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Reducing parts diversity in product design: a data centered approach

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ABSTRACT: To attract customers, manufacturers must design a large diversity of variants of products that suit to various requirements. But to reduce cost, manufacturers must reduce the diversity of components. We focus on part diversity, i.e. when two or more parts satisfy to the same need. Parts are described in several independent documents, or database, each one with its own information model. We claim that, to a large extend, part diversity results from lack of information and information exchange within the extended enterprise. So we propose to capture the whole part information through a single computerized representation based on the PLIB data model (ISO 13584). But designers must keep their own view of parts. So, various human-readable presentations will be generated from the PLIB representation by tools. One example is given. We discuss the creation of a database of fasteners in a manufacturing industry. We present the various steps to build the PLIB data model and we outline existing and in progress tools to generate various human-readable presentations (website in DHTML, paper document, …).

1 INTRODUCTION

To attract customers, manufacturers should design products that suit to various requirements. Customers become more and more exacting in their choices and they want their products to have a different appearance from other ones. Manufacturers must design several variants of product. But designing variants involve diversity. To reduce costs, manufacturers must reduce diversity in products. One solution is to reduce the number of different parts. Indeed, a number of internal parts do not play any role in the product appearance. Thus the number of parts which have the same functional use should be reduced. But we must first identify why designers cannot easily recognize parts which fulfill the same requirements.

One reason seems to be that designers can hardly compare various parts. Designers select their parts from various sources (paper catalog, website, CAD library, etc…). These sources often suggest different search criteria, thus different choice results. A possible solution to this problem would be create a single database with a unique computerized representation of all the part information which would allow generation of all needed human-readable presentations. Database should allow to gather the various human-readable information items to be included in the various presentations like drawing or dimensional properties. Moreover, it must provide mechanisms to make easier comparison between parts and it should suggest best-practice search criteria for parts selection. The goal of this paper is to show how these requirements may be fulfilled using the ISO 13584 data model.

The rest of this paper is organized as follows. In section 2, we discuss the origin of product diversity. Various solutions to restrict diversity are presented. Then we analyze the causes of parts diversity. In section 3, we propose a new approach, i.e. creation of a single database. We discuss the advantages of such approach, and potential difficulties. We outline the PLIB model (ISO 13584) that would allow us to create a database which would handle all presentations of all information items. Tools may be designed to generate various human-readable presentations from this computerized representation. Section 4 presents a case study on fasteners in manufacturing industry. We first discuss the context and then, we present different steps for the implementation of a PLIB database. Finally we show existing and in progress tools that can generate human-readable presentations.

2 THE DIVERSITY ISSUE

2.1 *Product diversity origin*

Manufacturers make products with low-cost perspectives and production profitability. Customers want to buy products that meet as such as possible their wishes. Two extreme scenarii exist. In the first one, a product fits to a large scope of customers. One product with no options, thus no diversity, matches with several needs because all functionalities are integrated. This approach exists in electrical domestic equipments. In the second scenario, manufacturers make one particular product for one particular customer, like in space industry (e.g. satellite). Automotive industries are in an intermediate state. They produce variants of car models in order to meet most customer needs. This approach requires a well-controlled diversity.

For automotive industries, product diversity exists since the 50's (Cialvaldini, C. & Loubet, J.L. 1995). Before these years, they used to make unique products with little or no diversity. The Ford T model from Ford Motor Company is the best example ("People can have the Model T in any color so long as it's black", Henry Ford). But after the 50's, came customized products. Some manufacturers created products with a number of variants and customers could customize the product to fit with their tastes. Then, this approach creates diversity of variants.

Diversity of variants is necessary to fit closely with customer needs, whereas reducing diversity is essential to reduce manufacturing costs (manufacturing approach versus marketing approach). That is the diversity issue. Automotive manufacturers want to produce different variants of car models, with several options or different bodies with the smallest number of different parts, in order to achieve two goals: meet all customer needs and produce enough to ensure profit. So they must define standardized elements or parts that they could use to design various finished products.

2.2 *From the final diversity to the intermediate diversity*

Reducing production costs by decreasing final diversity, i.e. variants diversity, is not an acceptable goal. But, in several engineering design fields, products to be designed are essentially assemblies of technical elements. So it has been suggested to keep variants diversity and to decrease the internal diversity of elements. Two approaches have been proposed: standardization and modular design.

