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KNOWLEDGE MANAGEMENT DATA MODEL APPLIED TO PRODUCT DEVELOPMENT PROCESS IN SMALL TECHNOLOGY-BASED COMPANIES

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Abstract. *The product development process (PDP) has become an increasingly vital process for the company's strategy. In situations of high uncertainty about the product scope, or the project scope, there is a strong necessity of an efficient change management process (engineering or process improvement change). This scenario is often found in technology-based companies, where the involvement of innovation and working with new technologies tend to generate considerable uncertainty about defining products. Against this uncertainty and intense changes scenario, it's possible to lose control over the relationship between the product artifacts and product requirements. Therefore, it becomes essential for decision making in PDP and in the change management process that mechanisms exist to ensure the traceability of each requirement. Thus, knowledge management can be adopted as a strategy for reducing uncertainty and search for definitions in PDP. This article present a knowledge data model focused on reduce uncertainty on early stages of PDP, and providing subsidies for requirements traceability. The focus on small companies define an additional constraint of resources in the system, that should be able to be implemented in terms of a few human and material resources, but without losing the benefit of the change management and traceability assurance.*

Keywords: *Knowledge Management, Knowledge Representation, Product Development Process*

1. INTRODUCTION

Given the current competitive model of the market overall organization, companies have focused on developing products that meet increasing customer needs, at restricted costs in a timely manner. To increase predictability (repeatability) in product development, which ensures greater compliance with estimates of cost, time and quality, it can be studied as a business process, and so it's defined the product development process (PDP).

The PDP consists of the activities involved in the entire product life cycle, from the initial idea, to disposal and removal of the product from the market. VERNADAT (1996) further states that the high complexity involved in the development of new products requires better management of business processes and greater integration between companies and teams working on collaborative projects. So, the multidisciplinarity involved in the process of product development ensures the collaborative nature of the projects executed by multiple teams. And, the collaborative nature is responsible for coupling the development process activities, being one of the complexity and uncertainty sources of developing new products.

The uncertainties through each product development phase lead to changes (in product or process), which may represent not meeting deadlines or quality and cost estimation from product development.

The focus of this work in small technology-based companies ensures a context marked by the presence of the innovation and development of new technologies, intensifying the presence of uncertainty throughout the product development process.

For better focus definition, DAHLSTAND (2007) points out differences in the definition of technology-based companies, but shows consensus in dependence on technology for the development and survival of these companies, although this technology does not necessarily need to be new or innovative.

The knowledge for the development of products with new technology is often acquired through a process of research and development (R&D). DAHLSTAND (2007) also states the ability to set technology-based companies measuring the amount invested in R&D, or the number of employees involved in R&D.

In the case of small businesses, the boundary between R&D and PDP becomes less clear where the activities of each process may be executed together. This phenomenon can be thought as a result of the attempt to reduce the development time of new products, or by the reduced number of employees, which leads an employee to perform activities from both processes.

If the separation between R&D and PDP in small companies may not be very clear, the classification of technology based company by investment and involvement in R&D may not be adequate. Thus, the definition adopted is: technology-based companies are companies of intense use of technology in the development of products or services.

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This technology can be embedded in the product development process, in the production process or at any other stage of the product life cycle.

As noted above, changes in excess can be translated into increased costs of development (whether financial cost, time or quality loss of the product generated by rework), but can also generate a second effect: the loss of product requirements traceability, i.e. changes that are not conducted in a coordinated manner, or not documented during the process, can make difficult the association between product features and initial product requirements, reducing the efficiency of the process as a whole.

Faced with this problematic of changes in the product development process, raises the question: How to improve the PDP management, increasing the predictability of the development process, reducing the number and impact of changes, focusing on small technology-based companies?

