Metadata Reference Model for IPS^2 Lifecycle Management

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Abstract
Metadata models are the nucleus of product data and lifecycle management. Current PLM solutions offer generic metadata models for physical products and consider only the product provider's requirements. They are not sufficient to meet the new requirements and have to be extended in order to provide support for industrial product-service system (IPS²).
Based on use case analyses, expert interviews and interviews with participants of the research project the different requirements of IPS^2 providers and customers are identified and a proposal for a metadata reference model for IPS^2 lifecycle management is introduced. This metadata model provides the foundation not only for basic PLM methods but also for advanced IPS^2 management methods like IPS^2 change management, IPS^2 customer feedback management and IPS^2 executive information management. The IPS² metadata reference model could be the basis for further standardisation activities.

Keywords:
IPS^2, Lifecycle Management, Metadata Reference Model

1 INTRODUCTION

Over the last decade PLM has become the central management approach in engineering. PLM is an integrated approach including a consistent set of models, methods and IT-tools for managing product data, engineering processes and supplications along the product lifecycle [1]. The nucleus of current PLM solutions is the so called metadata model. Metadata models are semantic and conceptual information models which describe the main product related object classes used by all the actors and applications along the product lifecycle. In addition PLM metadata models describe the main properties of the object classes as well as their relationships.

PLM metadata models could be seen as a directory of integrated engineering processes and serve as a basis for

- ensuring data consistency between the involved applications and partcipants,
- providing a trans-sectoral data search and access,
- recording the history (e.g. change history) of the managed product data along the lifecycle,
- representing links between models in different application systems.

PLM metadata models are always context-specific and have to be developed for a specific company or application area, before introducing a PLM solution.

In order to minimise the effort for the development of context-specific PLM metadata models and to guarantee the data capability and interoperability of collaborating partners using different PLM environments, a reference PDM/PLM metadata model has been developed from a standard proposal (STEP PDM). This metadata model serves as a reference for the development of current PLM solutions as well as for the exchange of data between different PLM environments.

The STEP PDM (**St**andard for the **E**xchange of **P**roduct model data **P**roduct **D**ata **M**anagement) metadata reference model considers the object classes physical product, related documents, engineering processes of the manufacturer as well as users and user roles. The semantic and knowledge contents of STEP PDM metadata reference models are very poor but sufficient for the current generation of PDM/PLM solutions. In the future, reference domain and product-specific ontologies could contribute to a higher level semantic standardisation and improve the efficiency of PLM solutions. The relationships between application-specific data models and metadata models, between reference context-specific and domain-specific ontology models are summarised in figure 1.

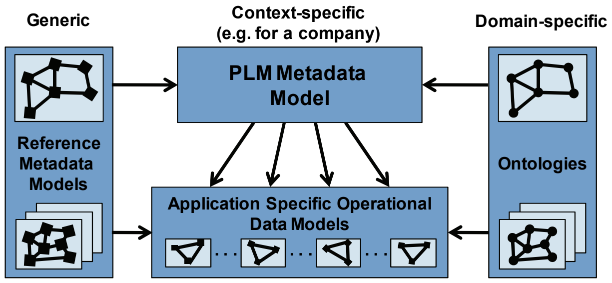

Figure 1: Relationship between generic, context-specific and domain-specific models

Within the interdisciplinary research project "Engineering of industrial product-service systems (IPS²)", nine German research institutes develop new methods and IT-tools for the engineering of future IPS². As the level of complexity of PSS data and processes is much higher as that of physical products an integrated management approach as well as powerful methods and tools for the IPS² lifecycle management (IPS² LM) are mandatory for a successful IPS² implementation.

As current PLM solutions do not meet the IPS² lifecycle requirements a new IPS² lifecycle management solution is developed within the above described project. The prerequisite for this solution is a reference metadata model for the IPS² LM. For this, the current STEP PDM reference metadata model has been extended to IPS² and to the new IPS² LM methods. The following solution describes the requirements and the proposal of the new metadata reference model.

2 REQUIREMENTS OF IPS² METADATA MODELS

For the identification of IPS² metadata model requirements use case analyses, expert interviews and interviews with participants of the described research project were conducted.

