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DYNAMIC LINKING AND RETRIEVAL OF PRODUCT MODELS TO PRODUCT DEVELOPMENT PROCESSES

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ABSTRACT
In product development processes, the retrieval of the right product information at the right time is an important factor to maintain efficient and effective processes. Existing approaches use e.g. software support like workflow and process management systems, where information in general is rigidly linked to the predefined processes. However, product development processes are characterized by iterations and dynamic sequences of process steps, which cannot be defined in advance of the actual happening of a process step. This leads to slowed down processes and even misinformation of the engineers. Under this circumstance, this paper introduces a novel approach to link product models to development processes dynamically. This approach follows the objective to provide users with most useful product information semi automatically, even if the process plan of the project has to be changed unpredictably. After the analysis of information retrieval in the industrial context, the development of a parameter based description method for product models is explained including a correlation analysis of the parameters. Finally, the prototypic software implementation of the approach is presented.

Keywords: semi automatic information retrieval, flexible workflow, dynamic processes, information linking, product model description, parameter based linking

1. INTRODUCTION
Product development processes grow in complexity and therefore are more and more difficult to manage. In these complex processes, especially the information retrieval plays a decisive role for the efficient and effective process execution. Since engineers have to cope with information overload and search for important information, they spend a lot of time to provide themselves with the required information [1]. Current support for engineers is realized by process or workflow management systems which model processes and corresponding information. However, they are only capable of modeling administrative processes, since these are highly repetitive and can be planned in advance [2]. Their support for development processes is limited, because these are iterative and have dynamic sequences which aggravate their modeling before the project starts. In consequence, especially documents containing product information (product models) are not provided sufficiently. Thus, this paper aims at the improvement of product model retrieval by providing dynamic linking of product models and processes. The dynamic linking allows the calculation of missing links of product models to processes caused by unexpected processes and even adapts to changed process situations. The solution approach is a parameter based description method of product models which is based on the principle of a vector space model [3]. By applying this principle known from the domain of information technology, product models can be linked to processes by calculating their distance to each other. The new description method uses a set of parameters which is used to place the product models and process steps into the same vector space. Thereby, the parameters and their values are to be understood as coordinates of the vector space.
This paper reports about the development of this description method. It starts with a screening of the initial situation of current product model retrieval (chapter 2), and derives objectives to be followed (chapter 3). It continues with the outlining of the method and the proceeding of its development (chapter 4 and 5). After the definition of the parameter set including a correlation analysis, the calibration of the parameter set and orientating evaluation is performed. Afterwards a prototypic software tool is implemented to build the basis for later evaluation of the approach in real product

development processes which is described in chapter 6. Finally, a conclusion and outlook are presented.

2. PRODUCT MODEL RETRIEVAL: INITIAL SITUATION

The initial situation of current product model retrieval in the industry is formed by many IT-tools which help to store, manage and retrieve all kinds of data and documents. In this context, product model is the term for documents which contain any kind of product information. Examples for product models are drawings, information about quality, product specifications, sketches, recycling protocols or CAD-data. Introduced IT-tools are well known like e.g. product data management systems (PDM), electronic data management systems (EDM) or product lifecycle management systems (PLM). They are essential to cope with the many data generated during development processes. Since 75% of design activities use already existing information [4] it has to be found on the servers accessed by mentioned IT-tools. Earlier research by Ullmann found out [5], engineers spend 60% of their time to search for information needed for the re-use of designs and to choose the most relevant. Basically, engineers have to obtain supporting information to perform their tasks and therefore, information should be provided effectively (right information) and efficiently (quickly) [6]. This is aggravated by the multiplicity of generated documents which strikes novice designers who cannot rely on their experience. Consequence is their need to use IT-tools and search engines to serve themselves with required information [6].

Though PDM/EDM/PLM and similar systems support the retrieval of product models, they only focus on the storage and management of the documents. Whilst following the product structure, they are not designed to link product models to development processes. Other tools like process management or workflow management systems (WfMS) consider the process view by modeling processes including corresponding documents. They resort to principles of mentioned data management systems as well. Companies use workflow management systems to provide their employees with the right information at the right time and start projects of workflow implementation [7]. However, only administrative processes which are highly repetitive and do not change during execution can be supported by these systems. In contrary, product development processes are iterative, flexible, situation dependent and hardly predictable.

