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TDKMS: A System for Managing Knowledge for the Design of Cables Terminations

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Abstract Knowledge has been recognized as one of the most valuable assets of an organisation. Advances in information technology play a major role for organisations to manage their knowledge and compete in the quality battlefield. An organisational memory is an artifact that exploits advances in information technology to support the Knowledge Management processes. This paper presents a prototype Knowledge Management system that aims to amplify the ability of an organisation to support the design of cable's termination[1] The system supports the basic knowledge and learning processes within the organisation. Major considerations that drove the design of the system were the adequate treatment of designers' functional experience and the seamless integration of the system in organisation's workflow.

Keywords: Knowledge Management, Organisational Memories

1 Introduction

The knowledge assets and the learning capabilities of an organisation are the main sources of competitive advantage [1]. In today's highly dynamic business environments, the effective and efficient management of knowledge within an organisation is indispensable for its success. A successful organisation should be a Learning and Adaptive Organisation that should act based on Organisation and Generative Learning for its survival [2].

The goal of knowledge management is to leverage the performance of any worker involved in any task requiring knowledge, by providing help to him towards achieving his goals. The aim is to get "knowledge-powered organisations", i.e. organisations where knowledge management happens in the background as part of the day-to-day job. Towards this aim, an individual must work at the "knowledge level": receive the right information at the right time and at the right form in order to perform a task in real time, stay connected with colleagues that may provide solutions or hints towards solving problems, form groups of people with different areas of expertise and/or different competencies to achieve a

[1] Roughly speaking, termination is an accessory for an electrical cable, which is used at the end of it.

shared goal, be equipped with the necessary applications and data to fulfil their tasks and form decisions in real time. Moreover, individuals should be able to provide feedback and share their knowledge, which must be actively and constantly captured, stored, and organized in the background, so as to be exploited in tasks performance and be disseminated to interested colleagues.

As already pointed in [6], work towards providing technological solutions for managing organisational knowledge is distinguished in two main streams: (a) The process-oriented view that understands Knowledge Management as a communication process that can be improved by groupware support systems, and (b) the product-centred view that focuses on knowledge-items (e.g. knowledge documents) and on their creation, storage and reuse in "organisational or corporate memories".

The objective of this paper is to describe a prototype system for managing knowledge for the design of terminations (Terminations Design Knowledge Management System - TDKMS). TDKMS follows the product-centred view towards assisting human designers to design terminations. It exploits formal design rules and tacit knowledge concerning terminations design. TDKMS retrieves previous design cases according to customers' requirements and design choices. It further provides designers with problems reported and corresponding solutions, related to each retrieved case. Reported problems are provided as user feedback to design cases and may include customers' feedback for the effectiveness or function of a termination, or designers' comments on a problematic situation that may arise due to a specific termination design. A solution to a problem may indicate a new design, some changes in the original design, or some thoughts on how the design can be further improved. In this way, people are able to provide feedback and share their knowledge in an active and constant way.

The paper is structured as follows: Section 2 gives some theoretical aspects of knowledge management systems and justifies the need of such a system for the design of terminations. Section 3 describes TDKMS and provides examples of its operation. In section 4 conclusions and future work issues are addressed.

2 Theoretical Aspects on Knowledge Management Systems

2.1 Knowledge Management

Human knowledge is distinguished between explicit[2] and tacit[3] knowledge as suggested by Polanyi [3]. Nonaka and Takeuchi formalised a model for knowledge's life-cycle indicating a flow between tacit and explicit knowledge through four different phases: Socialization, internalization, externalization and combination [4]. Under this view, Knowledge Management processes are defined to

[2] The knowledge that can be articulated in formal language including grammatical statements, mathematical expressions, rules, manuals and can be propagated easily.

[3] The knowledge that cannot be easily articulated. That kind of knowledge exists in people's mind and can be presented through their actions.

be those that support and facilitate knowledge flow through all the phases of the life-cycle. Knowledge Management can be tackled from several viewpoints: socio-organisational, financial and economical, technical, human, and legal [5].

