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ONTOLOGY BASED INNOVATIVE SUPPORT IN INDUSTRIAL PRODUCT DEVELOPMENT

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Abstract:
Within the unique and small series industrial product development, especially custom-made products assuming major responsibilities on management is required: assuming the responsibility of innovative technological solutions that ensure quality, the specification of purchase components with a reasonable quality/price rate, and with a quick response to market requirements with a very short production cycle. The generic product development model, based on the use of ontologies, will allow addressing the structuring of a variety of products, even of families of products, so that future projects may benefit from the historical background of a certain configuration. The purpose of this paper is to develop a generic ontology model for machine, machinery and equipment type products, which should be a support tool assisting the decision making on the structure and composition of the product. For the development of an ontology of an industrial product type it is required a framework common to that of design engineers. We summarize the results of product structuring operations developed in the design of the maintenance and service machines of sewerage facilities. Steps were taken in view of the ontological approach of the development process for the following types of equipment that are part of the same family: Suction Cum Jetting Machine, Cesspool emptier and Sewer Jetting Machine. Following the analyses carried out, 14 macro-structures were identified with which one can structure any type of machine mentioned above. Approaching the product development starting from subassemblies implicitly allows paralleling the design activity with the manufacturing activity.

Keywords: custom-made product, industrial product development, ontology engineering, innovative support tool, Protégé
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1. INTRODUCTION

Product development has focused in recent years on users' requirements. Excellence in this type of activity is supported by the use of the CAx systems from the product design phase and until its removal from service. An important aspect of these activities is the data management process that requires a holistic approach, a fusion between application systems, data, processes, techniques and skills. The product life cycle management through a PLM solution allows the inclusion of all the elements needed to ensure its traceability, such as modelling, document management, numerical analysis, the capitalization of know-how, etc., and of all the components of the information system that provide monitoring the product from manufacture to marketing and then to its disappearance or recycling (Zina et al., 2006).

Developing a product from idea to product design, draft, technology, production planning, manufacturing, operation, until it is withdrawn from service, requires activities that are based on reasoning, logic, technological, manufacturing, trade structures etc., all based on knowledge. However, the final cost of a product is heavily influenced by the quantity and quality of knowledge, still from the design stage. In a general framework, the competition on the developers of innovative products market is strongly influenced by the knowledge of the following basic concepts: cost, quality, training conditions, warranty, and post warranty services. For example, an accurate manufacturing cost estimated at the design stage leads to higher chances of success and a controlled competition. According to Sullivan, Bontadelli, and Wicks (2000) the design phase determines between 60% and 80% of the final cost of the product in the form of materials, construction costs, capital investment or ancillary costs. It is shown by this example that the design phase, not exceeding 5% of the product project budget, may influence both the final cost of a product and the economic performance of the company. Our own research on the development of one-of-a-kind or small series products led us to data showing that less than 1% of manufacturing costs were the costs of product design.

Given this finding, manufacturers take a high risk if the design phase is not well coordinated and supported by the knowledge base in various fields. Some of these risks are due to frequent changes of design solutions, budget alteration or implementation deadlines. The corporate objectives regarding profitability, competitiveness, innovation, quality increase, launching of new products, customer satisfaction and sustainability can only be achieved through the strategic approach of change management and understanding of all the factors influencing change.

Noting that a successful integration of information could not be achieved without an effective strategy on the exchange of information, many authors of artificial intelligence have developed techniques for capturing and representing knowledge in order to build a knowledge base in various fields. The existence of common knowledge within product development has given rise to the idea of meeting them in a common structure or a common vocabulary which then became "ontology".

Based on these findings, in this research we aimed to define a method of structuring a product with precise customer specifications and to create a generic ontology that can be addressed by this method. The solution was tested on a process of structuring members of a family of the maintenance and service machines of sewerage facilities.

2. PRODUCT DEVELOPMENT AND CUSTOMER-DRIVEN MANUFACTURING

Changes in the design process are intensified by shortening the product development time, by requiring a certain degree of innovation or by overlapping of activities in the product development process. To meet these challenges, designers are forced to take some risks in their work. These risks can be reduced by a constant access to information in a timely manner. Reusing the data from previous projects and the simultaneous coordination of certain product development activities will determine shortening the time of product launch on the market (Drăghici, 1999).