While the information retrieval for administrative processes is well established, also approaches for flexible workflow support are researched [8]. But still, product model retrieval for flexible development processes is still not addressed in current systems. Figure 1 indicates the situation where an unexpected process step is introduced, but no link to product models exists. This is a common problem, because the unexpected process could not be planned in advance and therefore no link between the process and the product model could be defined.

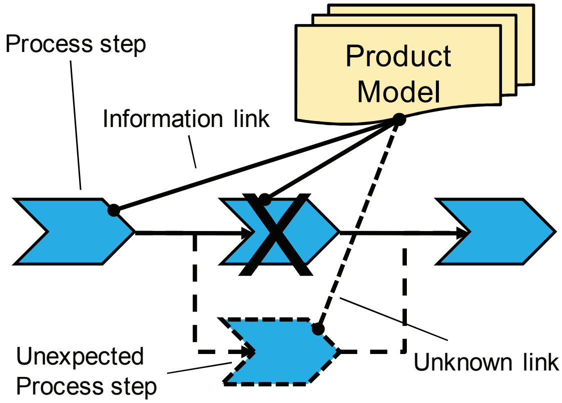

Figure 1. Flexible Workflow without flexible Product model integration

The analysis of a company's information retrieval project revealed (anonymized) a focus on the consistent data management on the one hand, and the definition of workflows derived from a generic process on the other hand. Proactive retrieval of information is implemented in the WfMS. It provides users with organizational or mandatory information and company specific information which is required to reach the next milestone. However, this mandatory information does not include all needed information for the engineer to perform his/her development task. Furthermore, the linking of the development process and corresponding product models is not considered in such a detail that the engineer can receive complementary information automatically. Another analysis is made in a student's racing team which can be compared to a small company, since it has an introduced organizational structure, real financial matters (sponsoring, target costs,…) and a real product (racing car). In this case, similar to the previous study, there are different systems and tools used for the information management such as content management system (CMS), PDM-system, folder based server and a database for documentations other than CAD-documents. The product model retrieval can be regarded as passive, since the users have to search and retrieve the needed product models on their own. They have no recommendations of useful product models for their current task and therefore spend a lot of time searching in the different systems, sometimes not even knowing what to look for exactly.

Companies and researchers work on the development of the improvement of information retrieval and information retrieval in particular. IT-focused approaches deal with the development of declarative modeling of the process to facilitate flexible workflow management systems [2]. But the dynamic retrieval of product models needed for flexible workflow systems has not been considered yet. Though research approaches try to arrange product models and the development process to relate them to each other in a multidimensional space [9,10], they do not follow the objective of information retrieval. They just classify the product models by concretion to arrange them rigidly to an abstract model of the process. Furthermore, the dimensions of the abstract model do not have values to calculate relations between product models and processes.

Also search engines are used to find most relevant information to a given query. Some are based on the vector space model [3] for comparing a query to available information. Such search engines can help to extend already provided information by the workflow management system. However, used systems in product development only handle queries which deal with names of documents, full text search or e.g. functions of components [11]. Additionally, novice engineers do not have the experience to know what they look for and how to start a useful query to find needed information. Though there are mighty search algorithms, they cannot be applied to existing structuring of product models in used IT-systems. Furthermore, it still costs time to perform the search itself in comparison to just getting it automatically, especially with relevance to the current process step.

3. OBJECTIVES

As described in the previous section, the retrieval of product models is essential for efficient and effective process execution. Since existing systems lack the support of especially product model retrieval for flexible process steps, there is a need for the improvement of the linkage of product models to a development process. Hence, the objective of this paper is to develop a parameter based product model description method which allows dynamic linking to process steps. This method shall provide the engineer with most appropriate product models for his/her current task or process step and decrease time spent on searching for useful product models. This means, even flexible and hardly predictable processes as product development processes can be connected to relevant product models which help the engineer to fulfill his/her task and proceed faster in the process. It has to be considered, that the parameters of the description method have to be intuitively understandable by the users to allow appropriate application of the method. Furthermore, it is the objective to implement a software tool supporting the application of the method for evaluation purposes in real development processes. The tool should offer functionalities to describe product models as well as process steps by given predefined parameters and has to display the results (relevant product models) of the automatic linking algorithm to the user.