The metadata model has to integrate various operative models from the different groups of participants from provider as well as from customer side involved in the IPS² lifecycle. The metadata model should be able to manage filtered information from different operative data sources along the whole lifecycle of an IPS² (see Fig. 2).

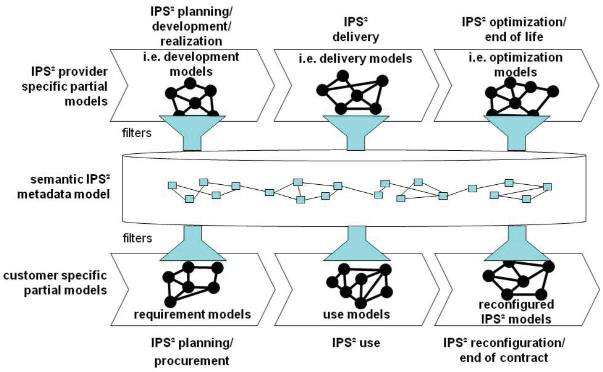

Figure 2: Information sources for IPS² LM metadata model

The new IPS² metadata reference model has to cover all the needs of the future LM solutions and to mirror all the types of future IPS². The main development dimensions of a future IPS² lifecycle management are (see Fig. 3):

- the management of new object types like services or IPS², considering product embedded information devices (like RFID tags, sensors, etc.)
- the coverage of all the lifecycle processes with the focus on the IPS² use phase
- the involvement of new user types with emphasis on customers
- the support of new process types like executive decision processes

The resulting requirements from these IPS² development directions are described in detail in the next sections.

2.1 Management of new object types

The IPS^2 provider or provider network has to be guaranteed that it can manage independent products and services as well as integrated product and service packages by the IPS² lifecycle system. In contrast to existing PLM solutions, this system has to manage individual customer-specific IPS^2 items which can change during the provision/use phase of an IPS^2 [2]. It is important to consider the fact that traditional PLM-systems only control data about product types since they focus on the product development phase. With the integration of the use phase it is necessary to consider individual product items. So far, the development and delivery of products and services has taken place in separate value-added processes. Here, the IPS^2 provider has to be given the opportunity to dynamically manage integrated overall solutions in the form of an IPS^2.

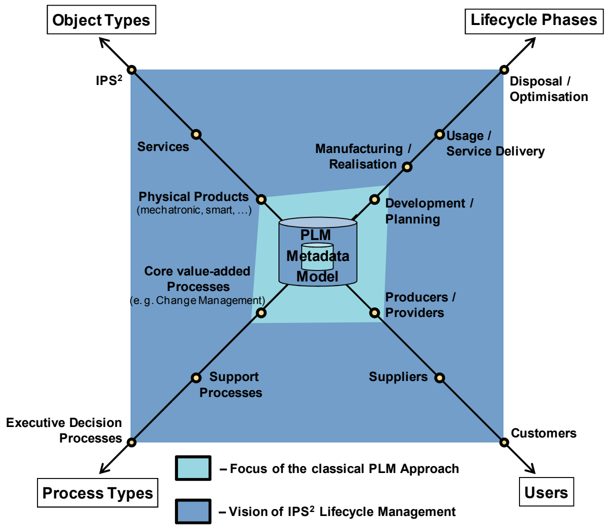

Figure 3: Multi dimensional extension of the IPS² LM

IPS² are characterised by a systematic combination and a corresponding synchronisation of the individual components, depending on customer requirements. IPS² can be classified by means of the business models function-oriented, availability-oriented and result-oriented [3] and the different characteristics like individuality, connectivity, complexity. The combine components cannot be considered individually due to the interdependency of the product share and the product-related services. Usually, a product share can be offered discretely without the product-related services. However, this turns out to be very difficult with regard to a product-related service, if no product is available.

Requirements for the extended metadata model are:

- management of independent product and service components
- management of integrated product and service packages (IPS²)
- management of dynamic relations between product and service components

2.2 Support of the whole IPS² lifecycle

Requirements Management

During the analysis, requirements of customers and providers are gathered which are to be taken into account for the later realization of the IPS^2 product [4]. Here, customer surveys, feedback analyses and lead user concepts, for instance, are used in order to determine customer requirements, satisfaction and preferences.

