into the PLM framework and help to establish a holistic PLM approach.

5 Core IT Aspects for Future PLM

Designing an IT infrastructure to fulfill the mentioned tasks, the challenges to be solved can be structured as following:

- Integration of heterogeneous applications
- Definition of a common data model
- Geographic and quantitative scalability

For the integration of applications it is essential to find suitable interface technologies. The use of established IT standards (like the ones from W3C[1]) is strongly recommended. This increases the probability to support existing applications, interface standards as well as the adoption of new applications with minimum effort. To reduce the overhead and allow the optimal re-usage of IT components, the overall functionality is separated in single components called services. For a specific task, these services are combined through the

[1] World Wide Web Consortium, http://www.w3.org/

appropriate process. This allows the flexible adaptation of the IT infrastructure to new business models, products and changes in the organization.

The direct linkage of applications within integration hubs is established via a bus architecture realized through an *Enterprise Service Bus (ESB)*, which manages the data exchange between the applications and handles necessary transformations. This approach reduces the communication overhead and guarantees maximum flexibility e.g. for a step by step rollout of the platform.

5.1 Flexible and Extendable Data Model

The main focus of a common data model is the management of PLM objects. Taking a view on the layer scheme in Figure 5, these objects are located in the *Semantic Integration Layer*. There, PLM objects are assigned as nodes and have according links forming the common data structure of the integration platform.
System wide services offered by the integration platform (e.g. workflow processing engine) include meta-models defining relations on domain level (such as e.g. development requirements). These services are located in the *Engineering & Business Services* layer and handle issues like “who is able to do what?” (offering a service registry), “what has been managed properly?” (by status- and event monitoring) and “who is allowed to do what” (managing safety, access and security).

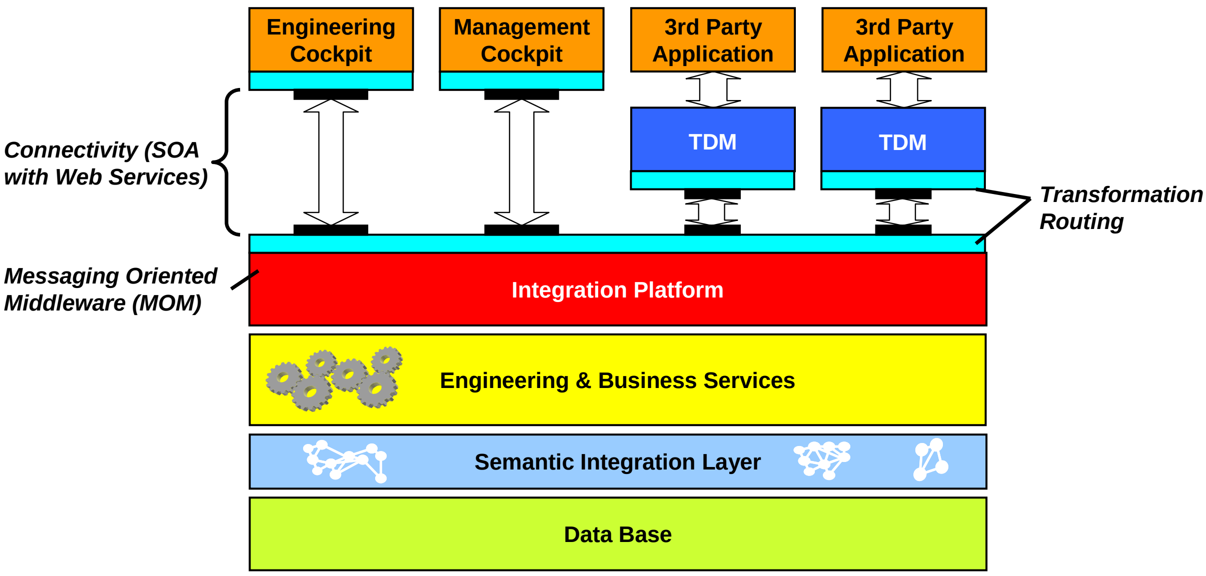

Figure 5: Scheme for a Common Data Model

In the first step, the data structure was optimized for integration aspects, allowing to bring together data of different disciplines. In the second step, this network got semantically and analytically enriched. This is done by the use of concepts from semantic web technologies (e.g. RDF and OWL) [13] and mathematical concepts like metagraphs (as described in chapter 3.2). The goal is to form a knowledge structure through the enterprise which allows the extraction and project independent management of the engineering and business know-how. The abstracted order scheme of this data structure is defined by an ontology. Rules are represented partly by the structure of the ontology itself with extension through explicit rules transparently stored in the data web. This data structure allows different views on the evolving product data, e.g. deriving views for design, simulation and test.

5.2 Server and Client Architecture of PLM Framework

To fulfill the requirements mentioned in chapter 5, a *Service Oriented Architecture (SOA)* has been established using an *Enterprise Service Bus (ESB)* as central communication infrastructure for the transportation of middleware messages. This is seen as today's most promising IT approach to realize future oriented PLM integration approaches and platforms.

The idea of SOA is a technical approach, where functions of software modules are organized as services. SOA defines the interfaces, where other systems use services via the network. Services as independent, loosely coupled units can be realized in different programming languages and on different system platform. Most oft the time they are build as "Web Services" with the "Web Service Protocol Stack" using XML, HTTP, SOAP[2], WSDL[3] and UDDI[4]. [14]

The ESB is designed to fulfill the requirements of integration, communication and transformation. As there is no standard what an Enterprise Service Bus is, we define an ESB in this content as:

- The connection part within the integration platform by establishing business process integration. It is the infrastructure for communication between service provider and service consumer.
- The technical interface for all internal and external applications along the business processes. It handles the transformation of data-formats and unifies the interface specification.

