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Knowledge based requirement engineering for one-of-a-kind complex systems

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Abstract

The success of requirement specification in new design projects largely depends on an accurate match between customer requirements and company product and process knowledge. Despite the recent developments in the domain there is still a lack of transparency and consistent definition and integration of the activities in requirement engineering (RE). There is also a lack of structured methods for capturing relevant enterprise knowledge and deploying it in support of decision making for requirement specification. This paper reports on the knowledge acquisition and sharing for requirement engineering (KARE) approach for requirement specification of one-of-a-kind complex systems. The approach provides a generic view of key RE processes clustered into three groups of activities: requirement elicitation, analysis and negotiation. The process is supported by a set of knowledge functions aimed at facilitating the requirement engineers in matching customer requirements to product characteristics. The reported research has been developed as part of the ESPRIT collaborative project KARE funded by the European Commission. © 2003 Elsevier Science B.V. All rights reserved.

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1. Introduction

Requirement engineering (RE) has evolved as a key stage of the overall system engineering process [1]. The increasing product complexity, market place globalisation and the changes in the product life cycles have underlined the need for increased re-use of components, information and knowledge across projects in order to deliver efficient and cost effective product solutions. This is particularly valid in one-of-a-kind large projects requiring significant effort at the initial product specification stages where a large proportion of the product cost is committed. The successful understanding of the user requirements and their transformation into clear product requirements therefore becomes a critical element within the overall realisation of a successful product [2]. Poor understanding of the RE process and inaccurate assumptions made during the elicitation and analysis of user requirements can have significant negative implications on the design and manufacture of the product affecting quality, lead times and cost [3].

Customers usually encode the knowledge related to their requirements of needs, into text, drawings, or verbal messages, i.e. into information. The conversion of this knowledge into explicit information depends greatly on the use of tacit knowledge [4], i.e. personal knowledge that is implicit and cannot easily be communicated. The main disadvantage of this form of knowledge is that it evades critical discussion. It is not objective and hard to falsify [5,6]. This therefore makes not only the management of the RE process more difficult but also can obstruct critical considerations and hence, the development of RE knowledge. When eliciting requirements the supplier decodes the customer's information into appropriate requirements. Such processes are more complex than simple coding and decoding, necessitating extended iterative interaction between customer and supplier. The complexity of the customer/supplier interaction is further exacerbated by intercultural differences between business partners. Requirement errors can be introduced when a supplier guesses as to what is implied by an incomplete or ambiguous requirement statement that has lost part of the explicit meaning through an incorrect translation of the customer's implicit knowledge [7,8]. Despite the recent developments in both RE and knowledge management there is still a lack of generic methods and models needed to support knowledge acquisition and sharing for RE in one-of-a-kind environment.

The paper reports on a new knowledge 'enriched' RE

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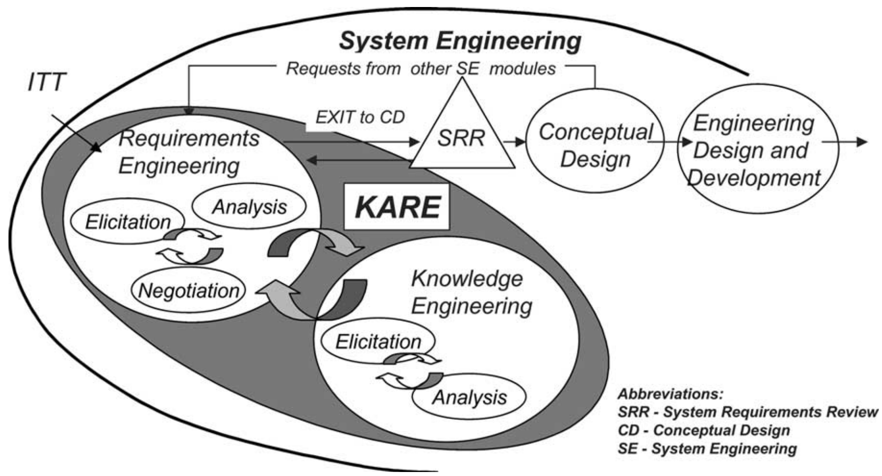

Fig. 1. The KARE Knowledge Enriched RE Approach.

approach for one-of-a-kind complex products. The methodology is based on development of a generic knowledge model that supports key RE steps such as requirement elicitation, formalisation, analysis and negotiation.

2. Overview of the KARE methodology

The KARE (Knowledge Acquisition and Sharing for RE) [9] methodology aims at supporting the RE process in one-of-a-kind environment. The RE process (see Fig. 1) starts with an invitation for tender (ITT) and finishes with a requirements baseline. KARE provides an interface for the system requirement review (SRR), which ensures that system requirements are sufficient to meet mission objectives, the expected performance and that cost figures of merit are realistic. SRR refers approved requirements to the conceptual design (CD) module.