4. SOLUTION APPROACH

As mentioned, dynamic processes change their sequence during execution. Since this unforeseen change cannot be considered before the start of the process, required information cannot be linked using today's retrieval methods. Therefore, this paper proposes a method allows adaptation of the links to changed conditions automatically. The dynamic linking can be achieved by the application of the vector space principle [12]. The method presented in this paper is based on this principle and uses parameters to describe product models and processes in a standardized way. As it is indicated in

Figure 2, the hypothesis is stated, that product models and process steps can be described by the same parameters and values. This set of parameters corresponds to the dimensions of a vector space and therefore can be used to arrange the product models and processes in the same multidimensional vector space, called development space. The dynamic of the processes and the product models is considered by the values of the parameters which can be changed by the users during the process. The changed values lead to changed positions of product models and processes in the vector space. Hence, distances between them change as well which results in new links. It is assumed, the more similar (by using this method) a product model is to a process step the more important or relevant it is for the engineer and therefore the shorter is the distance in-between. The distances are based on the Euclidean distance. Since the users should be provided with most relevant product models, a limit of the distance is defined to decide which product models are retrieved for the user. Since there are no parameters known for this kind of linking of product models and process steps, the structure of product models is analyzed first to derive the needed parameters and values for the vector space model (see following section).

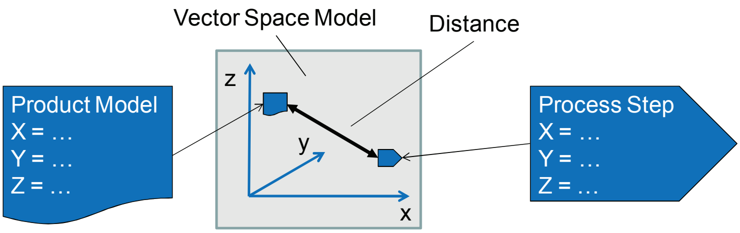

Figure 2. Linking product models to development process steps applying the principle of a Vector Space Model

5. DEVELOPMENT OF THE DESCRIPTION METHOD

Since the parameters are the basis of the description method, a text based property analysis of product models is performed to identify suitable parameters and values. Furthermore, the qualitative parameters are coded and correlations of the different parameters are evaluated. The same parameters have to be applied to process steps as well, so the description parameters of process steps used in other research are mapped to those of the product models. After the definition of the parameters, the Euclidean distance is defined as a measure of relevance. This is the basis for the decision which product models are retrieved for the user dependent on the current process step. Hence, an initial limit of the relevance is defined for the retrieval decision (see section 5.3). After this definition, the method is applied to the gathered product models and processes. For calibration purposes, the resulting links are compared to a reference system wherein the links of product models and processes are defined manually (see section 5.4). The calibration is performed to allow most appropriate effectiveness of the method also for other processes than the reference process. Finally, the description method is summed up in the end of this section.

5.1 Identification of description parameters for product models

For making the method work, the description parameters, which span the vector space have to be identified. First of all, the considered product models are gathered (see Figure 3, step 1) and described. Then, these product model descriptions are analyzed (2) for possible differentiators of the product model properties. The differentiators are transformed and merged to parameters used for the description of product models (dimensions of a vector space) (3). Finally, the parameters are evaluated concerning the used terms as being comprehensible easily for the users (4).

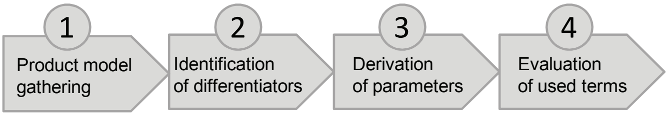

Figure 3. Procedure for building the vector space as basis for the description method

The proceeding is an adaptation of methods known from Multidimensional Scaling (MDS) and other research e.g. by Ahmed [13]. The gathering of product models and descriptions of this paper is accordant to the proceeding of Ahmed who transcribes information about design processes, splits it into property describing passages and derives differentiators. Furthermore, the analysis of descriptions of the properties of documents is described by Schiffman [12].