VERNADAT (1996) points out the integration issues involved in managing the development of products under five perspectives:

- Integration of markets: promoted by free trade agreements, where companies have to adapt to the competitiveness of regional products purchased;
- Integration between various development centers and manufacturing: integration between companies promoted by the development of complex products, causing flow of information, control and material between the companies;
- Integration along the supply chain: companies in the supply chain must synchronize its processes, in efforts to reduce production time, sharing the risks involved in the product launch;
- Integration between product design and production: the use of concurrent engineering in the quest for reduction in product development time and minimize design errors leads to the need for greater integration between the activities and the knowledge produced in the product design and production.
- Integration between potential suppliers of hardware and software: the search for this integration is needed primarily to allow the replacement of suppliers, reducing costs of redesign.

This integration problem is being solved by a set of computational tools that working in an integrated way compose PLM (Product Lifecycle Manegement) platform. CHANDRASEGARAN, et al. (2013) pointed out in his recent work that an effective computational tool must rely on efficient knowledge representation model, able to retain a large amount of information accumulated at the end of an execution of the development process. This information is crucial for further developments.

CHANDRASEGARAN, et al. (2013) further enhance that the knowledge representation from information obtained depends not only on the information content, but the context in which the information was produced, thus requiring the development support tool to capture the knowledge produced over process and save the information context in a relevant way.

It’s notable the need for a tool to support the development with a focus on knowledge management. However, efficient implementations of these tools tend to be complex and commit high amount of resources (human and financial), often becoming impracticable, but necessary, for small businesses.

So, this article proposes a data model for representing knowledge produced and used during the PDP, which can base a computational system to support the product development and can be deployed and operated with limited resources, targeting small businesses.

The following section 2 presents a review of the concepts involved in knowledge management. Section 3 presents the architecture ARCE-PDP, used as the basis for knowledge management system. In section 5, the proposed knowledge representation data model is introduced. And finally, Section 6 contains a discussion about the proposed model and future work over the knowledge management data model introduced.

2. KNOWLEDGE MANAGEMENT

In this section, we present the concepts related to knowledge management that are relevant to the definition of the proposed model.

2.1 What is Knowledge Management

According to AMARAL (2002), knowledge management can be defined as "a set of dedicated efforts to ensure and encourage the knowledge creation, registration and sharing". TERRA (2000) also presents the division of knowledge management in three levels: strategic, organizational (human resource policies, organizational culture and organizational structure) and infrastructure, containing information and results measurement systems, the focus of this article.

According to AMARAL (2002), the practical problem involved in knowledge management is based on the following:

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- Knowledge Registration;
- Knowledge Validation;
- Knowledge Maintenance;
- Knowledge Recovery.

BARROSO & GOMES (1999) reinforce the multiple fields involved in knowledge management, for example: organization theory, philosophy, cognitive psychology and information science, among others.

However, knowledge can be addressed in three major classes (DAVENPORT & PRUSAK, 1998): data (knowledge stored directly in the database, collected from events or objects in development), information (knowledge produced by interpreting a set of data and is strongly linked to the sender and receiver of information) and knowledge (according to AMARAL, 2002, is the union of experiences, values, contextual information and intuition). These classes corroborate the definition of knowledge brought by CHANDRASEGARAN, et al (2013), where knowledge is not directly available, but is obtained by interpreting information deduced from an analysis of data.

2.2 Knowledge Classification

CHANDRASEGARAN, et al. (2013) point out that "classifying knowledge, just like understanding knowledge, is crucial in order to determine ways to represent it". Fig. 1 shows three classifications of knowledge from different dimensions.