Designers use about 70% of their working time for the search and management of the knowledge involved in product design, so there is a significant decrease in the productivity of this activity (Kuffner & Ullman, 1991). Stauffer and Ullman (1991) studied why designers waste so much time to organize the knowledge of previous projects. One problem identified is that this knowledge is either inconsistently organized or not at all.

According to the Coopers and Lybrand study completed in 1994, 14% of an engineer's working time is spent on meetings especially in exchanging information, 21% of his time on the work that someone did before and 24% on the exchange of information and its recovery (ksvuori & Immonen, 2005). Only 29% of his time is spent on the actual work that is on engineering. This means that 59% of the time can be saved if the information system can help engineers extract, reuse and share information efficiently. PDM and PLM and other systems are designed to help users in the distribution of data and in simplifying the design process.

According to Ulrich, Eppinger, and Goyal (2011), product development is a specific set of activities based on the perception of market opportunities and ending with the beginning of production phase. This issue takes on new dimensions with the continuous diversification of the elements that contribute to the successful launch of a new product on the market. The characteristics of the stages in the life of a product are the following: quality, cost, development time, development cost and the capacity of enterprise development. Figure 1 shows the product development cycle specific to a business type point of view and Figure 2 shows the development cycle specific to customized products.

Figure 1: Product development cycle specific to a business type point of view

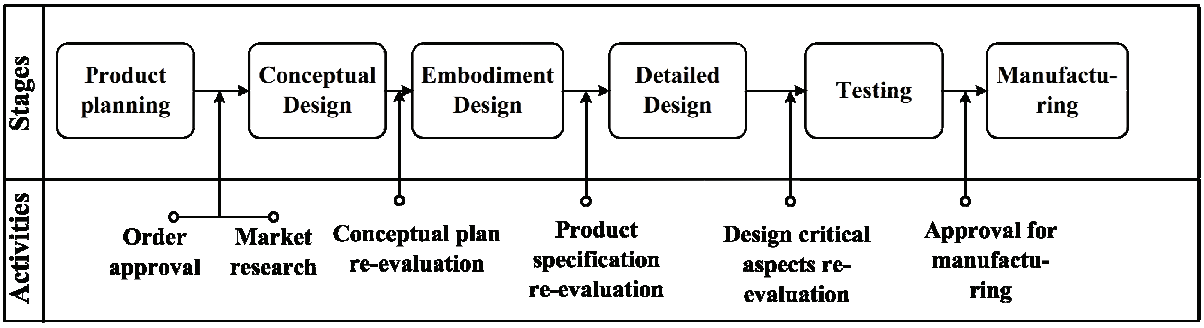
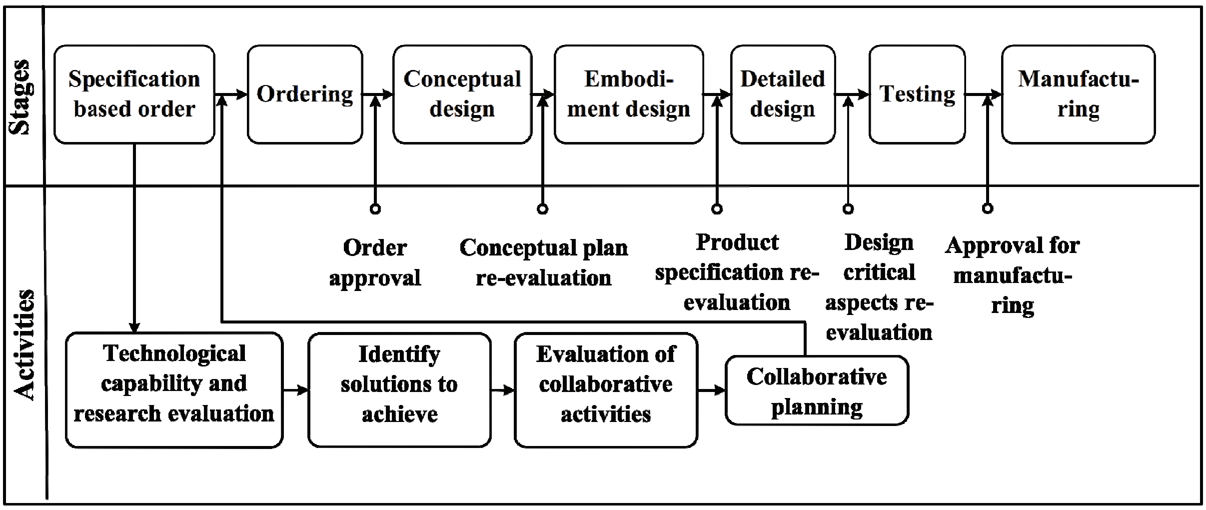