Major Knowledge Management processes are as follows:

- **Knowledge Acquisition:** This is the most valuable and critical process for Knowledge Management since the organisation must acquire the knowledge that is necessary for its operation and make it readily available to the organisation. Hence, there is a demand for efficient and effective harvesting of the "right"knowledge.
- **Knowledge Developing:** Organisations survive by the continuous development of new knowledge based on creative ideas. Knowledge items must be interlinked so as to support the potential for knowledge combination and analysis.
- **Knowledge Preservation:** Knowledge must be stored and organized for later use, so it can be maintained and re-engineered efficiently.
- **Knowledge Distribution/Retrieval:** Knowledge must be distributed to those who make use of it. Retrieval of knowledge items must be done in an efficient and precise way.

Therefore, knowledge management tools must facilitate and support the acquisition, preservation, exploitation and continuous improvement of organisation's - tacit and explicit - knowledge, which is relative to its goals.

2.2 Organisational Memory

Organisational or Corporate Memories are artefacts that aim to provide the necessary tools for supporting Knowledge Management processes. In [7], Prasad and Plaza define Organisational Memory as "the collective data and knowledge resources of a company including project experiences, problem solving expertise, design rationale, etc."It is a repository of company's, individuals' and groups' knowledge, with the purpose of supporting the effective performance of knowledge-intensive tasks. Kuhn and Abecker [6] successfully notice: "in analogy to human memory, which allows us to build on previous experiences and avoid a repetition of errors, an Organisational Memory is to capture information from various sources in an organisation and make it available for different tasks at hand".

Therefore, the basis for successful Knowledge Management involves the deployment of tools that increase organisation's learning capabilities. Organisational Memories aim exactly at supporting humans in knowledge-intensive tasks - increasing their problem-solving abilities - and at increasing the learning capabilities of organisations.

Deployment of Organisational Memories within organisations is a major issue. Organisation members must contribute and share their knowledge. Bottom-up knowledge acquisition through lessons learnt is considered to be a form of learning in an organisation [8]. This refers to the process where a member of the organisation learns something - a lesson - that might be useful in the future for the rest of the organisation. The term "lesson learnt"refers to any positive or negative functional experience, which can be used to enhance the performance of the organisation. The combination of the bottom-up form of learning and the use of organisational memories results to the development of Knowledge Repositories, which support storage, organisation, preservation, retrieval and exploitation of lessons learnt.

Figure 1 shows a model of a Knowledge Management system, which is based on an Organisational Memory and supports the basic knowledge processes and the learning types that have been described above.

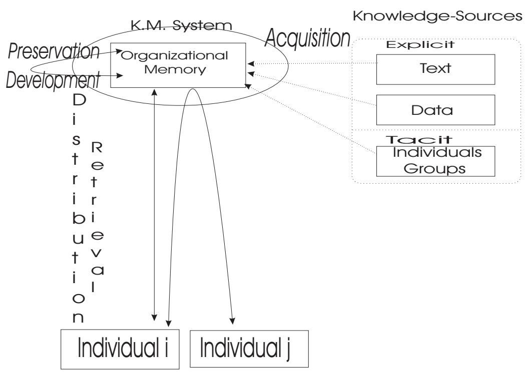

Figure 1. Knowledge Processes and Support for Learning

2.3 Organisational Memories at Work

Research in information technology to support knowledge management aims to develop systems and tools that are flexible to achieve the purposes of organisations, effective and efficient during their deployment in real settings. Examples of systems that exploit techniques similar to those exploited by the TDKMS are the following:
RENAULT created an organisational memory following the MEREX approach [9]; The memory consists of "digital sheets", i.e. forms, that set out solutions proposed by experts involved in the design and development of a vehicle. SG2C proposed by Poitou and DIADEME proposed by Elecricitie de France [10] are two knowledge management systems based on the construction of a product-centred, document-based organisational memory, which its main goal is to assist the preparation, storage, retrieval and process of documents. Kuhn and Abecker created KONUS based on the creation of an organisational memory in conjunction with an expert system [6], aiming to support the design of crankshafts.

In [11] [12] Simon describes an organisational memory, which operated in conjunction with a case-based reasoning system, in order to minimize error risks in design of new steels in metallurgy. A distributed organisational memory over the WWW was implemented in GNOSIS project [13]. Examples of organisational memory that function in combination to the bottom-up "lessons-learnt"type of learning can be found in NASA Space Engineering Lessons Learned (SELL) Program, in the US Department of Energy (DoE) Lessons Learned Program and in the Center for Army Lessons Learned (CALL) Program.