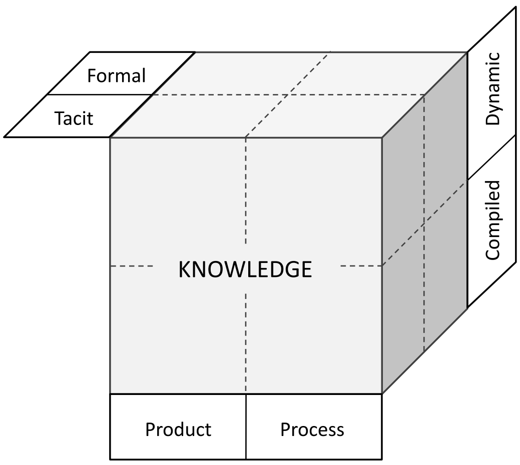

Figure 1. Classifying Knowledge – the different dimensions. CHANDRASEGARAN, et al (2013)

Nonaka and Takeuchi (1997) proposed the organization of knowledge into two basic types: explicit knowledge (formal) and tacit knowledge. Explicit knowledge is structured knowledge that can be translated and stored in a database, such as documents developed during the product development process.

However, tacit knowledge is knowledge coming from the people, i.e., the skills that each person possesses. This knowledge is difficult to record and broadcast within the organization. But, according to the authors, there is a cycle going on constantly in the company, responsible for the transformation of tacit knowledge into explicit knowledge and vice versa.

The transformations of knowledge happens in 4 stages:

- Socialization: it's the transformation of tacit knowledge into tacit knowledge, i.e., it is the transmission of skills or experience among people.
- Outsourcing: it's the transformation of tacit knowledge into explicit knowledge, i.e., when people write or record the knowledge gained during the process.
- Combination: it's the transformation of explicit knowledge into explicit knowledge. In this transformation, several sources of explicit knowledge are combined or grouped, using a systemic approach to knowledge.
- Internalization: it's the transformation of explicit knowledge into tacit knowledge, i.e., occurs when a person obtains the explicit knowledge and employ in practice, producing their own experiences and knowledge.

A graphical representation of the transitions can be observed in figure 2, which Nonaka and Takeuchi (1997) further reinforce that these transitions occur in spirals over the knowledge management. It is an evolutionary cycle.

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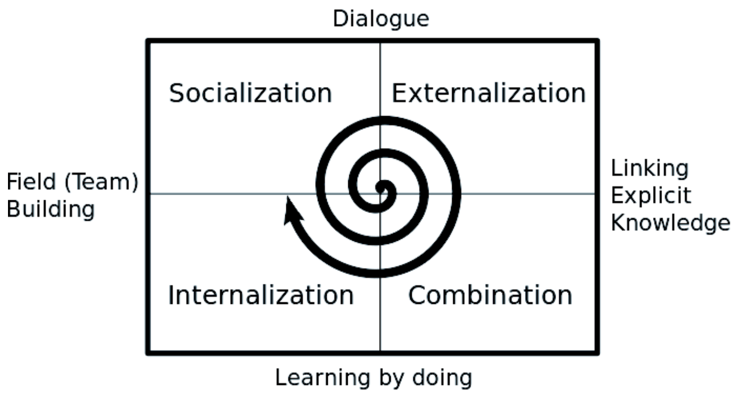

Figure 2. Knowledge Spiral. NONAKA e TAKEUCHI (1997)

The knowledge classification Product vs. Process comes from the knowledge generated during the product life cycle, dealing with knowledge about the product versus the knowledge generated about the process (the development, manufacturing or business process).

The knowledge classification Compiled vs. Dynamic deal with the knowledge structure, where the compiled knowledge is obtained and translated into rules, plans or roadmaps and the dynamic knowledge can still be used to generate new knowledge structures from implicit solutions.

2.3 Knowledge Representation

For AMARAL (2002), explicit knowledge, proposed by Nonaka & Takeuchi (1997), can be represented in eight ways, which are:

- Non-Standardized: it's the most common, and is represented by books, internal documents, reports, checklists, procedures, notes, etc. ANAND, MANZ & GLICK (1998) also claim that external knowledge sources cannot be neglected.
- Knowledge Maps: it's a form of explicit knowledge that points where is the knowledge, i.e., people, documents, database.
- Narratives: it's an explicit knowledge produced with narratives about events and happenings throughout the process. According to Davenport & Prusak (1998), this would be the closest form of tacit knowledge, which tries to represent experiences.
- Structured Language: by this way, knowledge is represented through a formed language, with standards and well-formed rules, which makes it less ambiguous.
- Rules: it's used in artificial intelligence and expert systems fields, having its origin much like structured language.
- Cognitive Maps: is a form of representation that generally uses arrows, which indicates the relationship between sentences, creating a knowledge map.
- Ontologies: it's explicit specifications of concepts related to a given domain.
- Business processes models: where knowledge is stored in the form of processes, dealing with every action of the day-to-day business.

