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HOLISTIC INTELLECTUAL PROPERTY PROTECTION OF VIRTUAL PRODUCT MODELS IN PRODUCT DEVELOPMENT NETWORKS

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ABSTRACT
Due to the increasing virtualization of the product development process a large amount of company-specific product know-how is stored within CAD models. The knowledge integrated in virtual product models represents a key competitive factor for companies in the context of a global collaborative product creation and, therefore, has to be protected from uncontrolled access.
This paper proposes a new process-oriented holistic approach for Intellectual Property Protection (IPP) of virtual product models. The core of the solution is a methodical framework for the development of virtual products under consideration of know-how protection aspects. The requirements for the IT-supported solution were generated from the analysis of a series of representative use cases. They consider a knowledge-intensive data exchange within cooperative product development projects and possible threat scenarios.

Keywords: Virtual Product Development, Virtual Product, Intellectual Property Protection (IPP)

1 INTRODUCTION
The development and launching of new products is mandatory for a continuous profitable company growth [1], [2]. Due to the immense pricing pressure in international markets caused by trade liberalization, companies are forced to reduce the costs for the development and manufacturing of new products and streamline their internal processes. The result is that many companies outsource less profitable sectors and concentrate on their core competences. The individuality of products demanded by the market leads to products becoming increasingly complex and being only developed and manufactured within interdisciplinary company cooperations.
The corporate landscape being shaped by these basic conditions allows the development of highly complex and innovative products but also has a lot of disadvantages. Many companies competing against each other try to get hold of external know-how by any means, legal or illegal in order to strengthen their own position in the market. Legal measures are not sufficient to stop the problem of plagiarism. Furthermore, normally these measures only take effect when the damage has already occurred. Besides legal protection measures a number of preventive protection concepts built on organizational and strategic measures are available. However, a representative study by the Technical University Munich concludes that the current use of different protection concepts in the industry is very poor [3]. Legal and organizational protection measures dominate and the technology for product protection is not used sufficiently due to various reasons. As a consequence, the concerned companies suffer from a loss in sales and heavy damage to their image resulting from copied products of inferior quality.
In the last years, the progress in information and communication technology has not only contributed to accelerating the product development within individual development phases considerably. It has also strongly influenced the whole development process. The increasing virtualization of the product development process results in today's product models becoming knowledge stores and thereby being in charge of company-specific know-how. The information content within virtual product models exceeding by far product geometry contains information about downstream processes, like manufacturing, installation, quality control etc. in addition to design knowledge. This knowledge constitutes a key competitive factor for companies and has to be effectively protected from uncontrolled access.

This paper presents a process-oriented approach which considers the aspects of knowledge protection already in early phases of the product development process and thereby closes security holes in existing protection measures.

2 USE CASE FROM THE WIND POWER INDUSTRY

In the last years, several representative studies have shown that the problem of know-how running out especially hits high-tech companies, like the wind power industry [3], [4].

The main component of a wind power plant is a gearbox which converts the rotor torque and drives an electric generator. For the initial development of wind power gearboxes manufacturers have resorted to the well-tried technique of industry gearboxes. This has resulted in an early breakdown of technical gear components like bearings and gear wheels due to extreme load cases in the housing which have not been sufficiently investigated. In the course of improvements and further developments of wind power gearboxes manufacturers and research institutions have built an enormous know-how in terms of design and manufacturing processes. Especially for the design of gear wheels new methods have been developed which improve the load-bearing capacity of the tooth flanks for the entire load range. These new manufacturing processes, furthermore, enable a more precise manufacturing of components and a superior quality of the processed surfaces. The suppliers of the bearings have invested larges sums into the enhancement of their own products whereas the improvements in the first instance concern the micro geometry of the rolling elements [5], [6]. Due to a deep focusing on special fields the development in these areas requires an intensive cooperation between manufacturers, suppliers and customers (Figure 1).