This method allows the IPS^2 provider to react to changes of requirement definitions in the most flexible way as these can have a significant impact on the planned concept, the feasibility and the costs of the whole IPS^2 [5]. Furthermore, the IPS^2 customer has to be provided with the opportunity to dynamically adapt or change the demands made on the IPS^2 item while using the product. Hence, the customer can react as flexibly as possible to potential changes in the work environment.

Functional description of processes and components

In order to support the approach of heterogeneous IPS^2 concept modeling [6] the IPS^2 metadata model should be able to link functional descriptions to all managed product and service components or component assemblies.

Resource management for IPS² items

Interfaces for managing necessary resources (employees, workplaces, machines) and their calendar of capacity and individual planning are to be integrated. Moreover, the qualification of employees can be saved for optimal resource planning. Therefore, it is possible to organise the resources necessary for the product and service shares of an IPS^2 product in a skill-based way (skill management) and to adjust them dynamically to the surrounding conditions [7]. Employees, physical spares as well as the tools required for carrying out service processes, for instance, count as resources.

Requirements for the extended metadata model are:

- management of dynamic requirements related to product and service components
- mapping functional descriptions to components or modules
- management of necessary resources related to a specific product or service

2.3 Supported process types

Due to the high complexity of IPS², future LM solutions have to cover not only value-added management processes but also management support processes like quality management, technical documentation, customer feedback management and executive decision processes.

Customer feedback-management

The extended IPS² lifecycle management includes product-related knowledge management. IPS^2 providers can only overcome the obstacles of shortened cycles of innovation and dynamically changing customer requirements, if they become aware of the importance of knowledge as a resource and strategically implement it [8]. The IPS^2 provider has to be enabled to generate and save the knowledge gained in any form. This includes customer information, generated through the IPS^2 customer feedback management [9], as well as the automatically created product use information [10] of the IPS^2 product.

On the one hand, the customer feedback management enables the customer to incorporate requirements and ideas for improvement directly into the product development by evaluation of the future product. Real-time gaining customer-specific demands and wishes parallel to product development processes ensures that customer needs are up-to-date [9]. On the other hand, the customer can incorporate his product experience as well as advantages and disadvantages of the product directly into the PLM system during the product's use phase. Additionally, usage information by the customers (e.g. complaints or queries) are indirectly extracted from the service and after sales domain of the IPS^2 provider and led back to the product development [9]. The totality of all objectively measurable information, which arises during the use phase of the IPS^2 product, counts as automatically generated product usage information. This could be, for instance, sensor data, environment parameters, maintenance information or recorded error lists. The statistical analysis of the saved product usage information should enable the thereby generated and condensed knowledge to be used for the development and conceptual design of new IPS^2 products. In addition to this, the data of the environmental IPS^2 usage conditions of potential product failures and of different usage profiles could be generated on the basis of the saved knowledge and used in the conceptual design phase of further IPS^2 products.

Integration of business performance indicators

For a successful conception and development of IPS^2 products it is necessary to link PDM data and the corresponding economic information, like costs, values and energy efficiency data already at an early stage [7]. From the point of view of the IPS^2 provider this means that, for instance, a prognosis based on a simulation of the economic consequences in case of variation of the offered product and service combinations should be supported [11]. However, it is important for the IPS^2 customer to have the costs related to the purchase of a certain IPS^2 product, in terms of an automatic total cost of ownership calculation [11]. This means, it is necessary to assign certain costs and values to individual product and service objects.

Requirements for the extended metadata model are:

- management of customer initiated feedback information
- management of product use information
- management of business performance indicators
- simulation of economic consequences

3 PROPOSAL FOR A METADATA REFERENCE MODEL FOR IPS^2 LIFECYCLE MANAGEMENT

Based on the analysis of the requirements of IPS^2 providers and customers and the different types of IPS², a proposal for a reference metadata model for the lifecycle management of IPS^2 was developed.

The proposed metadata model was developed based on the UML (Unified Modelling Language) object-oriented notation. In the course of the development parts of the STEP reference model "AP 214" [12] were taken into account and product-specific elements have been adapted. Figure 4 shows the top level class structure of the developed IPS² metadata reference model, which is an extract of the complete reference model. In order to make the diagram more clear to the reader obvious classes for data management (Document, File, etc.) and finer granulations of each main class have been omitted.