The KARE approach has two main integrated components a RE process and a knowledge engineering (KE) process. The KARE RE comprises a three-step process: (1) Requirements Elicitation, (2) Requirements Analysis, and (3) Requirements Negotiation. Requirements Elicitation is a process of discovering system requirements through consultation with stakeholders, from system documents, domain knowledge, or any other means of information. Requirements Elicitation and Analysis are closely linked processes. As requirements are discovered during elicitation, some analysis is inevitably carried out [7]. The requirements analysis investigates the requirements and different stakeholders confer to decide on which requirements are to be accepted. The RE processes establish an iterative sequence, sometimes referred to as stages. The KE module supports this sequence at all stages.

Customer and supplier confer requirements during the requirements negotiation. Both parties may agree on top-level requirements. Additional requirements may be derived according to customer needs; requirements may be updated and then, re-enter the Requirements Elicitation process. Customer and supplier negotiate requirements supported by the requirement request engine. Every negotiation potentially re-launches the

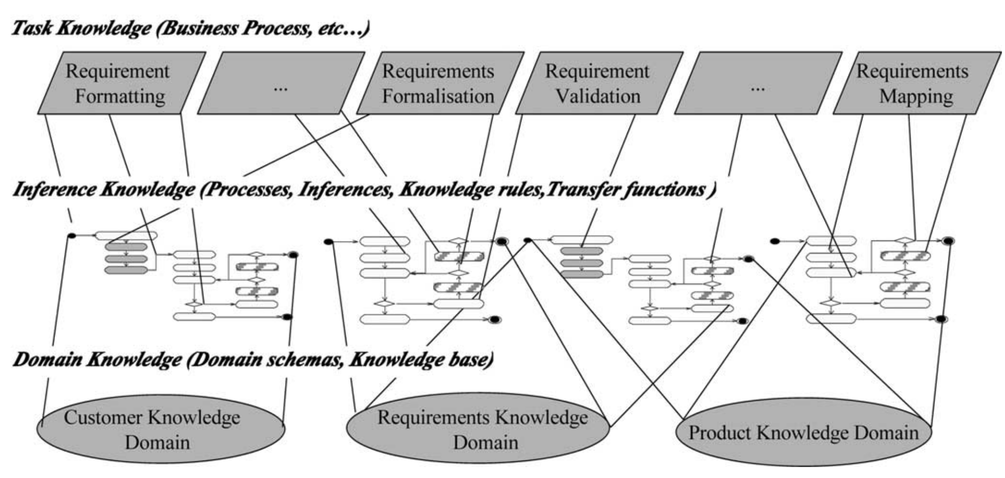

Fig. 2. KARE RE knowledge model.

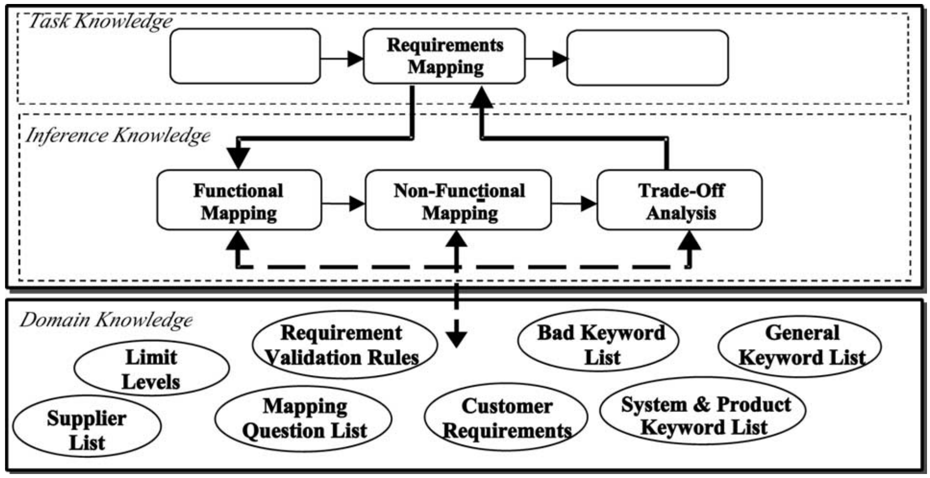

Fig. 3. KARE requirement mapping and knowledge domains.

Requirements Elicitation process until a baseline is defined.

The underlying component of the KARE system that supports and enriches the RE process is the KE module (refer to Fig. 1). KE supports the RE process through eliciting, analysing, and answering support requests. A second objective of the KE module is the transformation of implicit knowledge into explicit knowledge through conceptual modelling. The KE process features two types of activities: Knowledge Elicitation and Knowledge Analysis. In the KARE context the knowledge elicitation is defined as a process of collection, capture and formalisation of knowledge. The knowledge content is investigated in detail in the knowledge analysis process to validate and quantify the knowledge before the knowledge repository is added to and/or updated. The knowledge elicitation and knowledge analysis processes constitute a recursive loop that supports RE at any stage throughout the RE process.