Gathering of Product Models and their descriptions

The considerable product models and their descriptions are gathered for the later identification of the parameters of the method. Literature research and interviews of an industrial partner (OEM) as well as a student's racing team served as basis for the search for product models. Amongst others, the main literature source for product models is the VDI 2221 [14], an officially standardized procedure of product development processes including useful product models for single steps. Furthermore, the industrial partner of this research provided data concerning used product models in certain processes and complemented these with important documents from other processes as well. The industrial partner has been provided with the definition of product models and are interviewed during a workshop. The participating engineers are asked to name all considerable product models especially useful for engineers in product development processes.

By performing this approach, a useful number of product models are gathered very fast. Furthermore, a workflow management system of the same industrial partner is examined to gather additional product models. The mentioned student's racing team is analyzed as well. Here, the whole development process is modeled and all used product models are documented. All sources combine to a list of 57 product models in total. An extract of this list (including descriptions) is shown in Figure 4. Examples for considered product models in this research are the specifications list, sketches, CAD-models, simulation models and results, engineering standards, laws and provisions as well as solution principles.

Documents	Description
Change Document	The Change Document is a standardized document for the propagation of planned or already applied changes of a product as well as for changes of a contract. Change Documents always consist of single isolated changes. They can include links to other Change Documents and are edited by standardized procedures.
CA-Document	A Computer-Aided-Document represents a geometrical model of designed construction. It is generated during the design phase, underlies various changes (iterative development process) and is used for later assemblies and product analysis. A CA-Document has the status "In Progress", "Denied" or "Approved". It refers to the CA-document, which organises all CA-Documents of the complete model of the product.
Weight	This sums up all data on weight, which is available at position variants or a toolbox position If there are several actual weights, they are prioritised as work weight. This automatic prioritisation can also be edited manually.
Material	Description of the used material with identification number and characterising properties
Part	A constructive part or workshop facility
Instance in assembly	Position-dependent place of assembly of a single part or subassembly
…	…

Figure 4. Extract of the product model list including descriptions

The generation of the product model list is accompanied by the description of each of them by plain text. This means, every gathered product model is described either by the interviewed persons or an essence of information gained from literature. These descriptions are the starting point of the analysis for differentiators which are described in the following section.

Identification of differentiators by text based property analysis

Differentiators are derived from properties of product models and reflect a certain structure of product models. Since this structure is not known, as many properties as possible are to be gathered to identify relevant differentiators. Therefore, product models are described by plain text which is retrieved from interviewees. Their describing plain texts represent individual hidden structures of product models, which have to be transformed to a single representative structure for all product models based on named differentiators.

In the beginning of the analysis, the plain texts are analyzed for properties of a product model. This is performed for all descriptions of product models and results in an overview of the properties of product models. The properties are hidden as text fragments or identifying terms as e.g. a CAD-model is a "virtualized" representation of a product. Then, the properties are split into differentiators and their possible values. For example, red and blue balls differ by color (differentiator), so the values are blue and red. After the splitting, the differentiators (lines) and product models (columns) are arranged in a matrix (see Table 1).

Table 1. Extract of the matrix of product models (columns) and differentiators (lines)

Product models / Differentiators	Specifications	CAD-Model (3D)	Functional model	Complete Concept
Degree of Concretion	low	high	low	high
Frequency of Usage	punctual, comprehensive	comprehensive	stage specific	stage specific
Useability	high	differring	high	low
Modelling Effort	medium	high	high	high
Relevance	high	differring	low	high
Author	Client			

The values of corresponding differentiators are filled in the cells of the matrix, which allows an analyzable representation of each product model by the differentiators and values. This matrix facilitates the identification of differentiators, since product models can be compared systematically. The gained overview supports merging of overlapping differentiators which can be used to build a common structure for all product models. In this context, differentiators can be considered as similar if they have same values and meaning. This merging results in 15 possible differentiators for the differentiation of the considered product models (see Table 2).

Table 2. List of identified possible differentiators of product models

No.	Differentiators	No.	Differentiators
1	Degree of concretion	9	Author
2	Relevance	10	Information Source
3	Frequency of usage	11	Actuality
4	Effort for creation	12	Types of representation
5	Effort for usage	13	Purpose for process
6	Comprehensibility	14	Remaining development effort
7	Affiliation to process stage	15	Formulation
8	Presentation		

Not all of these differentiators are useful for a process oriented description. Hence, they are selected by their contribution to process linking. Concerning the number of used differentiators, research of multidimensional scaling says that the management of complexity at 3 differentiators increases significantly, which means the more of them the more difficult it is to differentiate clearly. Hence, it has to be examined how many differentiators are needed to achieve suitable linking [12] and keep the management of complexity in mind.