Figure 2: Product development cycle specific to customized products



Among the key technologies applied to the customer-oriented manufacture, to the product configuration and structure, there are two types of knowledge-based technologies: the first is based on the systematic reuse of standard components, and the second on predefinition in order to obtain customized products that meet both customer-specific requirements and the manufacturers' constraints and limitations.

Wortmann et al. (1997) describe three customer-driven manufacturing methods: assemble-to-order, make-to-order and engineer-to-order. In the assemble-to-order method, products are configured and customized based on the customer's specifications from existing standard components in stock, forming a hybrid between the manufacturing for stocks method (the products are made in advance) and custom manufacturing starting when taking the order. It is very useful to the extent that the customer receives the product in a very short time. The characteristic of this model is represented by a less complex structure, and stipulations can be resolved in a relatively short time.

The make-to-order method, although similar to the assemble-to-order approach by the fact that a product is configured from standard or predefined sets of components, differs in that they are not in stock, but will be produced at the time of order. The make-to-order is dominant at the moment, it covers areas such as automotive, aviation, machinery and equipment for engineering or civil engineering etc.

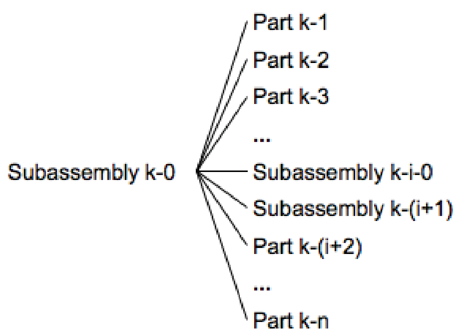
The engineer-to-order method is specific to products for which each product variant differs from the previous ones by integrating original components specially designed to serve and meet the individual customer requirements. In this approach, customers assume the right, by specification, to impose that certain requirements are met by predefined components, nonspecific to the company that makes the order, but of course within the limits set and agreed with the manufacturer. Predictably, the ease with which customers define the product, making use of many sets of predefined components in the product configuration, will not generate concrete or complete structures. In such cases design engineers will have to imagine product structures to satisfy all the requirements imposed by the specifications, the result of their work being always treated as a unique engineering project. Therefore, the product data specific to the project will be handled in a special way. Most often the design engineers involved in a manufacturing project engineering to order type will not be able to transfer knowledge within a family of products from one product to another, generally of the same type, because there are no methods and tools effective to this approach. Moreover, the documentation of such products will be very difficult to transfer from one product to another. For this reason, there are many design solutions resulting from previous projects, but which are likely to be excluded from the new product configuration. These are the main causes determining that the setup and structuring of products based on the engineering to make method are completely different from the other two approaches presented above.

Given these findings, the identification of a customer-driven product structuring method and a working mechanism by which this method can be easily implemented is the subject of the following section.