These forms of knowledge representation must be worked within the knowledge management context to improve its use in the model to achieve the following goals:

- Fast encoding of knowledge;
- Fast knowledge recovery;
- And efficiency in the use of the information obtained.

The knowledge representation classification presented by CHANDRASEGARAN (2013), et al. was not used, because it clearly focuses on mechanical products design, which bring limitations to the conceptualization baseline that is being used, where the focus is only restricted to products of technology-based companies, but not necessarily mechanical products.

2.4 Knowledge Management Systems

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According to AMARAL (2002), the information system involved in knowledge management (KMS) must go beyond information management, providing further tools for group work. And the specification of this system can be done in two major steps: defining forms of knowledge representation and definition of computer technologies that will be used to implement the system.

The knowledge representation must be able to guarantee speedup the coding process, speedup the search process and still enjoy the efficiency in consumption of the retrieved information.

There are several possibilities for technology to be used for the development of knowledge management systems, although there is a larger trend in the use of Web architectures for this development, given the facilities for sharing and group work, encouraging collaborative development.

3. EXPLICIT KNOWLEDGE REGISTER ARCHITECTURE OVER THE PRODUCT DEVELOPMENT PROCESS

To develop the data model for knowledge management systems in small technology-based companies, the start point was the architecture proposed by AMARAL (2002), ARCE-PDP (Fig. 3). This architecture consists of three major classes: the first one is the repository of knowledge, which is assembled in three layers: registry, sentences and models.

The registries are the information produced during the product development process, for example, through meetings, events, conversations, reports, documents, etc. This layer if formed by unstructured knowledge sources.

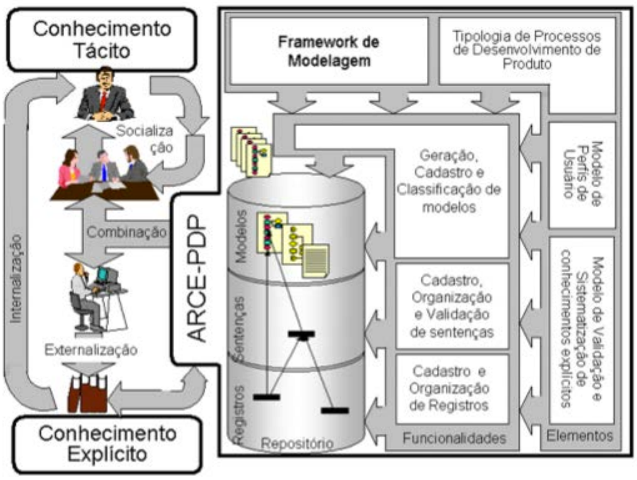

Figure 3. Explicit Knowledge Register Architecture over the Product Development Process (ARCE-PDP). Source: AMARAL (2002), p. 96.

The registries can be classified into six basic types: events, patterns, experts, interviews, cases, and bibliographical references.

The second layer, sentences, is structured forms of knowledge, which are formed primarily by rules, using one or more registries. According to AMARAL (2002), the sentences are essential for validation and systematization of knowledge produced during the PDP.

And the third layer, the models, is the representation of the process performed, or the whole structure knowledge acquired during the execution of the PDP. According to AMARAL (2002), it brings a systemic analysis of the process.