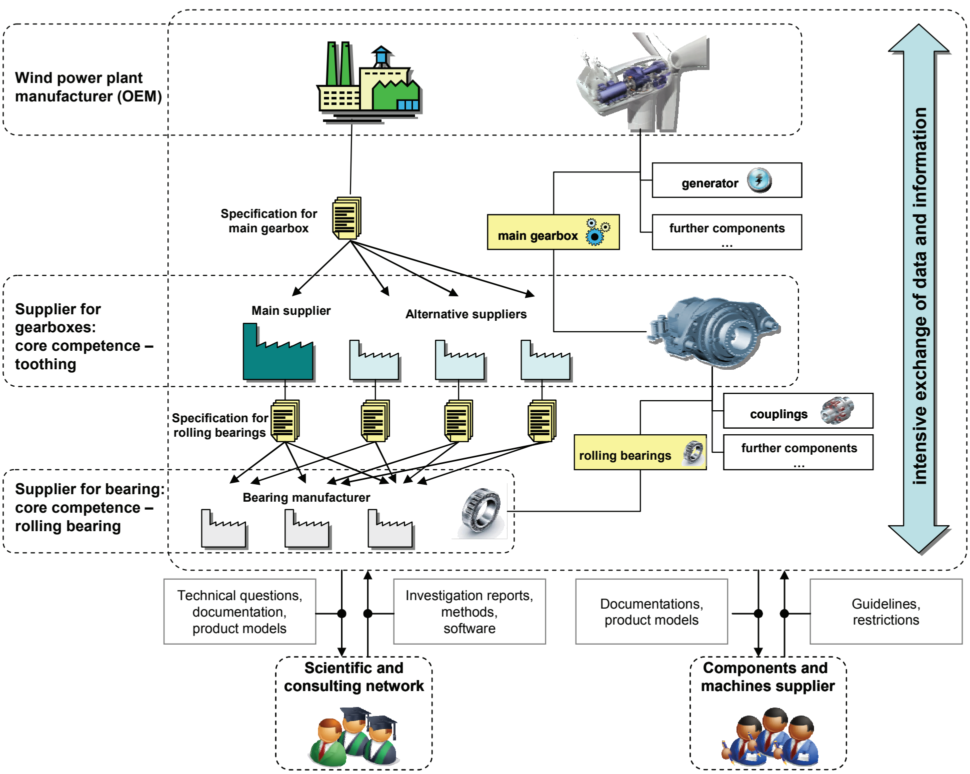

Figure 1. Participants in the R&D network for the development of a wind energy plant

The negative experiences of plant operators with early breakdowns in the past have also led to every type of plant having several gearbox suppliers which compete with each other. This constellation

ensures that in case the main supplier encounters technical difficulties the alternative suppliers can instantly provide replacement components.
The core competence of gearbox manufacturers is the development and manufacturing of tooth system components which are the main constituents of a gearbox. Based on the results of the tooth system design those bearings are chosen which can be applied especially in the scope of wind power deviant from universal standards (e.g. direct bearings for planet gears). A definite bearing design under consideration of the micro geometry of the rolling elements is conducted by bearing manufacturers which posses a special know-how in this field.
Figure 2 shows a typical gear wheel model which contains a lot of information about load distribution at the flank, grinding parameters and other elements in terms of product know-how in addition to the geometrical representation.