3. MODELING OF A PRODUCT HIERARCHY AND GENERIC ONTOLOGY

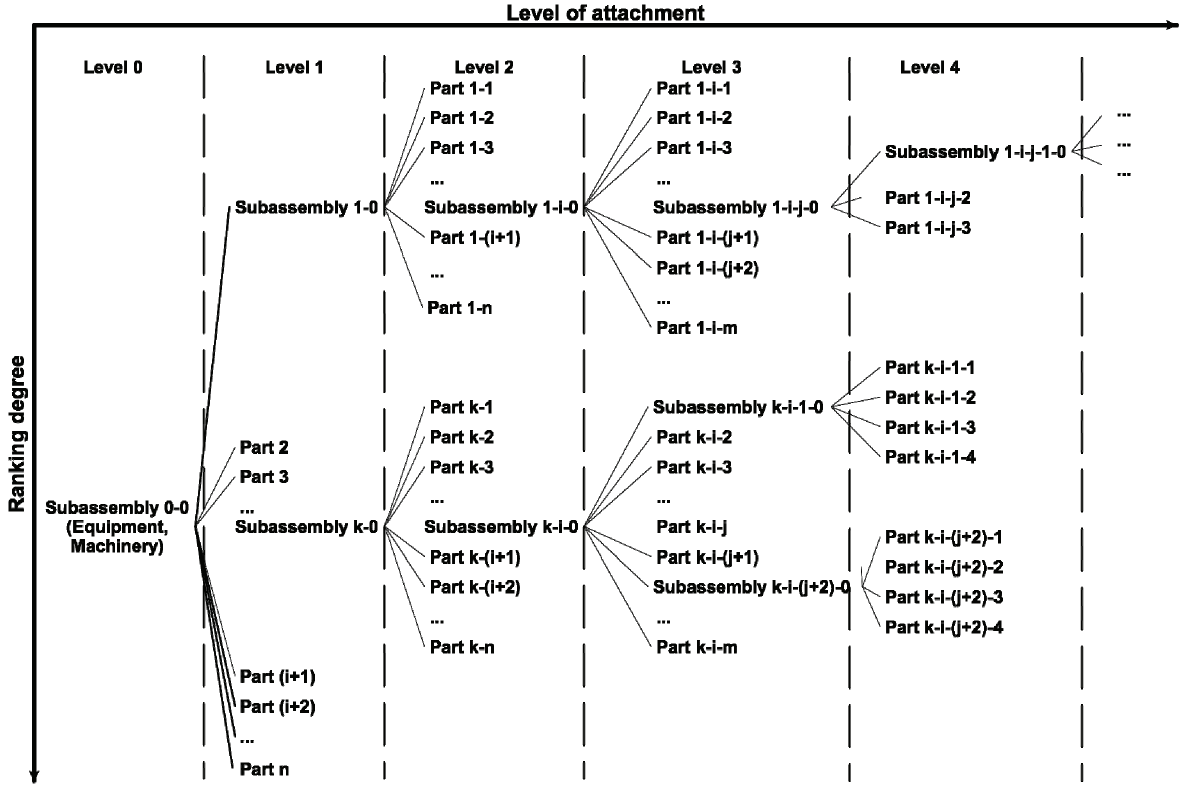
Van den Hamer and Lepoeter (1996) state that the concept of hierarchy is directly related to the semantic of the composition concept naturally recorded as having been obtained on the basis of *part_of* relations between objects. They also say that any product can be presented in different ways, the image of the product being completely different, e.g. between that which is done for the marketing department and the one used in the production departments. Both viewpoints describe basically the same object or product, the information of (re-)presentation being different. In the first case, the product image, from the seller's viewpoint, presents the characteristics of the product, possibly grouped by technical characteristics (formula, composition, shape, color, etc.), usage (performance, functions), psychological characteristics (behavioral, appearance) or associated characteristics (price, brand, service included, etc.) (Dubois et al., 1989). Instead, the product image as a seen by the manufacturer is completely different, having an tree structure of ordered objects and at the same time subordinated in an organized structure by attachment levels. Each level of this composition structure contains compositional structures of the type shown in Figure 3.

Figure 3: The structure of a subassembly *k* on level 1 of a hierarchy of a product



On such an approach it is noted that the components of a product are subassemblies and parts, not features like those presented by the seller. There is a clear distinction between the perspectives from which a product is seen and perceived. For an industrial product, machinery or equipment type, with a complex structure, a possible generic structure is shown in Figure 4. From this representation, the following are to be noted: the attachment level characterizes the degree of complexity of the product and the ranking degree characterizes the detail expressiveness of product structure.