2.2.1 *Standardization*

In the standardization approach, products are designed by using as much as possible the same existing parts. Consequently, the intermediate diversity decreases. Designers use tools that allow them to search and select components that fulfill to their search criteria in a restricted set of components.

But using a smaller number of parts might decrease the diversity of products, because we reduce possibility to differentiate product from another one. To keep final diversity, authorized components must not prevent the differentiation of products. Profitability of this method depends on the balance between the cost of standardization and the profits resulting from economies of scale and reduction in variety. Mathematical instrument was developed to find the best compromise (Lee, H.S. & Tang, C.S. 1997).

2.2.2 *Modular design*

In the modular design approach, designers identify repetitive units -elements or assembly of elements- called modules. A module is designed with several functional capabilities and standard interfaces. Diversity of functional capabilities allows using the same module in several products: some functional capabilities can be used in one product and not used in another one. Standard interfaces allow many configurations and permit interchangeability and independence of modules.

To produce a large variety of products at lower cost, one method to identify suitable modules has been proposed. It consists of using a matrix representation to model interactions between parts and functions and to break down the matrix to identify elements as modules (Huang, C.C. & Kusiak, A. 1998). Intermediate diversity decreases because modules are defined with many functional capabilities and interfaces in order to replace several parts or assembly of parts. As designers define modules with several capabilities, product diversity may not decrease and even more could increase it by using the new functional capabilities resulting from the module breakdown.

2.3 *Focus on parts diversity*

In the previous section, we outlined two methods to reduce intermediate diversity. In this paper, we focus on standardization of parts. But reducing the part diversity may decrease the variants diversity. To avoid this drawback, we try to identify the useless diversity that we define as the fact that two or more parts fulfill the same requirement. To avoid this kind of useless part diversity, we must understand the reasons why two different designers may select two different parts for the same requirement.

3 DEFINING A DATA CENTERED APPROACH: SWITCHING FROM DOCUMENT TO DATA

3.1 *Causes of parts diversity*

The first cause of useless part diversity seems to be the diversity of the information processed by the various actors. Several experts work on the design of product using tools adapted to their task like CAD library for designers, FEA models for stress analysis engineers or paper catalogues and Web sites for buyers. There are as many sources of information as there are documents or parts representations (Fig. 1). When a tool is updated, each representation should be updated too in order to guarantee the integrity of data. Update operations are very costly and so they are often not performed. Thus information is frequently not accurate.

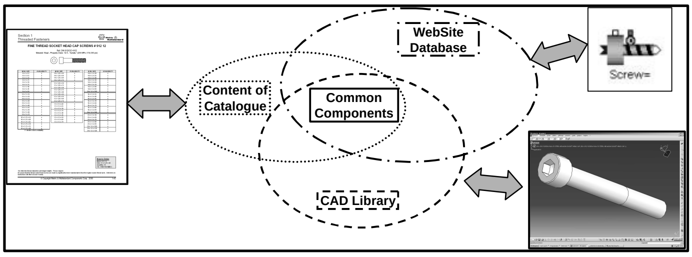

Figure 1: Difficulties with multi-sources of information

Moreover, structure of information which allows users to select components are often different from one representation to the other. Designers search parts according to the classification used in the representation. For CAD tools, designers search parts in a tree-representation defining families of parts. In paper catalog, parts are classified in family and users must choose a part-family before selecting the part corresponding to their needs. Libraries are modeled as a hierarchy of parts, but as a rule the hierarchy depends on the point of view of the representation's author. Part retrieval is driven by the hierarchy structure when it should be driven by the characteristics of the parts.

So we propose to make the same information available at the same time to all the actors of the extended enterprise by having **only one computerized representation** of each part in one database and moreover, to facilitate **selection by means of property value**, as independently as possible of the classification structure.

3.2 *From one computerized representation to several human-readable presentations*

But we cannot prescribe only one view on data. Experts who work on products have their own background and their own point of view on parts. It is impossible to create one part presentation structure for all needs (design, financial, stress analysis…). The solution we suggest is to have both a single computerized representation for each part but to offer several points of view on this information: **several human-readable presentations of the same computerized representation.**

Therefore, our approach consists in building first the (possibly distributed) database with all instances and all properties about data, and second generating presentations from this database for all the various disciplines, software tools and needed documentation.(Fig. 2). Presentations constitute various views of representations.