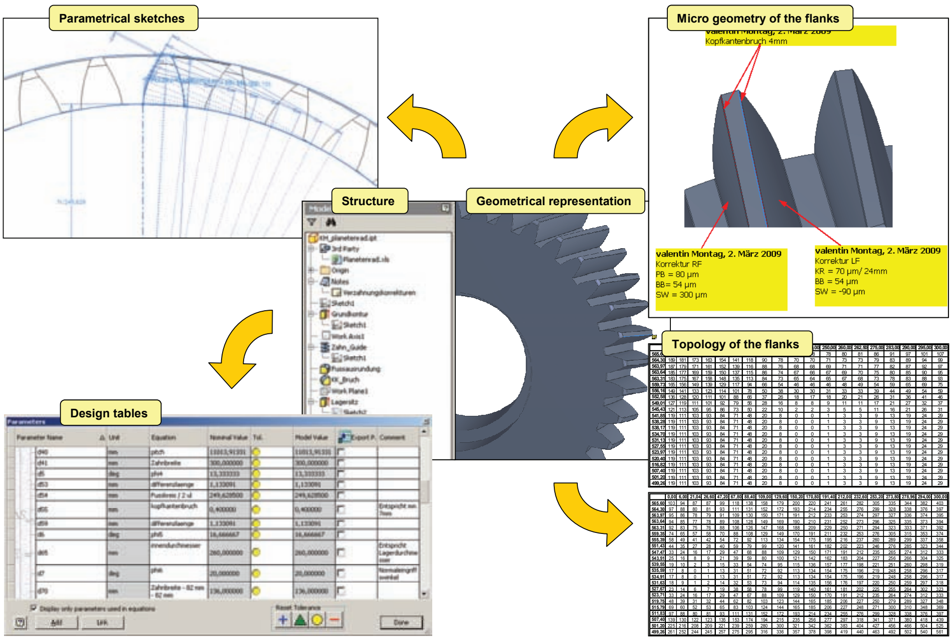

Figure 2. Product know-how integrated in the CAD-model of a gear wheel

The intensive cooperation between component manufacturers requires a constant exchange of product data and models which contain a company-specific know-how. Hard requirements by insurance companies, furthermore, require a comprehensive certification of all security-relevant components of a wind power plant. This forces companies to provide external institutions, which are closely related to possible competitors as well, with extensive product documentations and models.
Although existing IT systems offer a secure environment for exchange processes in form of electronic authorization and encryption, they cannot prevent an uncontrolled knowledge transfer through information transfer to third parties.

3 STATE OF THE ART

The existing measures for protecting intellectual property generally can be subdivided into two main categories:

- Reactive and control measures
- Preventive measures

From the point of view of the protection subjects these measures can focus on the products themselves, the product and brand labelling, the product data and information and/ or the accompanying processes. The implementation of these measures takes place with the help of legal, strategic, organizational and technical measures.

3.1 Reactive und control measures for Intellectual Property Protection

The reactive and control measures are mainly based on legal mechanisms and, moreover, take effect after the damage resulting from stealing intellectual property has already occurred. The registration of patents, brands and trade names as well as market and competition observations through permanent monitoring of trade platforms and trade fair visits are part of these measures. They are partly supported by technical measures which serve the identification of the origin of the physical products or product data [7], [8].

3.2 Preventive measures for Intellectual Property Protection

Preventive protection measures in their entirety aim at preventing product and process knowledge in any form and occurrence from passing defined boundaries. In general, they can be divided into strategic, organizational and technical measures.

Strategic measures in the first instance apply to the entire product and company policy and have a lasting impact on the company's success. They consider the future economic developments in the respective market environment, political basic conditions as well as the use of modern technologies in all phases of the product life cycle [9], [10].

Organizational measures as a rule are derived from the strategic aims of the company and apply to the organization of processes within individual company sectors and/ or trans-sectoral. Moreover, they define communication rules between the involved participants in the company and the partners outside of company boundaries [11], [12].

Technical protection measures also concern the IT infrastructure in the field of product development, data management and electronic communication besides constructive product adaptation and labelling of product models with the help of watermarking and fingerprinting methods. In contrast to technical solutions for already manufactured products early and late product development phases and their accompanying company processes constitute the main field of application of preventive technical measures [13], [14], [15], [16], [17], [18].

The protection of product models through filtering and falsification of geometry data, model structure and meta information also belongs to the group of preventive measures and can either be achieved by standard functionalities of CAx systems or by extended software systems.

3.2.1 Intellectual Property Protection with standard functions of CAx-Systems

Leading CAx systems (e.g. NX by Siemens PLM Software or CATIA V5 by Dassault Systémes) have certain basic functionalities for a simple know-how protection of virtual products. Therefore, in all CAx systems product models can be converted from native, i.e. system-specific, to neutral formats like e.g. STEP or IGES. As an outcome of this process all company-specific information as well as individual features and structural elements are removed from the model. In doing so, a geometric model comes into being which contains basic information about the source system as metadata. This solution is especially suitable for simple geometric product models, because, despite a high degree of maturity of the neutral CAD interfaces, some complex geometric elements cannot be converted flawlessly.

Another method for processing models for data exchange is to merge all single parts models which belong to an assembly model into one single part model only. In this case the information content in the model is strongly reduced as well.

These solutions coincide in that respect that conversion also means removing associative relations between individual elements and models.

3.2.2 Further applications for Intellectual Property Protection of CAD-models

IT tools which systematically simplify product models according to previously defined rules constitute an alternative to the above described approaches. In this way, certain model elements like e. g. parameter tables or constraints can be removed. These approaches are implemented in the commercial tools like e.g. IPPro (:em AG) and Knowledge Editor (ProSTEP). They allow the user to define in detail the elements to be removed. The underlying logic is based on internal CAD system-specific parameters and can be extended by e.g. company-specific terms. Thereby, all model elements that belong to a certain type (e.g. "parameter") or which contain a certain string in the term (e.g. "IP protection") can be automatically removed. Still, there is the risk that in case of possible input data errors corresponding elements will not be identified by the system.