The central technical attributes of an ESB (see also Figure 5) defined by e.g. the Gartner Group [15] can be seen as:

- Communication via Messaging-Oriented Middleware (MOM)
- Connectivity to internal and external applications based on web services
- Transformation and routing for realizing XML- and SOAP-messages

Complex integration of 3rd party originating applications may require different levels of integration approaches. The level of integration can vary from *light* to *total*.

- Light means unique references to the external data without the possibility of change tracking
- Medium integration through wrappers. Here the persistent data is hold in external applications, but metadata and links to other disciplines are managed by the integration platform
- Total integration means that all persistent data and meta data is held in the integration platform databases and file vaults

Within the architecture, data sources are mapped to a common semantic model that offers a scalable and maintainable way to manage and integrate enterprise data. The screenshot in Figure 6 shows the software user interface of the semantic view from the developed PLM platform with a part of the underlying data model on the right side. There are nodes and groups of nodes from different domains that are linked through specific typed links. Through that concept relations between PLM objects can be identified and handled.

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[2] SOAP = Simple Object Access Protocol
[3] WSDL = Web Services Description Language
[4] UDDI = Universal Description, Discovery and Integration

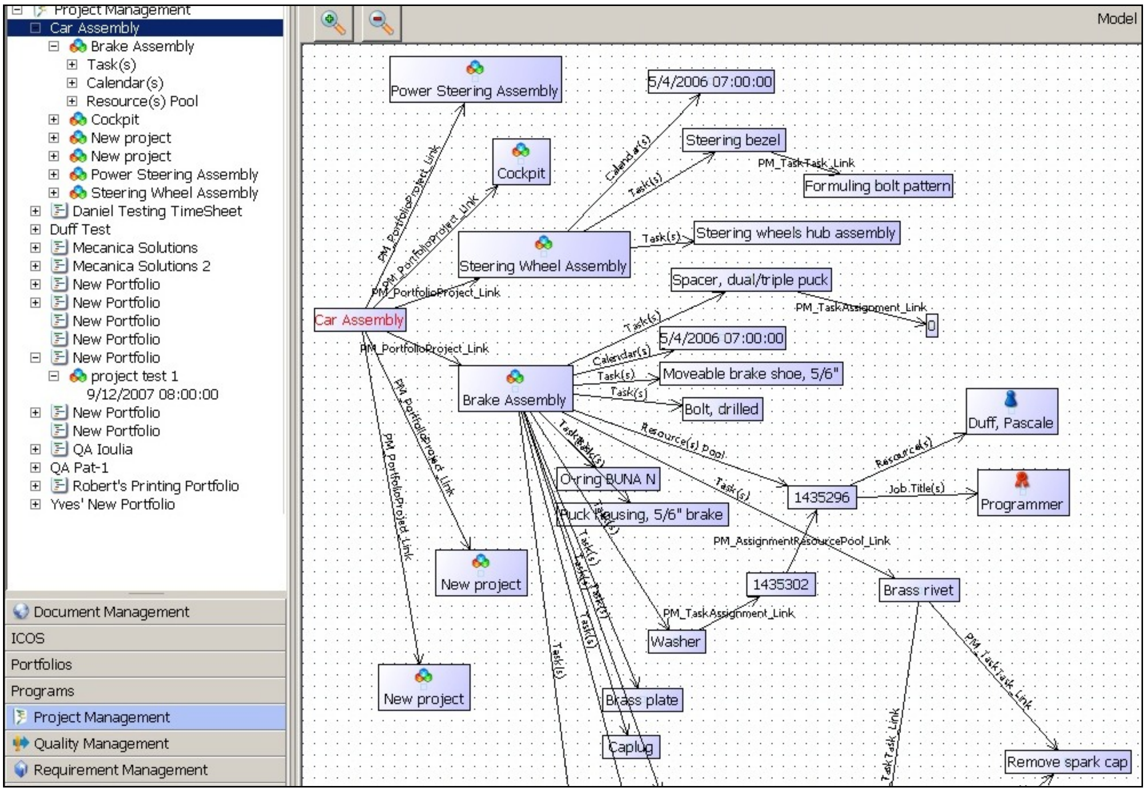

Figure 6: Screenshot of the User Interface with Corresponding Data Model

The use of semantic web technologies in the area of the enterprise application integration improves the flexibility by getting business logic separated from specific applications and moves into the semantic integration platform. This targets the improved use of existing information sources and the building of new know how by making it machine readable, as by the use of current systems most of the intelligence is in the hand of the user.

6 Summary and Outlook

This paper summarizes PLM related research results with specific focus on how to integrate knowledge, data and processes with a semantic approach. By describing how PLM evolved and what today's limitations are, it was discussed how new integration aspects that are out of scope of today's PLM systems can support development activities. The described holistic integration approach combines a methodical, process and IT based approach into one consistent integration strategy. This is done by cross-linking PLM objects within the IT concept and to enrich it with mathematical aspects to lift it from a representational to an analytic level. On the methodical point of view it was briefly described how to integrate e.g. product structuring or project management in the organizational level.

Focus, however was on process integration based on integrating metagraphs realized through enhanced capabilities of workflow management systems. Furthermore it was described how future PLM solutions may look and how the related data models need to offer necessary flexibility. Finally an IT architecture based on a realized PLM platform that fulfills such demands was described. Semantic enrichment was identified as a major issue.

Hence future activities are seen in completing semantic enrichment in form of integrated compilation of ontology's within the framework. Such ontology's are capable of handling complexity by processing interdependencies, constraints and rules. This is also a further step towards a holistic knowledge based management approach throughout the entire extended enterprise as well as the involved supply chain network.

7 Acknowledgements

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