Each IPS^2 represented by the main class *IPS_System* consists of several *IPS^2_Modules*, which are in turn composed of different *IPS^2_Elements*. *IPS^2_Elements* may be *Services* or *Products*. In this context *IPS^2_Element* is an abstract class, which is never instantiated. The class was only introduced in order to reduce the number of associations needed in the class diagram.

The class *Product* models the physical aspects of an IPS². A product class is a core element in every traditional PDM/PLM-System. It represents physical components, software and via the aggregation of these elements their specific product structure.

The class *Service* models services like planning, maintenance, implementation etc. Figure 5 shows exemplary a finer granulation of the top level class *Service*. In order to decrease the complexity of the shown IPS² metadata reference model the finer granulations of the other top level classes are omitted. The subdivision of the class *Service* is based on the classification in [13]. These services are like products part of the comprehensive IPS^2 the IPS^2 provider sells to the customer.

In general, *Services* need human resources, operational equipment, spare parts and tools in order to be provided. These elements are summarised in the class *Resource* on the top level of the metadata model.

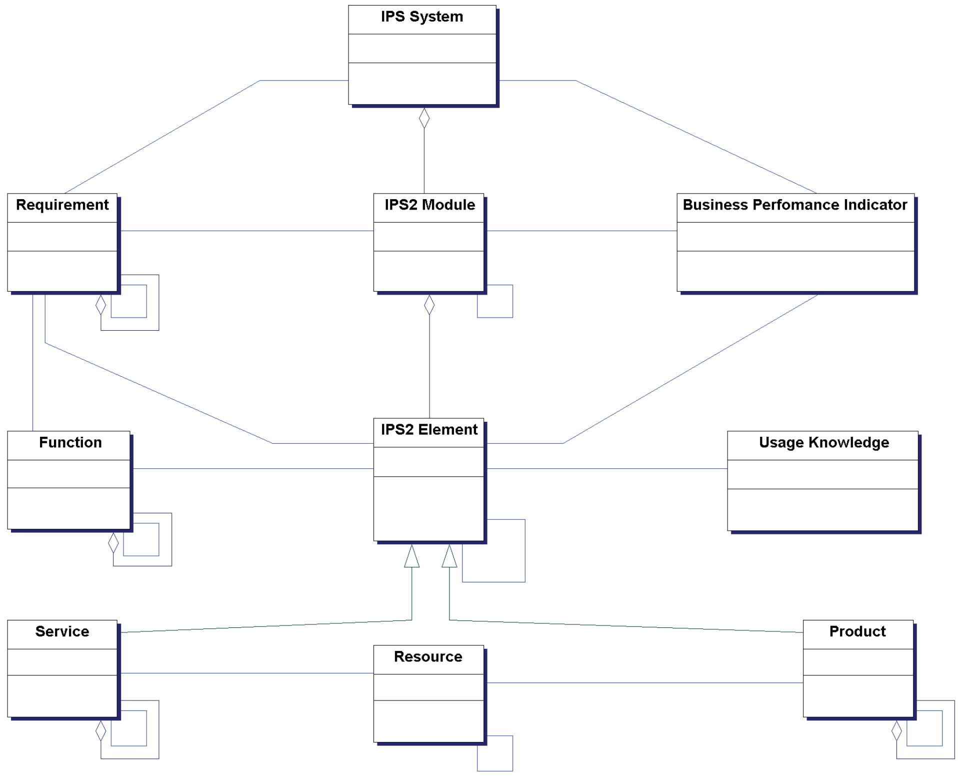

Figure 4: Top level of the proposed reference metadata model for IPS^2 lifecycle management

Additionally, *Usage_Knowledge*, *Business_Performance_indicators*, *Function* and *Requirement* may be associated to individual *Services* and *Products*.

Usage_Knowledge comprises active feedback which is customer initiated and passive feedback consisting of product use information gained in the IPS^2 use phase. Examples for product use information are sensor data, environment parameters, maintenance events and failures. Knowledge discovery methods support the extraction of implicit knowledge from product use information. This knowledge is also referenced via the class *Usage_Knowledge* and may be used to derive needed modifications for both existing IPS^2 and requirements for the development of new IPS^2.