In summary it can be said that all existing IT-supported solutions are focused on the product design phase and earlier stages of the product development process are not considered or insufficiently supported. The consideration of collaborative engineering is part of the Digital Right Management (DRM) solutions. However, product models are treated as normal electronic content without especially supporting the geometrical and structural elements. The above mentioned scientific approaches focus strongly on limited fields and are not implemented in the commercially offered IT systems.

4 HOLISTIC APPROACH FOR INTELLECTUAL PROPERTY PROTECTION IN VIRTUAL PRODUCT DEVELOPMENT

4.1 Concept overview

The complete representation of a real product in a virtual model entails considerable advantages for the optimization of development processes. However, in case of an unstructured realization it also reveals security holes which bring a high risk for the innovation of a company and its economic efficiency.

The challenge for companies in terms of know-how security is to ensure that product knowledge does not leave the boundaries of a defined system. Still, during the product development it is important to provide the participating partners with product data and information. A simple knowledge reduction in product models is not accepted by most customers. Instead, "intelligent" models are demanded which can be integrated into cross-product models and manipulated [14]. In this situation relief is produced by a controlled model processing. By such a differentiated view customer demands can be met as well as company-internal interests in terms of knowledge reduction in product models can be considered.

The approach for a holistic know-how protection of virtual product models also considers early phases of the product development process in addition to geometric CAD models as partial result of the development activity. The concept covers the standard design process for the development of new products (Figure 3).

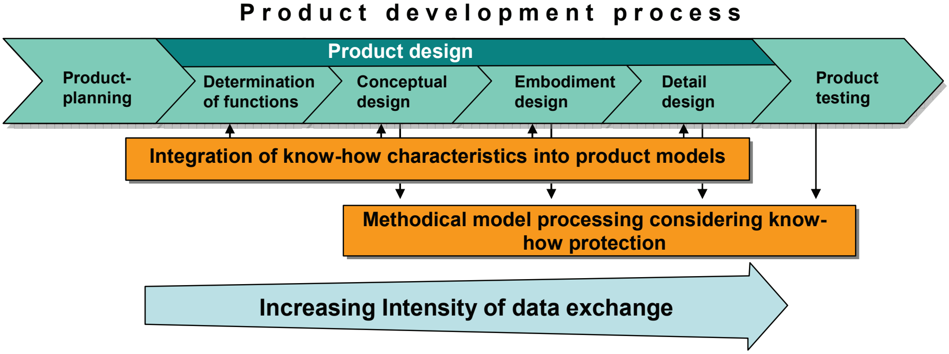

Figure 3. Rough concept for know-how protection of virtual products

The concept for know-how protection of virtual products in the first stage focuses on the early integration of CAD systems into the development process and supports all phases of the process which include a data exchange beyond the defined system boundary as necessary activity. The holistic consideration of the product development process in terms of know-how protection, furthermore, avoids a breaking of communication and ensures a simplified integration into the IT environment of the product developer.

During the function structure modeling phase functions are identified which represent a special know-how of the company. For a gears manufacturer such functions could be e.g. load transmission or shaft bearing. In the product context individual functions are fulfilled by certain components. Here, one function can be realized by several components. At the same time, one component can fulfill several functions. In the modeling context individual components are represented by certain features.

During model processing in consideration of know-how protection aspects individual features about the dependency of know-how relevant functions are automatically identified and in this way can be removed or simplified with the help of defined rules.

4.2 Definition of roles within R&D network

The company networks existing in practice in their totality have an unsystematic structure and no clearly defined boundaries [19]. Therefore, for the exact definition of system boundaries it is necessary to derive a network model which includes a clear role definition of the network participants. The roles of the participants in the network in the first instance should represent the process of creation and subsequent use of the model. Moreover, it is necessary to define a role of a competitor who uses the foreign know-how for his own purposes without consent of the creator.