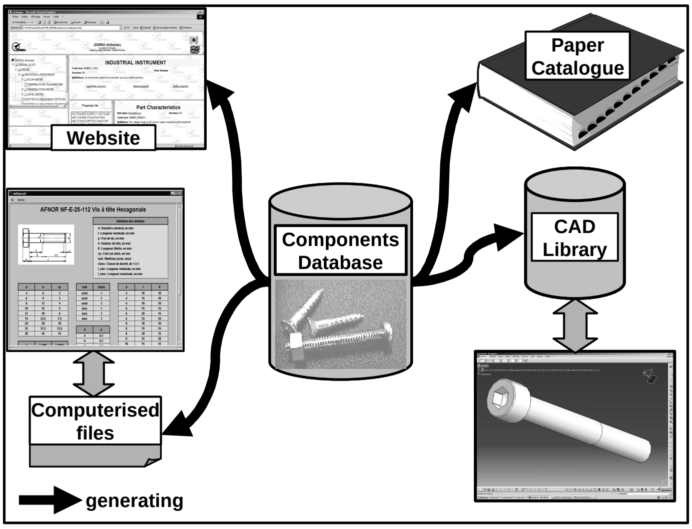

Figure 2: Generating human-readable presentations

Thus computerized representations to capture all the part data need to be created in one place. The set of points of view specific presentations is generated automatically from this database. Moreover, the database structure shall allow to compare parts according to their characteristic properties.

3.3 *Use properties to reduce parts diversity*

Moreover, to reduce the number of parts, we suggest to define a property for each part with the value Recommended/Not Recommended. A part expert will review the set of existing parts and selects those which are recommended and those which are not recommended. Substitution of not recommended parts by recommended parts will decrease the number of different parts. This process becomes possible when all the parts are accessible at the same time and are described by the same properties. It is possible for instance when a not-recommended part is selected to display and suggest all the recommended parts which share the same property values. Moreover this can be done in each discipline specific presentation.

3.4 *Obstacles*

Creating a single model for all information elements existing in legacy representations is a real challenge.

Different kinds of properties exist, like dimensional properties or commercial properties shall. Moreover, their integrity shall be guaranteed in particular by ensuring that the same currency for prices or units for length and mass measures always assumed. Usually, each point of view-specific representation has its own model and its own information structures. Commercial databases usually store information with a table-like structure. This computerized representation is common in most business-oriented activities. But in PDM (product data managers) systems, data are modeled by tree representations. Rules help users to select parts by hiding some paths according to the selection query they have specified. The unique computerized representation must federate all these data models and support in particular the same selection methods. Moreover, it must ensure properties integrity in their definition domain. Finally it should be able to associate with each part the various tool-specific presentation like CAD geometry models or marketing pictures.

It is precisely what the PLIB model allowed us to do. We summarize in the next clause the model capabilities.

3.5 *The PLIB model*

PLIB, for Parts Library, was a standardization initiative launched in the beginning of nineties. The PLIB standard ISO 13584 permits to model parts library data in computer sensible representation and enables an unambiguous exchange of parts between suppliers and users. We can characterize the PLIB approach in four points:

1. This standard uses an object oriented approach for capturing supplier's knowledge on parts;
2. PLIB is formally specified to guarantee independence between computer and software systems;
3. PLIB separates the data model from the data it models. The data model is defined at the dictionary level, while data are stored at the content level. A dictionary is defined with a hierarchy of model classes and supports integration of multi-supplier libraries. Each supplier can define his own library with parts (a screw, a bolt, a cutting tool …) and properties (screw diameter, bolt height, hardness of the cutting tool …). If several suppliers reference a common dictionary, libraries with structures can be defined.
4. The part definition and the part representations are separated. Representations have an independent hierarchy of functional model class, linked to dictionary model classes by relationship related to representation (view-of). This allow multi-representation (for drawing software or simulation) of parts.