TDKMS has been designed and implemented for being deployed within Raycap Corporation [16]. The system aims to support designers of cables terminations to perform their task, as well as to advance their learning abilities. Therefore, the sole purpose for which it has been implemented differentiates TDKMS from the above mentioned systems. More than that, TDKMS combines an organisational memory, which functions in accordance to the bottom-up type of learning, an expert system, which triggers rules providing active help to designers, and a limited case-based retrieval method for retrieving older design cases and lessons-learnt that are useful for the design case at hand. The combination of the three techniques, which none of above-mentioned systems utilizes in combination, makes TDKMS a tool that, in a greater extend that the above systems, supports users on the job - by providing active help- and facilitates sharing of knowledge and collaboration among workers.

3 Knowledge Management for Designing Cable Terminations

The section aims to motivate the need for developing an organisational memory to support the design of cable terminations and support learning within Raycap Corporation [16]. This section describes the terminations design task and points on issues concerning this task.

3.1 Motivation

Although, the following motivations suggest the development of an organisational memory for the design of terminations, they can be interpreted as general motivations for the deployment of Knowledge Management systems in industry. These are:

- Avoidance of loss of specialists' know-how.
- Exploitation of the experience acquired, storage and organisation of lessons learnt and distribution of them at need. The aim is to increase productivity during task performance, avoid the reproduction of errors, and get more effective products.
- Improvement on information circulation and information communication for the design process.
- Training new designers by examining the stored experience and the choices that have been recorded in relation to specific design cases.

– Retrieving relevant information stored into past cases, documents, manuals, problems reported and solutions given.
– Making people aware of the available information when it is needed.

3.2 The Design Process

The design of a termination goes through three main processes - stages: (a) Gathering of requirements from the customer, (b) Design stage and (c) Re-Design stage. Figure 2 shows the flow of the main processes.

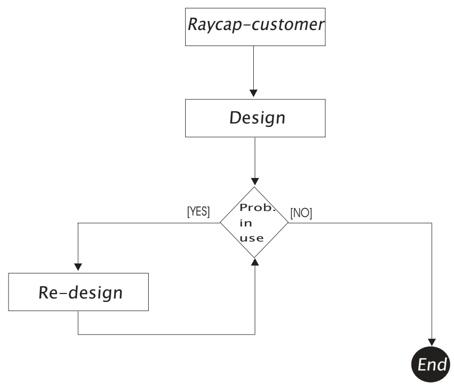

Figure 2. Generic Overview of the Design Process

– **Gathering Requirements.** Raycap collects all the necessary information for the design of a termination. This is done by posing standard questions to the customer. Questions concern the characteristics of the cable that will be terminated and the environment in which the termination will be used. Currently, designers write all the answers in semi-formal notation for further manipulation during the design process.
– **Design stage.** At this stage, the expert designer proceeds to the design process, taking into consideration the requirements gathered at the previous stage, standard references for the design of terminations, guidelines and rules for the selection of termination's components and instantiation of components' parameters. The design comprises the termination's components and the values that have been chosen for its characteristics (e.g. material, geometrical characteristics etc.).
– **Re-design stage.** This stage is activated only when a problem has been encountered during the manufacturing or use of a termination. In this case, the designer is called to solve the problem that came out by re-designing the problematic termination.

3.3 Termination Design Knowledge Management System (TDKMS)

TDKMS assist human designers to design cable terminations by exploiting formal design rules and tacit knowledge concerning terminations design. It is a hybrid system comprising an expert system (TDKMS-ES), exploiting explicit and formal knowledge, and an organisational memory (TDKMS-OM) whose purpose is to exploit and retrieve tacit knowledge concerning lessons-learnt from past cases, as well as information concerning guidelines, standards, and regulations.

The main goal of the TDKMS-ES has been the selection of terminations parts', instantiation of parts' characteristics based on design standards, generic design rules and rules that come from human experts. Furthermore, TDKMS-ES retrieves previous design cases according to customers' requirements and design choices. Case-based retrieval of past design cases happens as the designer proceeds to the design process.