This constellation allows the reduction of a complex company network to a triplet with the following participants (Figure 4):

- Know-how creator – producer of a virtual product through using his own know-how (e.g. n^{th}-tier in a supplier chain)
- Legal receiver (of information, data) – every partner in a network who is entitled to use the creators' models in his own virtual products (e.g. OEM producer) or for earmarked investigations (e.g. consultant or order developer)
- Illegal receiver (of information, data) – e.g. manufacturer of identical or similar products like know-how creator

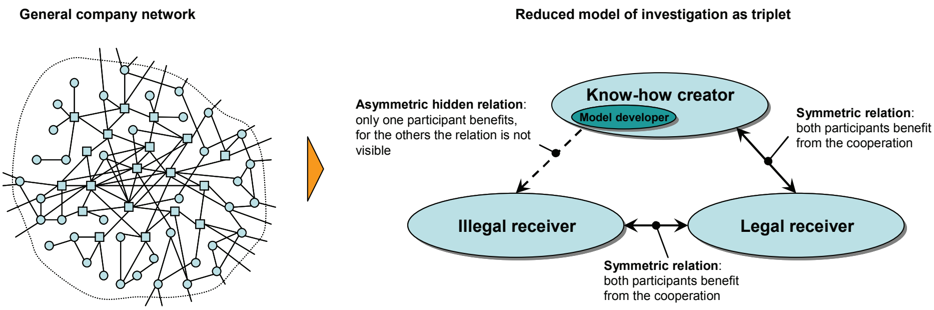

Figure 4. Definition of roles within R&D network

In order to develop a complete scenario it is necessary to conduct a differentiated consideration within the role "know-how creator". This role represents a company which consists of various entities. The product models are generated by one entity – model developer. The other entities which use the product models for several purposes (e.g. sales) are referred to as internal model customers [20]. Model developers have no direct interface with other participants in the network; the outward communication takes place via internal model customers.

On the basis of defined roles of the participants in a network and the relations between them levels of confidentiality are introduced which play a significant role with respect to the reduction of knowledge content of the product models for the transfer to the partners. Figure 5 shows how the levels of confidentiality are assigned to the defined roles.

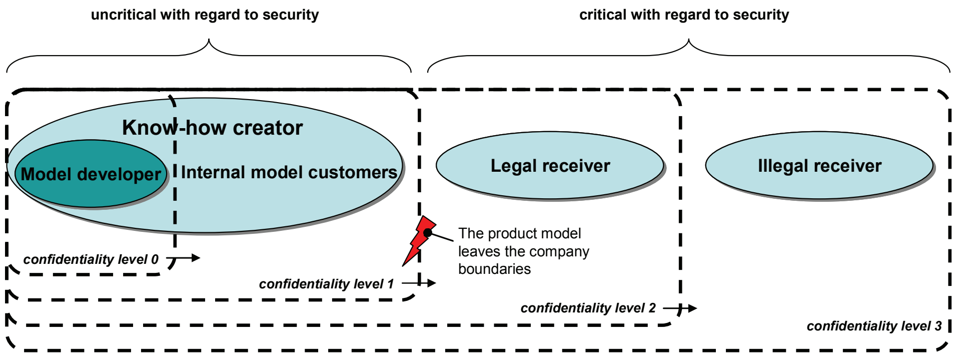

Figure 5. Definition of the levels of confidentiality in the modeled network

From the point of view of the know-how creator there is no risk for him, if a product model is within confidentiality levels 0 and 1. The know-how integrated in the model does not leave the company boundaries and thereby is not accessible to business competitors. Therefore, these levels can be seen as uncritical with regard to security.
If models exceed company boundaries and reach legal receivers (confidentiality level 2) the know-how creator has no influence on the transfer of the model to illegal receivers (confidentiality level 3). For this reason both confidentiality levels 2 and 3 are to be regarded as critical from the point of view of the creator.
The developed concept primarily concentrates on the interface between know-how creator and legal receiver which is marked by the fact that the know-how creator looses full control over his own product models.

4.3 Methodology for the Integration of Intellectual Property Protection into Virtual Products

4.3.1 Process Integration

An essential feature of the concept of know-how protection for product models is the consideration of know-how relevant aspects already in the early product development phases. They consist of the definition of requirements, determination of functions and operation structure modeling of technical systems. The integration of know-how protection characteristics mainly takes place in the phases determination of functions and operation structure modeling. Here, the central point of the process integration is the function structure of the future product.
The identification of the functions to be protected is an iterative process (Figure 6). During the first step it has to be determined which functions generally belong to the core competences of a company. The answer to this question mostly arises from the strategic orientation of the company and strongly correlates with company goals in the field of developing technical products. Here, it is crucial that the function structure is resolved to the lowest level of the sub-function in the analysis phase. Handing down characteristics according to the top-down method from the main functions to the sub-functions does not make sense because by this some other functions are included as well which are fulfilled by supplier components or standard solutions. In case of a data exchange in later phases this can be in conflict to data quality guidelines of the client and thereby raise the expenses and efforts for model processing.