Figure 4: The ranked structure of a subassembly

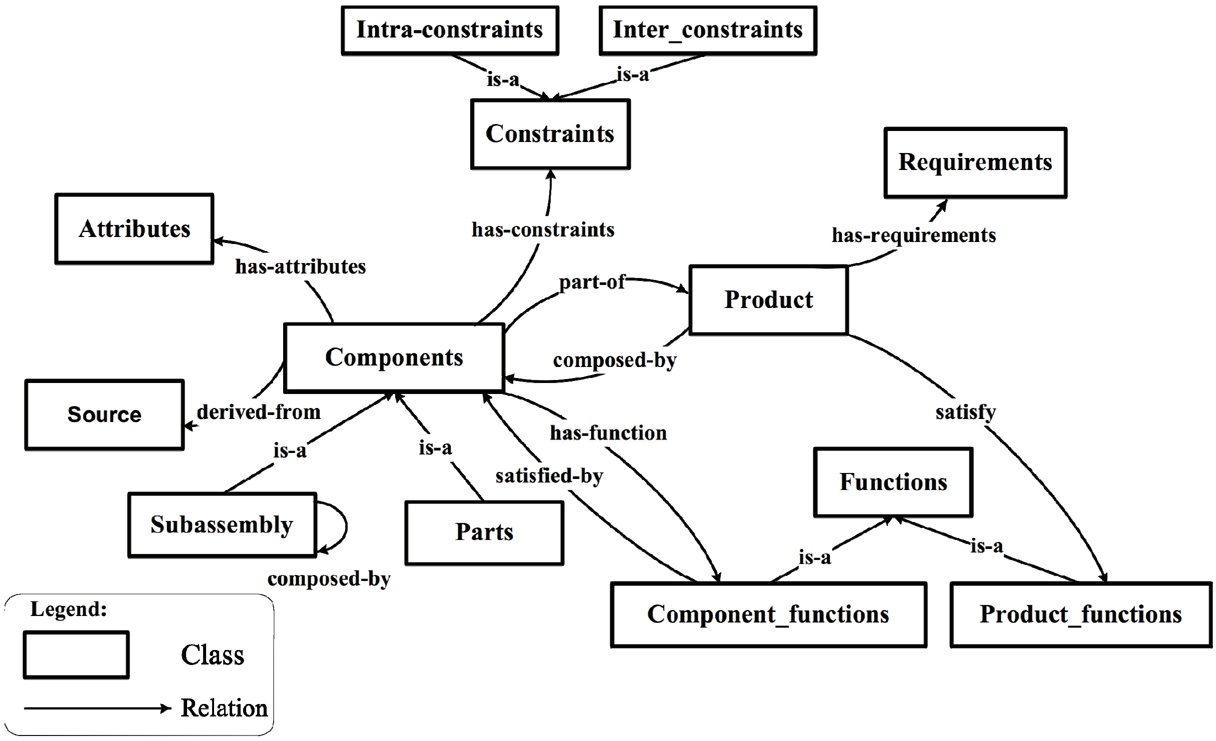


A widely accepted definition of ontology is given by Gruber (1993), namely: "ontology is a formal specification of a conceptualization". Gruber states that the term conceptualization is an abstract notion, a simplified view of the world that we want to represent with a particular purpose.

Several approaches to developing ontologies for products and services are known in several areas: biology (Gene Ontology, 2013; Lewis, 2005; Myhre et al., 2006), medicine (Bickmore, Schulman, & Sidner, 2011; Matei, 2008), design (Contraş & Pintescu, 2013) and geosciences (Hu, Tang, & Lu, 2014; Jung, Sun, & Yuan, 2013). Regarding special products like machines or industrial equipment, problems were treated relatively briefly in Barbau et al. (2012); Panetto, Dassisti, and Tursi (2012).