3.5.1 *Modeling of data parts family-the PLIB dictionary*

To define computer sensible parts library, we must identify which important items characterize existing libraries. In paper catalogues, suppliers expose their lists of parts. A user selects a part according to the family he specifies or according to the value of a given part property. Nevertheless, the user must consider the knowledge of the point of view the supplier used in order to define the parts and the associated library. This knowledge is either processable (if it is computerized) from library. In paper catalogues, suppliers often describe categories of parts, their properties and their classification. These concepts define supplier ontology. Thus, in order to get benefits of all the concepts, computerized, parts library must supply this ontology information with the catalogue content.

To handle such ontology, PLIB uses an information model (Sardet, E. & Pierra, G. 1997), written in the EXPRESS language (ISO/IS 10303-11 1994, Schenck, D. & Wilson P. 1994) and a methodology developed and published by IEC (the International Electrotechnical Commission) and the ISO (International Standard Organization). As example, IEC has developed a specific dictionary to define technical properties and parts family for electrotechnical parts (IEC 61360-4 1997). Other dictionaries are under development, especially one for fasteners (ISO/CD 13584-511 2002).

PLIB dictionary (Pierra, G. 1994) allows to define a classification tree to identify families and properties and also information to qualify each part and each property.

A part family is identified through a unique code, a version number, its author identification and other information like definitions, superclass and subclass. The superclass gives a single inheritance tree and allows hierarchical classification thanks to the is-a relationship. Technical properties fill up the definition.

A technical property is identified similarly with information like code, number of version, identification of the class where it was defined and other information (translation, domain of values, symbol …). Properties are classified in three families:

– Non dependent property: an invariable property whose value is fixed once the part is defined. E.g. a screw's diameter or a nut's height;
– Condition property: a context parameter whose value characterizes the part use condition. E.g. torque to screw parts in one sort of material;
– Dependent property: a property whose value depends on condition property i.e. it is computed from the depending on the values of a condition property.

To design a catalogue according to the PLIB approach, suppliers define a dictionary level before storing their part. So, they use the previous concepts to build a tree of classes and properties or they can reference an existing dictionary, thanks to the codes of classes and/or properties. When referencing the dictionary, suppliers can define their own parts hierarchy by selecting parts families and properties used in their catalogues. This relationship between the normalized dictionary and the supplier dictionary is called is-case-of. If several suppliers define their own catalogues with the same dictionary, users can compare them without ambiguity on knowledge. This is the basis of integration on federation of data in PLIB.

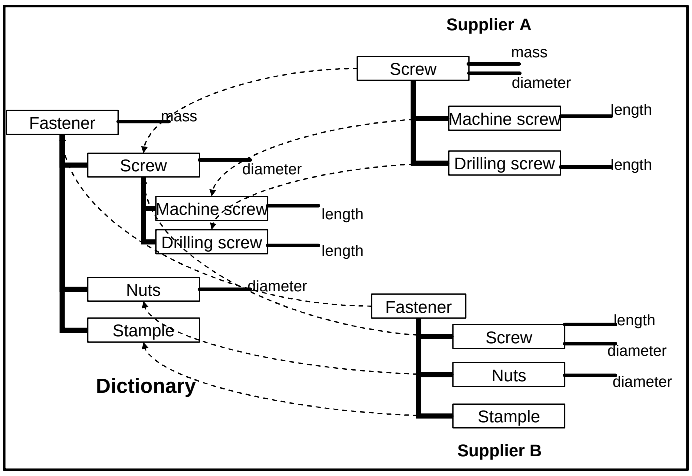

Figure 3: Dictionary with several catalogues

3.5.2 *Modeling contents*

3.5.3 *Modeling representations*

According to our previous presentation, PLIB suggests to represent another hierarchy with functional classes for storing tool-oriented presentation (Pierra, G. 1993). A functional model class of the representation hierarchy refers to one or several classes of the general model by the view-of relationship and allows to represent technical models with several points of view. Properties (non dependant, dependant and context properties) needed for the view are identified. Then, some attributes, called representation attributes, are derived from model properties.