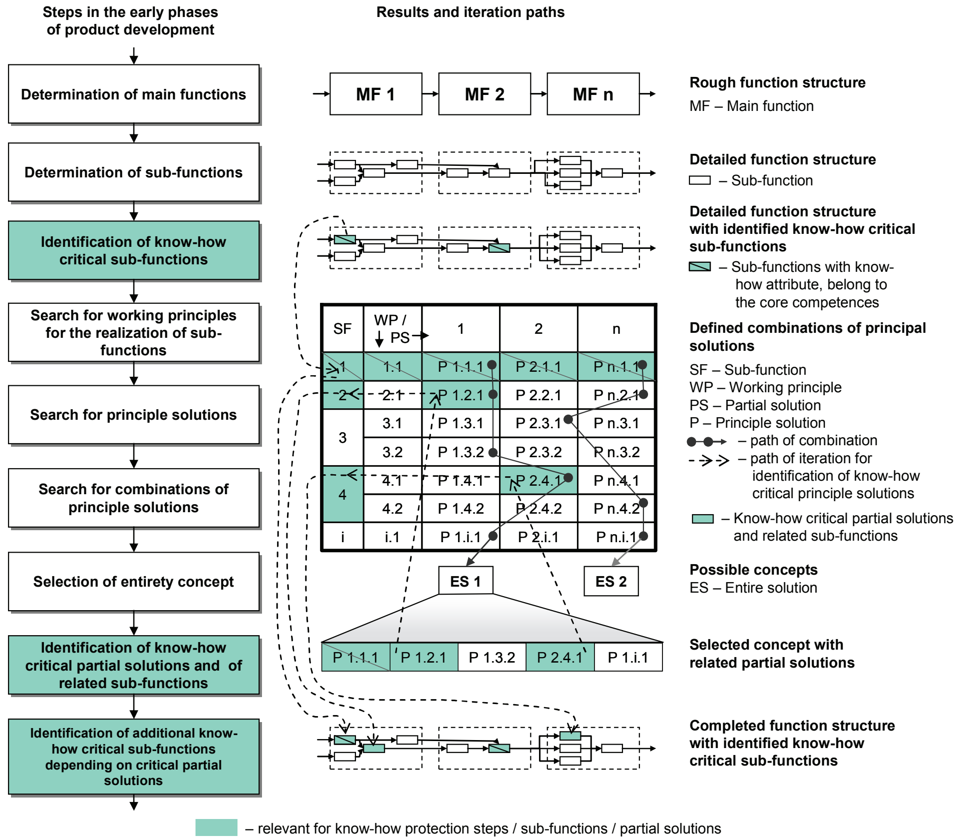

Figure 6. Methodical approach for identification of know-how critical functions in the early product development phases

In the further phases of the methodical product development concepts created in the early phases are transformed into geometric models. The general approach for the identification of models derived from the function structure, which possess an especially high degree of innovation, is shown in Figure 7. As a result of this approach a model is identified whose parts – single part models and features – have to be provided with protection properties. This also includes those elements which do not necessarily represent know-how and, therefore, can lead to higher expenses for the integration of know-how protection features into the product models. This is why the approach is complemented by a purging process which aims at filtering out uncritical elements from the element amount identified in the first step and at considering special customer requirements. During the last process step those model elements which have been classified as know-how uncritical at the beginning of the identification process are tested for their knowledge content. This procedure is necessary in order to protect know-how by the creator which as a standard is applied in the modeling process for model development or sheds light on the used technology processes. This observation takes place exclusively on the feature level.