The general approach used to design the generic ontology follows the general principles described in literature (Fernández-López, Gómez-Pérez, & Juristo, 1997), highlighting the need of ontology evaluation throughout the whole design process, especially through the documentation of use cases and competency questions. The generic model is inspired by previous modeling work (Petrovan, Lobon□iu, & Ravai-Nagy, 2013; Petrovan et al., 2014), complemented with the analysis of the most used models of product structuring. In the first phase, they identified the relevant terms and concepts within the domain of structuring the products developed by the engineer-to-order method. In this regard, they identified, in the first phase, terms such as *Components*, *Subassembly*, *Parts*, *Product*, *Functions*, *Attributes*, *Requirements*, *Constraints* and *Source*. Subsequently, they have resulted in distinct classes.
In addition to the identified classes, the next stage is the process of modeling the domain involved defining relationships. Through these relationships the ontology instances will be interlinked. Figure 5 shows the generic ontology of product structuring, visualizing the relations between ontology classes.

Figure 5: The generic ontology of product structuring



The distribution on levels of the product is also a tool of analysis, documentation and communication of the results of a project and is part of the product planning techniques. In such a representation, the result provides a clear and unambiguous statement of the structure, assembly and delivery of the product. This technique is similar in approach to the technical distribution by activity in the manufacturing process of a product, but it is used in a preliminary stage and focuses on cataloging all the components, the requirements that will serve through the functions that they satisfy, the imposed constraints or the results of technical and economic analysis, the provenance of parts etc.

4. CASE STUDY: APPLYING THE GENERIC ONTOLOGY TO STRUCTURE PRODUCTS OF A PRODUCT FAMILY

This study summarizes the results of the product structuring activity developed under the contracts for the design of sewerage facilities servicing and maintenance equipment for the SC ADISS S.A Company. In this regard we have taken the steps outlined in (Petrovan, Lobon□iu, & Ravai-Nagy, 2012), namely the ontological approach to the development process for the following equipments: *Suction Cum Jetting Machine*, *Cesspool emptier* and *Sewer Jetting Machine*.

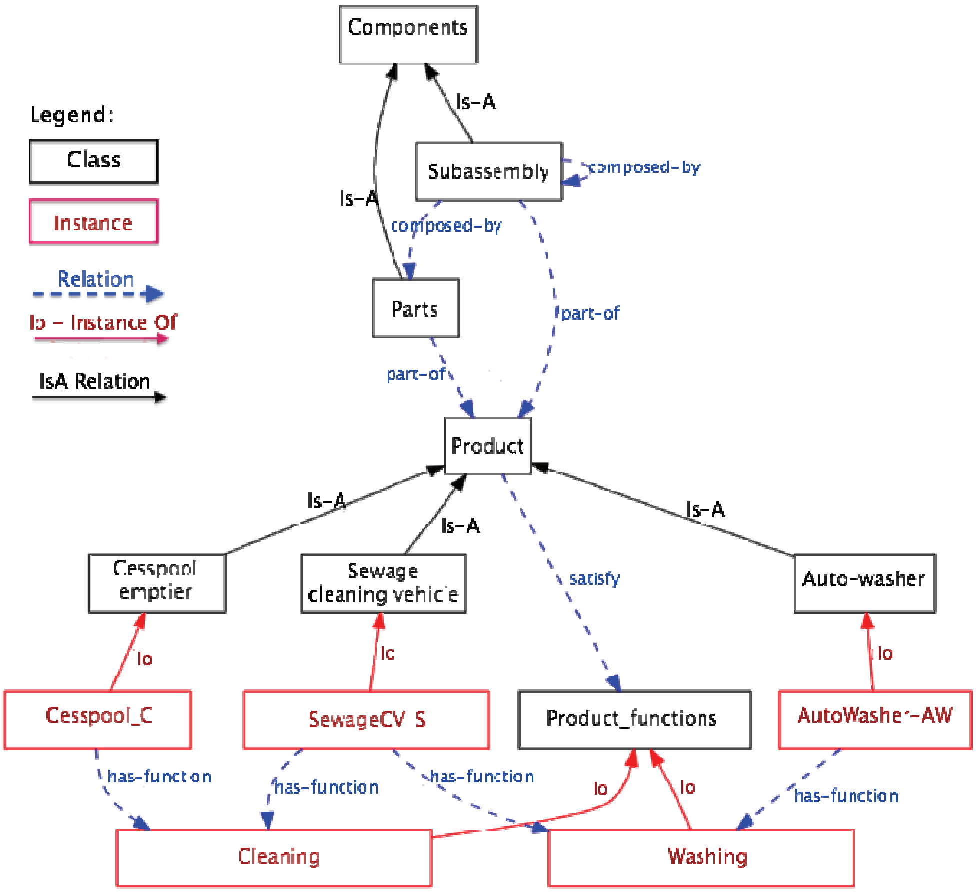
According to our analysis, we identified a set of 14 macro-structures with which one can structure any type of equipment mentioned above. Having once achieved the previously described generic ontology for modeling the products of this family, we derived ontology by introducing the following subclasses, which are subordinated to the *Product* class: *Suction Cum Jetting Machine*, *Cesspool emptier* and *Sewer Jetting Machine*. These classes inherit the *Product* class relations so that they will be able to be structured from the *Components* class, to which the *Subassembly* class being subordinated, the following subclasses were added: *Auto-chassis*, *Additional chassis*, *Power transmission system*, *Tank*, *Washing system*, *Absorption system*, *Water heater*, *Depth Absorption system*, *Cleaning system*, *Electric system*, *Pneumatic system*, *Hydraulic system*, *RAR system* and *Accessories* (Table 1). All these classes inherit the characteristics of the *Components* superclass.