Derivation of a set of process oriented parameters

To reduce the number of differentiators to a useful number (see previous section) and to derive parameters, overlapping terms and basically similar differentiators are grouped together. This avoids having too many dependent differentiators which would make the vector space more complicated than needed. The grouped differentiators are derived to new terms (parameters) describing the included ones representatively.

Since this research focuses on product models to be linked to processes dynamically, the previously identified differentiators (see Table 2) are evaluated for their usefulness for process orientation. All differentiators are discussed concerning their effect to a later process linking. Though the complexity of managing the differentiators increases above three, a number of five differentiators is considered to be essentially needed for dynamical linking. After the derivation of new terms from the five differentiators, the result is five parameters. The new terms can also be rated intuitively by engineers which is a basic requirement for semi automatic linking. After this selection, the corresponding values of the parameters are also grouped and a representative list of values is generated. The resulting parameters and their values are shown in Table 3.

Table 3. Derived process oriented parameters and their values

Parameters	*Values of parameters*
Content	*Property Description, Evaluation / Calculation, Geometrical Representation, Requirements, Solution Ideas*
Purpose	*Production, Frontloading, Coverage, Identification of Properties, Search for Solutions*
Degree of concretion	*Clarification of task, Conceptual Design, Rough Design, Detailed Design, Approval*
Development Status	*0% -20% (Start of development), 21%-40%,…, 81%-100% (product completely developed, start of production possible)*
Degree of cross linking	*1 (no cross linking), 2, …, 5 (highest cross linking)*

For the transformation of the qualitative terms (nominal scale) to a quantifiable approach, the values are coded with natural numbers in ascending order from 1 to 5 which is correspondent to the listed sequence given in Table 3. After the definition of parameters and values, their correlation is analyzed in the following section.

Correlation analysis

For the estimation of the behavior of the method and the identification of redundant parameters, the correlation between the parameters has to be examined. The calculation of the correlation coefficient is based on the Bravais-Pearson equation [15]. Thereby, the closer the value to one, the more is the correlation between the parameters. Zero-correlation means independent parameters with no correlation.

$$Kor_e(X,Y) = r_{x,y} = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2} \cdot \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{1}$$

The correlation analysis is applied to a set of product models, which is described by several engineers using the previously defined parameters and values (see Table 4). This data base is analyzed using the formula above. The result of the calculation is shown in Table 5.

Table 4. Extract of the data base used for correlation analysis

Product models	***Parameters***				
	Content	Purpose	Degree of concretion	Development Status	Degree of Cross Linking
Parts catalog	2	3	2	2	1
Change document	3	4	3	3	5
Assembly description	3	1	3	3	4
Operation instructions	3	4	5	5	5
Operating data	3	1	5	5	5
Functional model	3	2	1	1	3

As indicated in the matrix of Table 5, most of the coefficients are about the margin 0.5 with an average of 0.53 excluding cell with bold frame. This is the only correlation coefficient significantly close to one representing a close correlation between the Degree of Concretion and Development Status. Usually, such a result is interpreted as a redundancy of one of the parameters or a need for merging them to a new parameter. However, though they correlate strongly, it is expected that both parameters contribute to the understanding of the users and therefore improve the useability of the method.

Table 5. Correlation coefficients of the parameters

	Content	Purpose	Concretion	Development Status	Cross Linking
Content	x	0.54	0.50	0.45	0.43
Purpose		x	0.63	0.63	0.40
Concretion			x	0.94	0.61
Development				x	0.60
Cross-linking					x

Additionally, maintaining both parameters puts weighting on them which consciously influences the results of the applied method. The effect of this weighting has to be evaluated in the future if the constituted compromise between useability and correlation is appropriate. All other correlations are considered to be appropriate, since no complete independence of the parameters is required for the method, the values between 0.4 and 0.63 are acceptable.