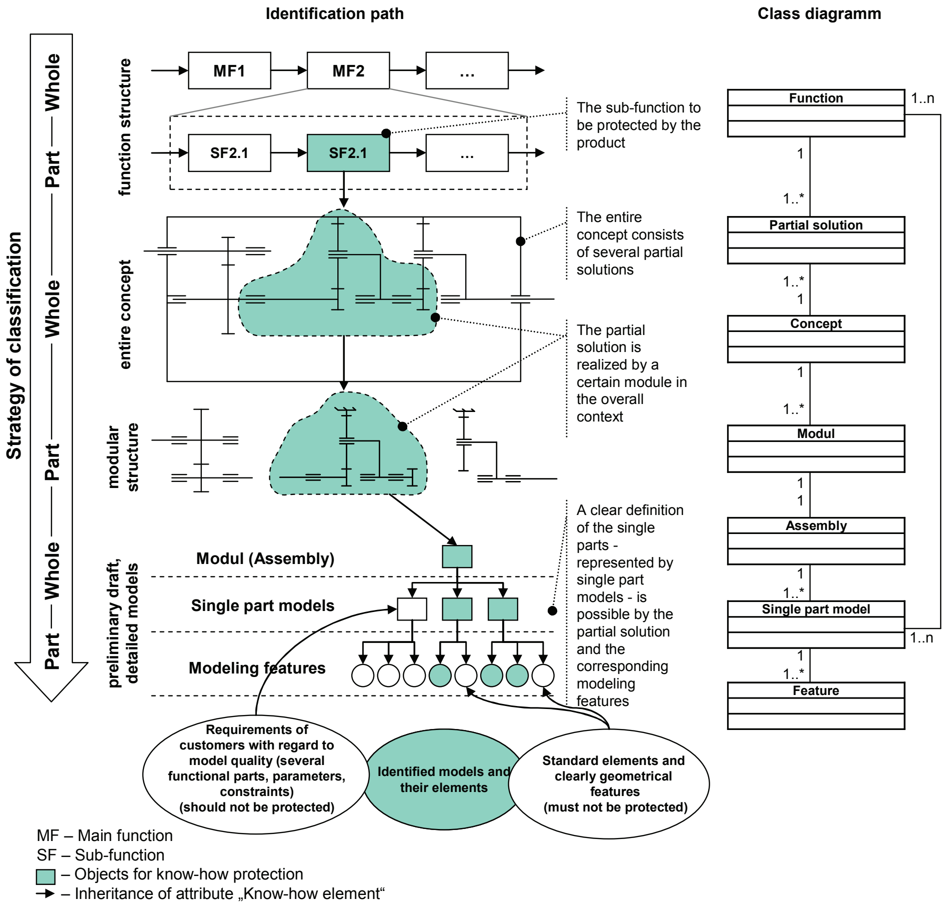

Figure 7. Approach for the identification of know-how critical single part models and modeling features starting by the function structure

4.3.2 Preparation of Product Models

The basic methods for the integration of know-how protection features into the product models are:

- String extension and assignment of attributes
- Parameter and rule integration
- Integration of 2D and 3D elements

The method of string extension is a standardized denomination of models or model elements respectively with one or more predefined prefixes. As a standard the denominations of model elements are created by the CAx system or by the integrated PDM system (default setting). An extended denomination (string extension) of an element can include information about its necessary treatment during the model processing. An example can look as follows: “know-how-xxxxx” (x serves as the placeholder for the default string). By this the marked parametric volume elements can be substituted by BRep geometries (boundary representation) in the downstream process steps whereby the “intelligence” is removed from the model. Furthermore, certain strings can be allocated to further operations, e.g. variation of parameters.

The assignment of attributes to elements is a definition of model and element qualities which are not directly apparent to the user. The attributes allow a targeted access to the elements and their manipulation governed by further rules.

The integrated parameters and rules can systematically govern the dimension and design of an object and thereby directly influence the effective geometry of a model. The know-how relevant parameters are integrated into the CAD model with the help of parameter tables. The table necessarily contains two parameter sets which each are activated depending on the event. The activation of parameter sets within a CAD model can be controlled by integrated rules. A higher degree of geometry falsification for the know-how protection can be achieved by an event-driven variation of the geometric elements.

The integration of 2D and 3D geometry elements extends the existing CAD model by additional geometries which, though, are only activated if required and which replace the know-how critical elements present in the model. In contrast to pure design variations this method allows a systematic manipulation of several model areas and is also suitable for the application of complex geometry. During the integration of 2D elements one or more outlines are integrated into the model to be protected in the form of auxiliary elements. This represents an alternative geometry which does not influence physical characteristics of the model (volume, mass) for the model's further use within the defined system boundaries. It can also be converted in an event-driven way into volume elements and thereby superimposes the original geometry. Subsequently, the manipulated model can be transposed into a BRep body, whereby original elements cannot be restored. Alternatively, the superimposed original geometries can be removed from the model.

The difference in the approach for the integration of 3D elements is that they are simply deactivated in the original model in the normal state and are only shown when the activating incidences occur. Here, no additional volume-generating operations are necessary. In comparison to integrated 2D elements, however, they can influence the physical properties of the existing model depending on the applied CAx system.