TDKMS-OM, on the other hand, goes deeper in the knowledge task, retrieving and providing advice that could not be formalized, information provided by human designers as feedback to the design of a certain termination, problems reported by customers and solutions given, or pointers to relevant designs. These knowledge items may also include knowledge whose formalization cost is very high considering the benefits they provide. Problems and solutions are lessons learnt by designers: These are captured, stored and organized, so as to be effectively exploited by the system. These facilities enable people to provide feedback and share their knowledge in an active and constant way.

TDKMS-OM operates in conjunction with TDKMS-ES while the designer completes a design: Retrieved cases are presented to the user while he makes the relevant design choices without interrupting her/him from its task. These cases are linked with knowledge items that include tacit knowledge. Therefore, information is provided to users in a context sensitive and therefore, precise way.

3.4 TDKMS Specifications

Automation of the Design Task: TDKMS Expert System (TDKMS-ES). The main goal of the TDKMS expert system has been the automatic selection of termination's components and instantiation of components characteristics based on design standards, generic design rules and information that come from human experts. The generic format of the rules exploited by the system are as follows:

$$\text{Conjunction of instantiation constraints} \Rightarrow \text{Instantiation constraint}$$

An example of a rule involving termination characteristics instantiation constraints in both parts of the rule is the following:

$$< paper\_cable\_shield >= BELTED \Rightarrow < voltage >< 12$$

According to this rule, if the type of shield of a paper cable is belted then the cable should work under voltage with value less than 12 voltages. The following generic rule specifies that when both parameters of the hypothesis have been instantiated, then the number of the termination's skirts can be determined.

$$< voltage >, < kind\_of\_termination > \Rightarrow < numb\_of\_skirts >$$

Rules are triggered in a forward-chaining fashion, while the designer specifies terminations' characteristics. Doing so, TDKMS provides active help by suggesting proper values for some of the characteristics of the termination, according to designer's choices. The designer may change systems' design suggestions in his own initiative, or he can try to guide the system by providing some preferences as to which components shall be used and/or what the characteristics of some of the components shall be. Furthermore, based on users preferences, which may be specified gradually during the design process, the TDKMS-ES may retrieve design cases from the case-repository and provide them as further advices to the designer. Thus, the system actively helps the designer to locate an already designed termination in order this to be analyzed, criticized, or re-designed. In particular, designers may refine/adapt an older design according to their current requirements. The design procedure may be stopped or postponed at any stage.

Managing knowledge: TDKMS Organisational Memory (TDKMS-OM). The organisational memory of TDKMS acquires, organizes and exploits the functional experiences of designers. Functional experiences may comprise formal, but mostly, tacit knowledge gathered through experience. The specifications and functions of the organisational memory are exposed through the basic knowledge processes as follows:

- **Knowledge Acquisition** is done through the design process, capturing the functional experience of the designer, as well as lessons learnt in specific design cases. Functional experience and lessons learnt comprise problems and potential solutions, as well as any knowledge item from which the task can benefit. The designer should be able to characterise his/her functional experience as case-specific or global. A functional experience is characterised to be case-specific, when it shall be provided only in relation to a similar design case. Each case specific functional experience is a lesson learnt and comprises a problem and at least one proposal for its solution. There are six features (five cable's characteristics plus the usage of the termination - see fig. 5) that might raise a problem to a termination's component. Hence, any combination of these features may index a problem, whereas the indexing of a proposed solution is made by the problem it refers to, the date stored, and the name of the designer that proposed it. A global functional experience is a knowledge item with generic (case-independent) design knowledge. The later type of functional experience can be used to support the tutoring nature of the system suggesting generic strategies/methods and providing general critiques on the design procedure. The name of the designer that introduced a knowledge-item is valuable information. This may lead colleagues to cooperate and get in contact towards solving a difficult design case.