The second class is formed by functions: registration, storage, validation and updating of explicit knowledge, sentences, and generated models. These features are implemented based on the elements, which forms the third class. The elements are:

- Modeling Framework;
- Typology of the Product Development Process;
- Model of User Profiles;
- Model validation and systematization of explicit knowledge.

4. PROPOSED MODEL

According VERNADAT (1996), model is a useful representation of a given object, subject or knowledge. It is a representation of reality expressed in terms of formalism defined by modeling structures provided to the user. Following this definition, the proposed model will be presented as a relational data model used in knowledge management (tables and relationships between tables, Fig 4).

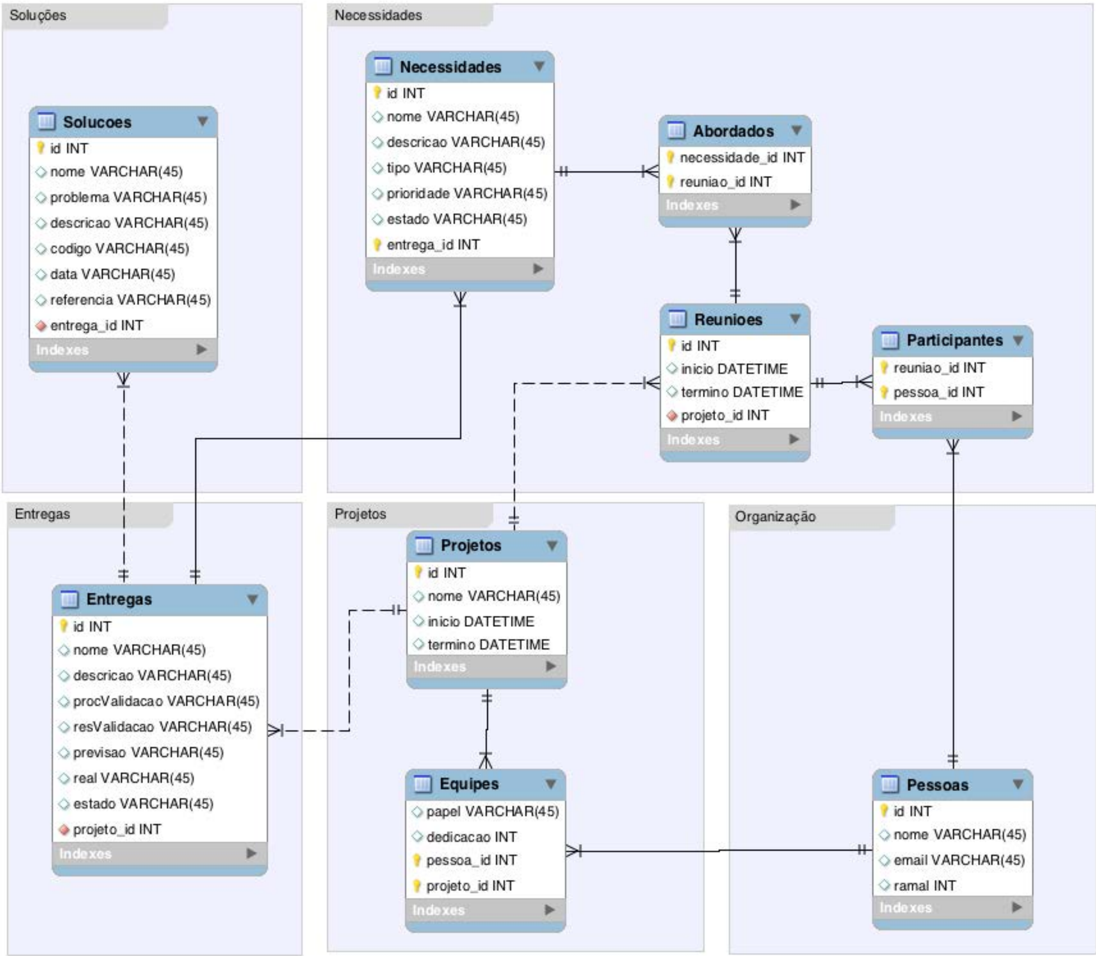

Figure 4. Proposed Model.