3. Requirement engineering knowledge model

The KARE RE process is supported by a knowledge model described in Fig. 2. The model includes the following levels of representation [10]:

- *Control Knowledge*. This defines both the content and structure of task and inference specific knowledge in a procedural form. Control knowledge consists of two knowledge categories:

  Task Knowledge. It is defined by a goal and describes how to decompose the key activities in the RE process and provide internal control for their realisation.

  Inference Knowledge. This describes the basic inference steps that need to be taken in order to complete the task.
- *Domain Knowledge*. This is a static knowledge and consists of the concepts, relations and facts that are needed to reason about a certain application domain. It defines both the content and structure of domain specific knowledge in declarative form.

The knowledge sharing function in the KARE approach is focused on the RE process and is supported by the knowledge acquisition, analysis and mapping processes. The knowledge acquisition and analysis processes consist of rule-based procedural knowledge, which is coded into the KARE workbench.

The knowledge components are linked to their process applications. For instance, the customer knowledge is mainly applied to customer requirement knowledge is applied throughout the RE process.

Fig. 3 shows an example of a requirement mapping process, whereby domain knowledge is mapped to individual requirements using a list of questions as a reasoning process to validate the mapping link between a specific item of knowledge and the requirement in question. The system and product keyword list domain is linked to a supplier domain. This knowledge domain features a list of competitors and suppliers with their artefacts and artefact properties. The domain covers knowledge about competing artefacts, including attributes such as price and delivery data, which are used to evaluate the market position of the supplier. Knowledge content is company specific and thus dependent on the business processes employed for RE.

4. System implementation

The KARE knowledge model and methodology have been implemented in a prototype software 'workbench' aimed at facilitating the RE activities performed by system engineers. The KARE workbench utilises the newly proposed ISO STEP application protocol AP233

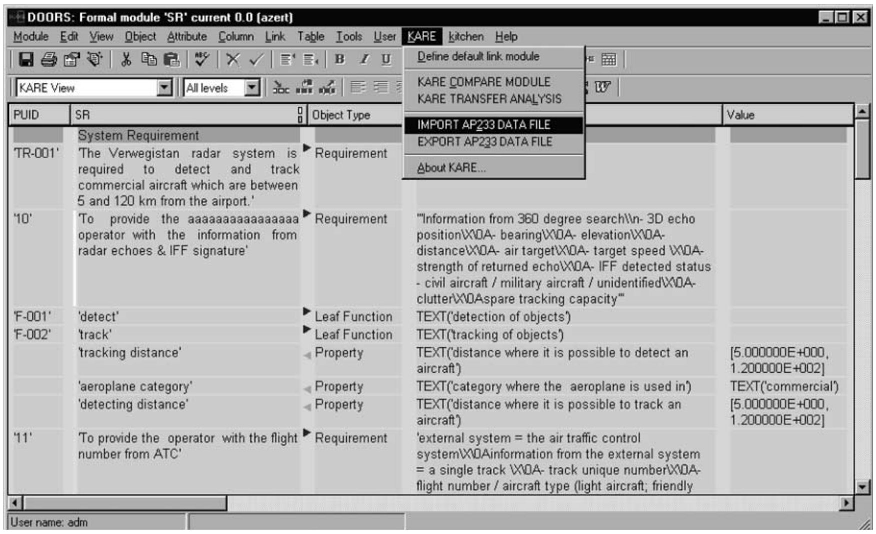

Fig. 4. KARE prototype workbench interface in DOORS™.

[11] for data modelling and exchange which incorporates the requirement data model developed within the KARE project. The KARE workbench has been developed as a plug-in environment to the system engineering tool DOORS™ [12]. It utilises two proprietary packages, a requirement formalisation tool *Demanda II* [13] and a knowledge management tool WISDOM™ [14] that have been integrated to deliver the key features of the KARE approach. A screen shot of the user interface in processing the requirements relating to system architecture is shown in Fig. 4.

The KARE model, methodology and prototype workbench have been validated through a number of industrial cases. One of those cases illustrates the support provided by the KARE approach for collaboration between customer and supplier on defining a 'baseline' system specification for a complex aerospace system.

Three types of RE activities are considered:

supplier tasks: definition of company organisation, level of knowledge application by the project team, role of RE and use of related tools, methods for system architectural design;

customer/supplier exchanges tasks: elicitation of high-level requirements, refinement of requirements, suitability analysis, and baseline definition;

requirement and knowledge interface: determination of product range, system type, domain knowledge updates, definition of system raw price, delivery schedule and missing/incomplete requirements.

The results from the industrial validation of the KARE prototype workbench have shown significant improvement in terms of accuracy and consistency of requirement specification and reduced overall lead-time.

5. Conclusions

The KARE methodology has been developed to support requirement engineers in capturing, processing and managing requirements in one-of-a-kind product environment. A key element of the reported research is the new customisable RE knowledge model that comprises task, inference and domain level knowledge categories specific to the system engineering activities at the early product specification stages. The KARE RE knowledge model and methodology have been applied using industrial validation cases to illustrate the key benefits of the approach in terms of improved accuracy and consistency of requirement specification, reduced number of iterations and as a result, reduced overall lead-time and cost of system specification.

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