4 CASE STUDY: FASTENERS IN MANUFACTURING INDUSTRY

To illustrate the use of PLIB for reducing the diversity of data through integration and federation, a case study was performed. In an automotive industry, designers search their fasteners in independent supports like paper catalogues, intranet websites, CAD libraries for CATIA, specific software libraries to perform stress analysis, etc… A single part may is currently described on several supports. We tried to centralize all fastener data in a single computerized representation using the PLIB data model.

4.1 *Methodology*

Various documents, paper catalogues or intranet websites represent views of a same application domain (fasteners). Each support has its own classification. Therefore various search methods according to the used document have to be defined and mastered. The diversity of the information points of view has not been contested. But due to the heterogeneity, updates between the different formats are handmade. This entails costs and delays, due to difficulties to update parts information. The diversity of points of view leads to different structures and different definition formats as listed below.

- Paper catalogues are generally written with MS word. The structure of these documents is presentation-oriented. Therefore parts information is presented to be human-understandable. Parts families are followed by other parts families in order to build a list;
- Intranet web sites use a similar approach. Information is structured to be understandable for readers. Parts families do not appear as a list but they appear as a tree displayed on a screen. Families appear in the leaves of the tree;
- CATIA uses PDM (like Enovia VPM) as parts library. It is based on a tree-oriented structure different from the website tree structure;
- Specific software like stress analysis tools uses CSV files to load part's definitions.

4.2 *Our approach*

Our goal is to evaluate the feasibility of a unique representation of all the necessary information. We propose to create a PLIB-oriented database and to generate, using an automatic processing, all the discipline-specific presentations from this database. The use of one single database is important to consolidate all part information in a single place. The PLIB format allows to support the previously listed representation structures and gives flexibility to define the data model at the dictionary level. An object-oriented structuring is efficient to capture the part model. Moreover, the definition of properties allows to give not only domain values but also units for properties and other useful characteristics. Separation between a general model (representing part families) and a functional model (representing presentations) facilitates the generations of presentations. Moreover, the use of EXPRESS language gives a neutral format from which several presentations can be generated by automatic tools.

So the development of a PLIB database requires three steps:

1 Collecting information related to the knowledge on fasteners;

2 Defining the fasteners ontology allowing to categorize the knowledge concepts, by using PLIB model;
3 Designing tools for generation human-readable and discipline-specific presentations of the set of fasteners.

These steps are described in details in the following subsections.

4.2.1 *Collecting existing information on fasteners*

To collect the existing information on fasteners, information in the automotive manufacturer item database, in fastener suppliers' catalogs and websites are first considered. They contain families of fasteners, but only dimensional properties are itemized. Specific stress analysis software require also mechanical properties for computation. We extracted them for the software library. So, all the information elements about fastener existing in the company are now gathered.

We group all these information items on a single support. We use MS Excel worksheets for the following reasons:

- This software is available on most of the computer systems;
- The structure of the worksheets gives a table like structure. Facility for adding/removing columns allows us to add or remove properties;
- Sheets permit to do a first information structuring separating the parts family (for example a family per sheet);
- The MS Excel software can save information under CSV (coma separated files) this format is exploitable by automatic tools.

With this first step, information on fasteners is available in a computer format that may be understood by human beings. All elements are centralized, in a flexible structure that allows adding or removing families and/or family properties.

4.2.2 *Defining and modeling fasteners ontology*

At this stage, all information about fasteners like: families, properties and list of parts are consolidated. The next step consists in associating a PLIB representation. Using PLIB concepts, the associated data model will be defined at the dictionary-level (ISO 13584-42 1998) and the parts at the content level (ISO 13584-24 2002, ISO 13584-25 2003). The design of fastener dictionary is facilitated thanks to the PLIB Editor tool.

PLIB Editor is a JAVA application designed by the Laboratory of Applied Computer Science (LISI/ENSMA) for browsing, modifying and creating a parts library according to the PLIB specification. A data model or a dictionary is defined by using a hierarchy of classes and properties definitions. Windows display part in a table. User can input part values or load CSV files issued from MS Excel or any other software. PLIB Editor generates portable STEP files in order to exchange PLIB libraries between computers. But, how do we build the dictionary? We suggest two approaches.