Orientating Survey

Prior to a field evaluation of the method as a whole, the defined terms of the parameters and values have been evaluated by an orientating survey at the student's racing team Tufast. A questionnaire has been prepared to find out if the meaning of the terms is understood intuitively. The questionnaire consists of a description of the motivation of the survey and qualitative feedback questions. The interviewees have to describe product models using the defined terms. The interviewees have to choose the most matching value term of a parameter and add feedback comments about the comprehensiveness of the terms. In the near future, the questionnaire will be basis for further surveys to gain an empirical evaluation of the terms. The orientating survey shows that some terms are difficult to understand. Hence, the terms need to be reviewed prior to the main evaluation of the method and its terms in real product development environment which is planned for the near future.

5.2 Application of identified parameters to process steps

After the definition of the parameters and values for the description of product models, development process steps have to be described as well to arrange them in the vector space accordingly. It is assumed that parameters of product models work for process steps as well. Standardization of process modeling defines the possibility of describing a process step by criteria [16], but does not prescribe exactly what criteria to be used. Further research of e.g. Bichlmaier introduces criteria for a modular description of process steps to use them in a tool box [17]. When comparing his criteria to the parameters of presented resarch in this paper, several of them are similar to each other. The criteria "description" of Bichlmaier includes the parameters "Purpose" and "Content". The attribute "Relation" of Bichlmaier corresponds to the parameter "Degree of Concretion", since it is introduced to compare process steps with similar degree of concretion. The parameters "Development Status" and "Degree of Cross Linking" do not have a pendant in Bichlmaier's process description, but still they are added to maintain the possibility of managing a approximate phase specific allocation.
Since there are similarities between the reasearch about process description especially by Bichlmaier and parameters introduced in this paper, the parameters are considered to be suitable for process steps as well. Based on the transfer of product model parameters to process steps, the latter are described by the authors subjectively using the description method and arranged in the vector space. Future research will also deal with the evaluation of this description of processes in particular to tap as much potential of the description method as possible.

5.3 Calculating relevance of product models for process steps

After the product models and processes can be arranged in the same vector space, they have to be related to each other to achieve dynamic linking of them. Therefore, the measure of relavance is introduced which represents the Euclidean distances between processes and product models. For the calculation of the relevance, the formula for the Euclidean distance is applied:

$$d = \sqrt{\sum_{i=1}^{n} (x_i - y_i)^2} \tag{2}$$

The Euclidean distance is a well known measure to calculate similarity and relevance in the domain of information technology and is appropriate for this use case as well. The shorter the distance between a product model and a process step in the vector space the more relevant they are for each other. Since the users have to be provided with most useful and relevant product models, a limit of the maximal distance (relevance) has to be defined. The limit of the Euclidean distance has major influence on the relevance of displayed product models and has to be adjusted to satisfy the user's information needs. During calibration of the system which is described in the following section, an initial limiting distance is assumed and is adapted successively to optimize the results.

5.4 Calibration of the parameters

Since every system needs calibration to work properly, the limit of relevance and the parameters have to be calibrated. For that reason, a reference system is created which allows mapping of the two systems. The system is created during workshops which use an existing reference process as basis for a static linking of product models to it. During the workshops, the usefulness of product models for engineers in certain process steps is discussed and documented in a relational matrix. The created linking system stores a possible retrieval of required product models to a given task of the reference process (links). The built reference system is considered being an appropriate basis for calibrating the method, since the system is close to real processes and slight differences can be tolerated.
By applying the parameter based description method for product models and processes, the same linking system as of the reference system is expected to be calculated automatically. For calculating the links, the initial limit of relevance is defined as 2.5 scale divisions. Hence, all product models within a distance of 2.5 scale divisions to a process step are displayed as relevant for the user executing the process step (linked). Afterwards, the method is applied to product models and processes filling in the values of the parameters for each element. This application results in several links of relevance which are compared to the relevancies of the reference system. The identified differences of links between the retrieved product models and the reference system are analyzed. The values of the parameters and the value of the relevance limit are adjusted during several iterations to improve the matching of the links. After this calibration of the method, it can be stated that the proposed product models even expand the links of the reference system helpfully.

5.5 Conclusion of the description method

The approach for the development of the product model description method starts with the gathering of product models, their description and the following analysis for the identification of differentiators of product models. Consecutively, the 15 identified differentiators are derived to five process oriented parameters each of them with corresponding values (see Table 3). For a proper definition of chosen terms, an orientating survey is performed which aims at the comprehensiveness and useability of the method's terms. Afterwards, the method is applied to process steps, so they can be arranged in the same vector space as the product models (see schematic Figure 2).
After the development of the method, it has to be evaluated in the field and therefore needs to be supported by a tool for the ease of use. The implementation of this supportive tool is explained in the following section.