Table 1: Macro-structure components in the family of sewerage facilities servicing and maintenance equipment.

Crt.	Macro-structure	Suction Cum Jetting Machine	Cesspool emptier	Sewer Jetting Machine
1	Auto-chassis	☐	☐	☐
2	Additional chassis	☐	☐	☐
3	Power transmission system	☐	☐	☐
4	Tank (water, mud, mud + water)	☐	☐	☐
5	Washing system	☐		☐
6	Absorption System	☐	☐	
7	Water heater in winter	☐		☐
8	Depth Absorption System, > 8m	☐	☐	
9	Cleaning system at the working place	☐	☐	
10	Electric system	☐	☐	☐
11	Pneumatic system	☐	☐	☐
12	Hydraulic system	☐	☐	☐
13	RAR system	☐	☐	☐
14	Accessories (tools, materials, etc.)	☐	☐	☐

To illustrate the structuring process, within this case study, the modeling of one member in the family of products (*Suction Cum Jetting Machine*, *Cesspool emptier* and *Sewer Jetting Machine*), one may see in Figure 6 the relations of meeting the functions of product within the generic ontology.

Figure 6: The satisfaction of product functions within the generic ontology



5. CONCLUSIONS

In this paper we presented a model of modern development of industrial products with an engineer-to-order approach. It can be said that this model is based on systems engineering principles, since according to them are defined the product development phases, beginning with the assessment of requirements and ending with product testing. These principles are presented and applied in all branches of product collaborative development.

The whole process described as an ontological framework of product development was successfully validated by the results obtained and the solutions to design contracts concluded with SC ADISS S.A.

Considering the results of the case study presented in this paper the following conclusions are to be underlined:

- Using the principles of product components hierarchy, we created a generic ontology that can be used when addressing the structure of any industrial product;
- Practically, for any product and at anytime, one can complete the structure of subassemblies and parts, being able to perform any review, update, and knowledge annotation;
- The ontological model allows in addition to providing a product structure the creation of a knowledge base of components (subassemblies and parts) with information on the functions they fulfill, on their origin, and attachments to other parts or products;
- A steady accumulation of knowledge will increase the volume and diversity of the knowledge base and will allow a prompt approach to the process of product structuring;
- Given that through the created generic ontology one can promptly generate product structures, we believe that this approach should become a current method in the design process.

The ontology of product development and especially of the families of products represents an innovative support because:

- It contributes to a rapid product structuring within a family of products;
- It contributes to the prompt specification of the components and subassemblies that are purchased from specialized companies;
- It allows the product development on subassemblies and implicitly the parallelization of design activity;
- Innovating on each component is the innovation of a product family;
- It creates the support for the collaboration in view of innovation and of open innovation;
- It enables the parallelization of production with the design of subassemblies in detail. All those presented above represent in fact the sustainability value of the industrial product ontology development.

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