1 Define our own dictionary. Each concept is defined during the first step and several documents explain how structuring the data-model. Thus the dictionary meets our needs but nothing ensures that all fasteners manufacturers and users have the same concepts and definitions.
2 Define our dictionary by referencing a normalized existing dictionary like the one developed by the CNIS (China National Institute of Standardisation) (ISO 13584-511 2002), which has proposed a fasteners dictionary, standardized at ISO level according to PLIB concepts. Thus we can define our dictionary by referencing the CNIS dictionary. Technically, the case-of relationship, defined in PLIB is used to support this referencing mechanism.

4.2.3 *Generating human-readable presentations*

As asserted in previous sections, PLIB based database are stored in a neutral computer sensible format. Various presentations, essentially websites, paper catalogues and CSV files, will be generated from this PLIB database.

4.2.3.1 Documents for the web

Web sites purpose is to show suppliers fasteners for users. In most existing Web site, the document presented on the web site has some flaws. Indeed, if designers search a family of parts in a tree, they find a page in HTML or PDF format that shows all parts of the family. They must read the whole page to select the part they are looking for. This document gives nothing more than a paper catalogue. Information within the documents is static.

However, in a PLIB based approach, and thanks to the explicit modeling of information, it is possible to generate dynamic documents for the web from PLIB database. A tool which is able to generate HTML webpage in order to put them on the web can be defined. Moreover it is possible to enrich the document by dynamic information. Such a tool exists. PLIB Browser takes a PLIB file and generates an electronic document in DHTML (Dynamic Hypertext Markup Language). With such a document, designers can select a part by evaluating some part properties. It is possible to select particular parts thanks to filters defined on properties instead of reading a static document.

4.2.3.2 Paper documents

To search parts in paper catalog, designers use either summary (sums up the catalogue and follows its classification) or tables made to help selection. PLIB data base content allow automatic generation of these documents. A tool called P21toXML generates XML files from PLIB files that reflect the information structure as defined in PLIB (semantic tagging). But the main advantage of paper documents is the ordered and tree-structured presentation of information. The structure of object-oriented files used by PLIB is different from the structure of documents. Therefore, the PLIB approach proposes to define a document model using HTML tags. A Style sheet written in XSLT takes the XML file and the HTML model and generates the HTML document.

4.2.3.3 Specific files for software

Specific software like stress analysis tools generally use CSV files to load components model. Such tools are used by designers to compute screws and bolts characteristics in an assembly. Users specify properties of the assembly with dimensional properties and context constraints. Software selects screws and nuts corresponding to the parameters. Such tools need specific internal representations of fasteners. A file format exists to allow updating of the tool library of fasteners. These files correspond to CSV files with keywords identifying information. A tool that we developed takes PLIB files and generates files conform to the software specification (i.e., using keywords).

Another proposition will be to load PLIB files in such tools but we must modify each software.

5 CONCLUSION

The purpose of this paper is to contribute to reduce the diversity of parts in the manufacturing industry. We have first identified one cause of part diversity: the diversity of part description and their content heterogeneity. Each description is a stand alone representation and needs to be updated by users using a handmade approach. As a consequence all the human-readable presentations of these descriptions are not at the same updating state. Moreover, some parts appear only on some descriptions and not on the others. Each description suggests its own selection methods and can not allow powerful comparison between parts.

We propose to create a single computerized representation of each part within a database. This database is based on the PLIB data model which defines all the useful mechanisms to capture all the aspects of a part description in computer sensible representation. Its standard format allows to generate any kind of human-readable presentations with tools like the generation of DHTML document by PLIB Browser.

We have presented the implementation of our proposal through a case study: the management of fasteners in some manufacturing industry. Before our study, there were no description (document or whatever) that contained all the information on the used fastener. Each document has its own list of parts and some parts appear only in one document. Several steps were defined. The first step was to group all information items about parts family and properties of parts defining the fasteners ontology. In the next step, this information is put into PLIB format using the PLIB Editor tool. Then all the existing presentations have been re-generated (with an improved content) by an existing tool like PLIB Browser. These tools are based on JAVA and use PLIB API to manage PLIB files and to produce the needed documents.

This approach, based on the PLIB technology, gives a whole methodology, supported by automatic tools which allow to centralize all relevant technical data for parts in a PLIB database. Moreover, tool-specific representations (like CAD models) may be attached. This approach has been validated on a non trivial case study in manufacturing industry: the fasteners.

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