6. IMPLEMENTATION OF A RETRIEVAL TOOL

The method requires tool support to be accepted by users in the product development context and is basis for realistic evaluation of the method. Therefore, a prototypic software tool is set up which provides a graphical user interface (GUI) for the users, see a schematic view in Figure 5. For most simple usage in later evaluation, it is designed as a web based application using hypertext markup language (HTML) for the GUI and Python-scripts. The information objects of product models and process steps are stored in a relational data base using MySQL. The software tool concentrates on the documentation of used product models during the product development process. Therein, the product models are described using the defined parameters and values (mandatory parameters and drop down lists) by the users as meta-data and are stored in the data base (see Figure 5, lower part, left).

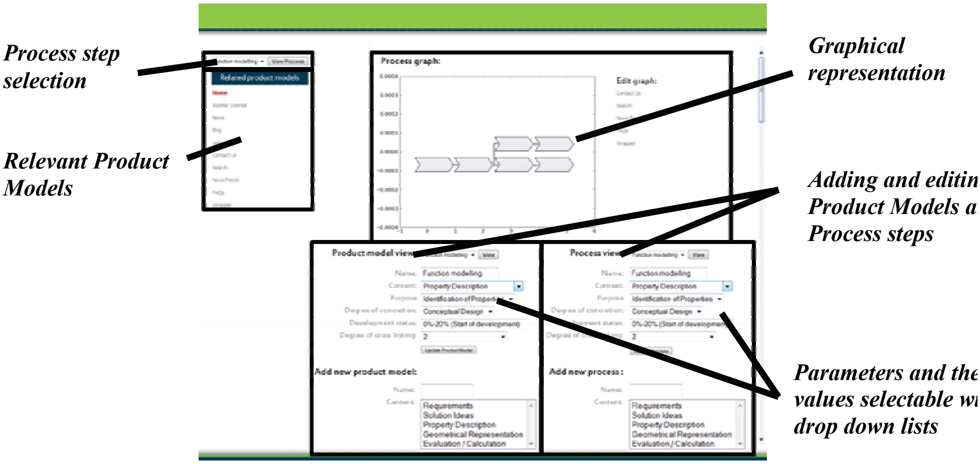

Figure 5. Schematic view of the graphical user interface of the prototypic software tool

Additional to the product models, executed process steps can be described and stored (process mining) as well (see Figure 5, lower part, right). The process steps are either inserted to the graphical representation of the process in the main frame or added as a new process step in the lower part "Add new process". The adding of a process step comes with their mandatory description by the method. In the left frame, the current process step can be selected and the corresponding relevant product models are dynamically displayed below (upper part). The relevance of the product models to a process step is calculated with the algorithm based on the Euclidean distance mentioned in section 5.3. This way, the user has only to select a process step and then is provided with relevant information for his task. The software tool can be used as basis for later software development extending useability and compatibility for the usage in real industrial environment, but since it is still in ptotypic stage, it does not fullfil common standards of software ergonomics yet.

7. CONCEPT OF UPCOMING EVALUATION

For future research, a concept of evaluation is outlined in the following. Basis of this concept is the developed software tool described in section 6. The concept of further evaluation aims at the effectiveness, efficiency and useability of the method in a real case scenario. It consists of a product development of a gokart which has strong emphasize on mechatronics. Therefore, an interdisciplinary team has to be established which imitates the real environment in industrial practice. Furthermore, a representative product development process has to be executed starting with planning, requirements definition and ending with start of production. Therein, the tool which represents the method, has to be used to document the performed process steps (content, purpose, sequence,…) as well as all occurred and used product models. During the process, the effectiveness of proposed product models to the users have to be rated in a questionnaire. The opinion of the interviewed persons about the efficiency of retrieved product model is also investigated during the accompanying survey throughout the process.