As already pointed out by CHANDRASEGARAN, et al. (2013), the knowledge model should be able to represent context information in which the knowledge was produced, so it was set up the regions Organization and Projects, where it's possible to explicitly represent when and who was involved in the act in which knowledge was worked.

Then it was studied the format in which knowledge is produced through the projects in product development and noted that knowledge is produced in the search for solutions for each project deliveries (deliveries in any stage of development), these deliveries are defined by a set of requirements that must be met. And, every need was discussed, defined and stipulated in meetings, with the project team or with clients, consultants and specialists.

But within the architecture ARCE-PDP presented, this model should support the registries, composed by:

- Events: in the suggested model, it's represented by the meetings;
- Standards: except in special cases, it can be treated as solutions that add value to the concluded delivery;
- Experts: he/she can be seen as solutions if he/she is only mentioned, or as meeting participant if he/she has been involved in development to aid in finding on implement the solution.
- Cases (which may be the narrative representation) appear in the table of solutions, which may be a case of failure, but that record knowledge for its failure to resolve a delivery;
- Bibliographic References (or quotes) will be added to the table of solutions, mapping references to problems or classes of problems, allowing them to be consulted in similar situations in the future.

The following section provides a more detailed discussion about the decisions taken in this model, with regard to the scope of the model comparing the performance of the product development process.

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5. DISCUSSION AND FUTURE WORK

To place the solution according to the concepts previously presented, it can be observed that the proposed model comprises part of the infrastructure of knowledge management, using the field of information systems focusing on the development data.

Regarding the classification of knowledge, clearly it worked with explicit knowledge, arising from transitions of externalization and combination, i.e., the written formalization of knowledge in a database. The other two classifications mentioned, it could be said that there wasn't a clear distinction between the knowledge of the process and the product, as well as between knowledge compiled and dynamic, these can all be present and be worked indiscriminately in this proposal.

Based on architecture ARCE-PDP (in first class: knowledge repository), the model focuses knowledge represented as non-standard, i.e. it registers the knowledge produced in the product development process, there is still the possibility of managing narratives as well.

As shown by Nonaka and Takeuchi (1997), it was observed that the knowledge and the actual execution of the product development process can be seen as a spiral, in which the construction of knowledge and the refinement of product development happens in an evolutionary way and iteratively ensuring this spiral behavior.

The approach of iterative process for product development is interesting from the perspective of knowledge management as it ensures the simplification of the data model and the refinement of knowledge generated in previous iterations, this refinement that will serve as input to the early stages of new product development reducing uncertainty and the need for changes in product and process throughout the development. The iterative process also helps the knowledge validation, which is one of functions of the knowledge management system.

The relationship between deliveries and needs (or requirements) warrants to design a record of traceability, where it creates a bond of each delivery with every need or requirement stipulated during the project running. Going further, in case of change in the needs or requirements, we can immediately verify which deliveries will be affected by such change and new traceability relationships are established, increasing control over the development at each iteration.

Reached the goal of enabling a reduction in the number and impact of changes, there was also the goal of traceability requirements being met throughout the design. But it is important to emphasize that the purpose of this model is to solve the problem of knowledge management as a strategy for improving the management of the product development process, with no intention of bringing project management model assignments for this model, which is a proposal for future evolution of the concept: integrate this model of knowledge management with the model to project management, establishing the union of these models in a single development methodology.

For the practical application of this data model for managing knowledge, it is also necessary to specify the interface to the user perspective, where the user will feed this structure according to the development process implemented in the target company. This interface is preferably WEB interface, with resources for collaborative development, acquiring the target of knowledge dissemination, with knowledge retrieval.

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7. RESPONSIBILITY NOTICE

The authors, André Luiz Pereira Corrêa e Andrea Cristina dos Santos, are the only responsible for the printed material included in this paper.