- **Knowledge Distribution/Retrieval.** The functional experience is actively distributed to those who need it and when they need it. As already pointed out, this is done by a case-matching mechanism using the fixed set of termination characteristicsthat are employed for case indexing. Thus, during a design session, instantiated design parameters are compared to existing design cases. Doing so, user gets custom solutions that can be further refined, but they also get valuable case-specific knowledge-items. Furthermore, the system provides to the designer the capability to search for a specific knowledge item (passive distribution). The system employs a simple string matching technique for that.
- **Knowledge Development.** The system keeps relevant knowledge-items interlinked: Solutions are related to the corresponding problems, which in their turn may be further related to their causes, i.e., to the characteristics that have caused them, as well as have global experiences interrelated. Doing so, the designer is facilitated to analyse and deduct useful conclusions, which can drive him/her to the development of new knowledge.

3.5 System Architecture and Design

The whole system has been developed using Oracle's Data Base Management System (DBMS) [14]. Specifically, the organisational memory has been developed using Oracle's DBMS while the expert system and the knowledge processes supported, were specified using PL/SQL [15]. The choice of the specific platform is due to the need to integrate TDKMS with the existent information system of Raycap in a seamless way.

As fig. 3 depicts, the system comprises four bases: The knowledge items repository, the terminations parameters repository , the case base and the rule base. The rule base stores all the formal rules exploited by the expert system, the case base stores all older design cases, indexed by the designed termination characteristics, the knowledge-items repository organizes all knowledge items and their interrelations, and finally, the terminations' parameters repository stores each termination parameter and related constraints. TDKMS-ES exploits the terminations parameters repository, the case base and the rule base. The system, based on designer's decisions retrieves previous cases that are further linked with case specific knowledge-items, which are retrieved by the TDKMS-OM. Moreover, TDKMS-OM retrieves global knowledge-items. Retrieved information is given to the user via the user interface.

The following figures give a flavor of the functionality of the forms and how they interface with the TDKMS-ES and TDKMS-OM. Figure 4 depicts a part of the design form. This form declares a complete design. Termination's components and parameters of each component are shown in respective fields. The designer is able to change a component by updating its code. The field "candidate problems"appears relative to each component, indicating possible problems that might have appeared. Pushing the button "see"the designer can be navigated through these functional experiences. The button "add"gives him the capability to add his/her functional experience.

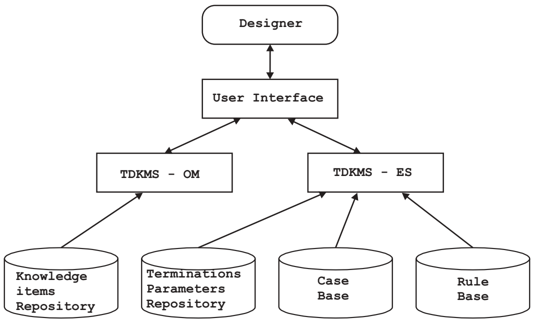

Figure 3. TDKMS Overall Architecture

Figure 4. Design form

The form depicted in Figure 5 facilitates users to specify the causes of a problem. The designer can tick the specific component that have caused the problem (case-specific functional experience) or may characterize his/her functional experience as case-independent.

4 Conclusions and Future Work

This paper reported on TDKMS. This is system that supports knowledge management and learning within an organisation in the context of the cables termination design task. TDKMS comprises two subsystems: TDKMS-ES and TDKMS-OM.

TDKMS is able to capture, organize, exploit and distribute tacit as well as formal knowledge through the tight integration of its two subsystems. Designers

Figure 5. Form for the specifications of Knowledge Items

are supported to report lessons learnt with respect to specific design cases, as well as generic knowledge items, related to the design process as a whole.

PL/SQL worked quite well for the development of the TDKMS-ES and for the development of the knowledge processes. Although we did not conduct a systematic evaluation of the system, the system seems to be beneficial for the design department of Raycap Corp. who have highly appreciated it. From our cooperation with Raycap we concluded that industry needs value-added solutions, which are explicitly correlated to cost-effectiveness, quality creativeness and innovation. However, it must be pointed that the system needs extensive evaluation in order to report on its deployment within Raycap.

The current prototype version of the TDKMS is able to capture the profile only one user's. Future work concerns extending the system for multiple users' profiles sharing their functional experiences over the WWW.

A major issue here concerns modelling users, so that information retrieval and exploitation to become user and context specific, enhancing further the management of knowledge.

Furthermore, ontologies can be used for flexible and more efficient management of knowledge.

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