8. CONCLUSION AND FUTURE WORK

The presented research describes a new approach for information retrieval in the field of the development of technical products. This approach considers the dynamic characteristics of product development processes and the resulting insufficient information supply for the engineers. Based on the principle of a vector space and the Euclidean distance, dynamic linking between product models and processes is achieved. For the definition of the needed vector space, product models are analyzed for differentiators which are then derived to parameters/dimensions of the vector space. Furthermore, the values of the parameters are coded (1 to 5) resulting in a scale to allow the application of the Euclidean distance. Then, a correlation analysis is performed to evaluate the dependency of the parameters. Though, the correlation coefficient between Degree of Concretion and Development Status is about 0.94, it is maintained due to the useability of the approach. After the definition of parameters and values also process steps are described using the approach. Though the parameters are derived from product models, the hypothesis is followed, that the same description parameters can be applied to process steps as well. After the application of the approach resulting links between product models and processes are compared to a reference system built during several process modeling workshops. Referring to the results of this comparison, the order of parameters and their values is arranged incrementally to optimize the effectiveness of displayed relevant product models (calibration). Afterwards, a prototypic software tool is implemented to support the usage of the approach. It includes features for the administration of product models and processes based on the approach and it displays most relevant product models for process steps calculated by the approach automatically. The presented concept of evaluation uses the software tool and aims at the assessment of used parameters, terms, and effectiveness. It will be performed in the context of real product development with a team of six to eight students and will be complemented by surveys at industrial partners.

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REFERENCES

[1] Weber, C., Werner, H., Deubel, T. A Different View on PDM and its Future Potentials. *In International Design Conference, Design 2002, Vol. 1*, Dubrovnik, May 2002, p. 101-112.

[2] M. Pesic, W. M. P. v. d. A. A Declarative Approach for Flexible Business Processes Management. *BPM 2006 Workshops*, Heidelberg 2006, p. 169-180.

[3] Salton, G. *Automatic Information Organisation and Retrieval,* McGraw-Hill, New York, St. Louis, 1968

[4] Li, Z.; Liu, M.; Ramani, K. Review of Product Information Retrieval: Representation and Indexing. *In Proceedings of Design Engineering Technical Conferences 2004*, Salt Lake City, Utah, 2004.

[5] Ullmann, D.G. *The Mechanical Design Process*. 2nd edition, McGraw-Hill, 1997.

[6] Ahmed, S.; Wallace, K.M. How engineering designers obtain information. *In Human Behaviour in Design. Individuals, teams, tools.* Springer, 2004.

[7] Dika, A.A.N., Eynard, B., Lafon, P., Deneux, D. From Workflow Specification to Implementation: An Industrial Use Case. *In International Design Conference, Design 2008,* Dubrovnik, May 19-22, 2008.

[8] Reichert, M. Dynamische *Ablaufänderungen in Workflow-Management-Systemen*. Dissertation, Universität Ulm, Ulm (2000).

[9] Rude, S. *Wissensbasiertes Konstruieren*. Aachen, Shaker 1998.

[10] Hartmann, D. *Modell zur qualitätsgerechten Konstruktion*, PhD-thesis, Technische Universität Clausthal-Zellerfeld, 1996.

[11] Japiske, R.; Langdon, P.; Wallace, K.M. Structuring Engineering Design Information Using a Model of how Engineers Intuitively Structure Design Information. *In Proceedings of the 14th International Conference on Engineering Design 2003, ICED '03*, Stockholm, 2003.

[12] Schiffman, S., Reynolds, M., Young, F. W. Introduction to Multidimensional Scaling: Theory, Methods, and Applications. New York: Academic Press, Inc. 1981.

[13] Ahmed, S., Wallace, K.: Indexing Design Knowledge Based Upon Description of Design Processes. *In Proceedings of the 14th International Conference on Engineering Design 2003, ICED '03*, Stockholm, 2003.

[14] VDI-Richtlinie *VDI 2221: Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkte.* VDI-Gesellschaft Entwicklung Konstruktion Vertrieb, 1993.

[15] Backhaus, K., Erichson, B., Plinke, W., Weiber, R. *Multivariate Analysemethoden - Eine anwendungsorientierte Einführung.* Springer Berlin Heidelberg 2006, Germany.

[16] VDI/VDE-Richtlinie *VDI/VDE 3682: Formalisierte Prozessbeschreibungen.* VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik, 2005.

[17] Bichlmaier, C. *Methoden zur flexiblen Gestaltung von integrierten Produktentwicklungsprozessen.* Dissertation, Technische Universität München, Munich, 2000.

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