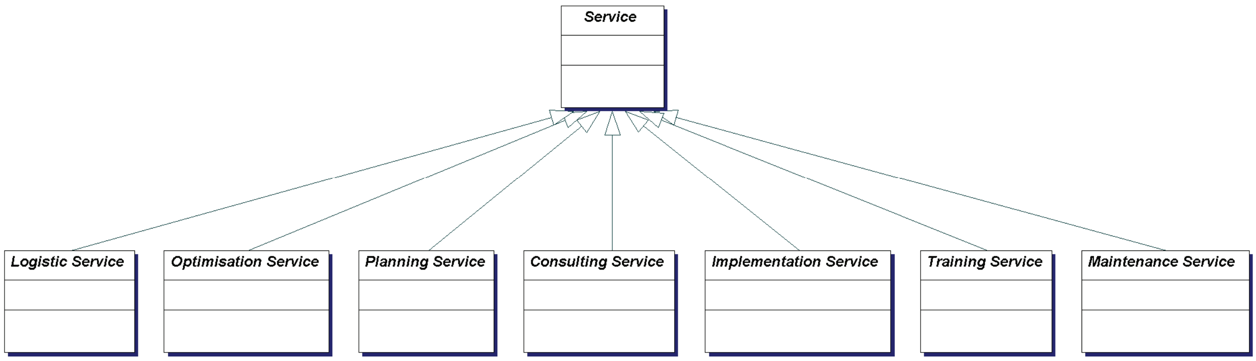

Figure 5: Finer granulation of services

Requirements (for example as a result of analysing usage knowledge) may be attached directly to the whole *IPS_System*, to an *IPS^2_Module* or to a single *IPS2_Element* (*Product* or *Service*). The different associated requirements may depend on each other or even conflict each other, which is underlined by the self-association. The initial requirements may change during the IPS² lifecycle (e.g. use-phase) and have to be updated in order to satisfy the customer's demands. In this context, the omitted super-class *PLM_Item* bundles and provides fundamental attributes in order to manage the dynamic of requirement engineering resulting from changing and new upcoming requirements.

The class *Function* represents functions or functional behaviours like the inspection of a component XY which may be implemented via a sensor (an instance of the class *Product*) or a human who inspects the component manually. In the last case, the *Resource* "human" is associated with a *Service* "manual inspection of component XY" which is in turn associated with the *Function* "inspection of component XY".

To support the IPS² engineering process it is important to cover each specific requirement with a set of functions which is realised with certain *IPS²_Elements*. This reflects the capability of substitution of products and services. A specific function may be realised by a physical product or a service. Therefore relations between the classes *Requirement*, *Function* and *IPS²_Element* have been set up.

Additionally business performance indicators like costs, values and energy efficiency factors can be associated by the subclasses of *Business_Performance_Indicators* to each product or service via the inheritance association to *IPS^2_Element*. Of course, individual costs may be aggregated in order to determine the total costs for an *IPS²_Module* or a complete IPS². In this context, the IPS² metadata reference model offers support for the different types of IPS² business models. In the case of a function-oriented IPS² only physical product structures are instantiated. Obviously an availability-oriented IPS² consisting of IPS²-modules which comprises certain product and service components may also be represented by instantiating the appropriate classes.

4 OUTLOOK

The presented IPS^2 metadata reference model within the research project TransRegio29 (TR29) has been designed in close collaboration with the project partners who develop operative IPS^2-methods and tools.

On the basis of the use cases, the IPS² metadata reference model has been validated according to its applicability. The investigations have shown that all domains of the individual use cases could be represented. The metadata model can therefore be considered to be coherent and hence be used.

The proposed IPS² metadata reference model could be the basis for the future standardisation of future PLM metadata models. In the scope of further research activities, the expansion of the existing PLM approach by the development of new concepts and methods in the field of intelligent change management, customer feedback management as well as executive information management is carried out. In addition, the development of a top level ontology is necessary in order to create a semantic level for the description of the data. This level, with the help of semantic relations, will allow the intelligent data administration of the gathered information along the whole product lifecycle. The proposed IPS² metadata reference model will be reviewed and refined by the involved research partners.

5 ACKNOWLEDGEMENTS

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