4.4 Methodical Purge of Product Models

Model processing before the data exchange aims at changing the representation of a product model or its parts. In principle, processing methods can be subdivided into the following categories:

- Model processing as regards content
- Structural model processing
- Model conversion

For processing as regards content the aim is to purge the product model with regard to certain elements which represent a special modeling or product knowledge. Here, the geometric design of a product model is modified. For the structural processing the changes only affect the structure representation of the model on the level of components or single parts. The model conversion is based on the intrasystem change of the model representation and shows a great interface with other methods.

For the methodical approach of the model processing the aspects described in earlier chapters have to be systematically considered regarding the knowledge content of the element groups in product models as well as confidentiality levels of the model receiver. The conflicting requirements are tested for their compatibility by priorization algorithms.

If a model is processed for the data exchange, an automatic search or similarities in the PDM system is conducted and similar models (similar geometries, applications, customers etc.) are identified with predefined IP profiles. If no search result is reported, it is necessary to create a profile specific to the component family. Creating an IP profile is supported by the software tool IP editor. The profile includes information on necessary geometry manipulations of the parameters, simplifications of the model structure, replacement of know-how critical features through predefined geometry elements.

In addition to component-specific features the handling of special technology knowledge is also defined in separate cross-model IP profiles. This knowledge can be represented in a model through certain semantic features like e.g. hole with production parameters.

In order to minimize data administration efforts the simplified data model created for the data exchange is not stored in the PDM system, but is immediately transmitted to the receiver. Only a sequence with product number and IP profile combination is stored in the PDM system which enables a repeated reproducible model processing (Figure 8).

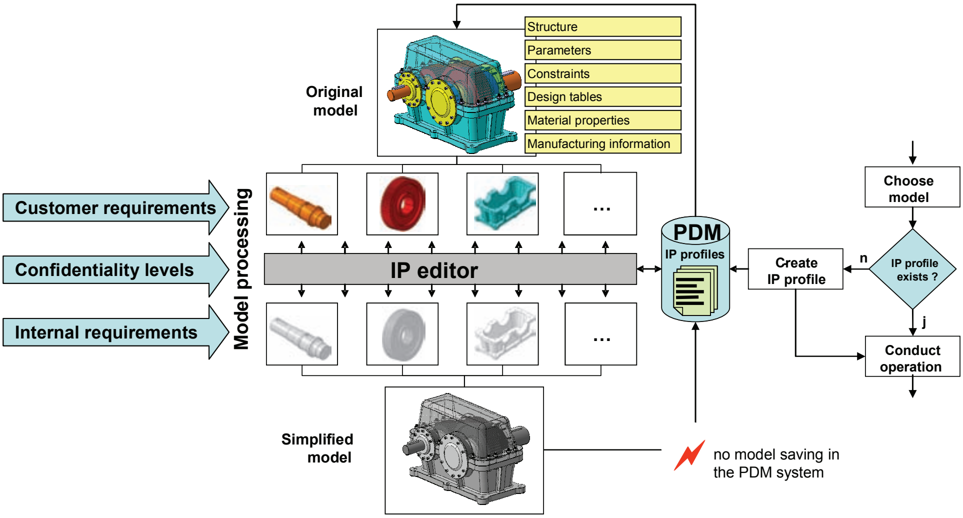

Figure 8. Process of model processing

4.5 Concept Verification

The described know-how protection concept at the moment is verified in practice within the framework of an industry cooperation at a medium-sized automotive supplier. The status quo of the implementation concentrates on the integration of the software tool IP editor into the existing CAD system CATIA V5. The first results have shown that besides the increased data quality of the simplified models also much time can be saved by integrated automatisms.

5 CONCLUSION

Protecting intellectual property gains more and more importance in today's development-intensive company networks. Existing IT solutions enable a sporadic improvement of the situation, however, a holistic know-how protection of virtual products is still missing.

Besides model-related aspects the developed know-how protection concept also considers the development processes starting in the early product development phases. The integration of know-how protection characteristics is already automatically supported during the function structure creation and later for the model development through the IT tool IP editor. The tool supports the user by the combination of different methods for purging CAD models and enables the protection of model-specific and product-specific know-how. A deep integration into the company-specific PDM system serves the standardization and optimization of data exchange processes and effectively avoids an uncontrolled distribution of company-specific knowledge.

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