Knowledge re-use for decision support

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Abstract

Effective decision support has already been identified as a fundamental requirement for the realisation of Network Enabled Capability. Decision making itself is a knowledge-intensive process, and it is known that right decisions can only be reached based on decision maker's good judgement, which in turn is based on sufficient knowledge. It is not unusual for decision makers to make incorrect decisions because of insufficient knowledge. However, it is not always possible for decision makers to have all the knowledge needed for making decisions in complex situations without external support. The re-use of knowledge has been identified as providing an important contribution to such support, and this paper considers one, hitherto unexplored, aspect of how this may be achieved.

This paper is concerned with the computational view of knowledge re-use to establish an understanding of a knowledge-based system for decision support. The paper explores knowledge re-use for decision support from two perspectives: knowledge provider's and knowledge re-user's. Key issues and challenges of knowledge re-use are identified from both perspectives. A structural model for knowledge re-use is proposed with initial evaluation through empirical study of both experienced and novice decision maker's behaviour in reusing knowledge to make decisions. The proposed structural model for knowledge re-use captures five main elements (knowledge re-uers, knowledge types, knowledge sources, environment, and integration strategies) as well as the relationships between the elements, which forms a foundation for constructing a knowledge-based decision support system. The paper suggests that further research should be investigating the relationship between knowledge re-use and learning to achieve intelligent decision support.

Keywords

knowledge-based decision support, knowledge re-use situations, knowledge re-use behaviour, knowledge re-use models, re-use and learning

1 Introduction and related work

Network Enabled Capability (NEC) has been envisaged as the coherent integration of sensors, decision-makers and effectors to achieve a more flexible and responsive military effect to shared battle space. Some key support capabilities have been identified to deliver NEC, including communication systems, information systems, knowledge and operational procedures [1]. This paper is concerned with the knowledge support for realising NEC, and focuses on the exploration of knowledge re-use for better decision support, as illustrated in Figure 1. Through re-use, all decision makers on the decision network can have sufficient knowledge to make good judgement on the decision problems.

Knowledge re-use has been recognised with potential in achieving faster and more consistent decision support, without respect to the decision maker's experience in the domain [2, 3]. If the decision makers are novices in the domain that a decision needs to be made, through re-using external knowledge of their peers, it is more likely for them to have the chance to make the right decisions. For expert decision makers, through knowledge re-use, they can reapply proven solutions, and make more consistent decisions over time [4]. Furthermore, through knowledge re-use, decision makers can tap into past experience, learn from use and failures, avoid pitfalls and increase the chances to make

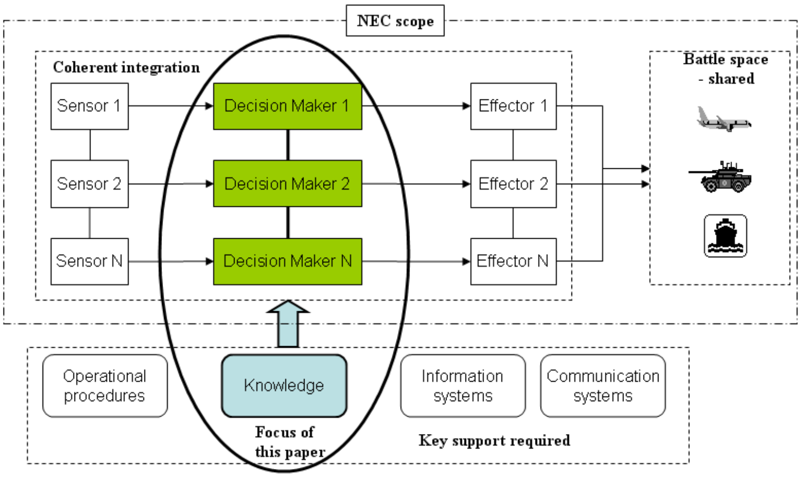

Figure 1 Knowledge support for decision networks within NEC

the right decisions first time [5, 6].

There has been wide interest in knowledge re-use research. Existing work can be classified into two major categories: knowledge re-use in general, and knowledge re-use in specific domains. In the first category, the research has addressed common issues arising in knowledge re-use. For example, Markus [7] proposed a framework for knowledge re-use, including a knowledge re-use process, types of knowledge re-users, and design principles for knowledge repository to facilitate re-use. The issue of communication and collaborative mechanisms to enable knowledge re-use is discussed in [8]. It was identified that such mechanisms as taxonomical structures should be provided to enable knowledge re-users to search for expertise within the knowledge network. However, the paper acknowledged that knowledge re-use could thrive in the absence of structure so long as a context for the shared knowledge exists. This view was supported by earlier publication, in which definition as well as proceduralisation of context knowledge was presented and explained [9, 10]. In the meantime, more existing research has focused on knowledge re-use in specific domains. Themes in recent literature have explored knowledge re-use, for example, in engineering design [11, 12], in architecture and construction [13], for collaborative work [14], and for innovation [15].

But none of the existing research has addressed the issue of knowledge re-use in decision support. This paper identifies the key issues and challenges of knowledge re-use in decision support from different views. A structural model for knowledge re-use is proposed based on the study of knowledge re-use situations in decision making. The application of the model is explored through a ship maintenance case study. Further research on the topic has been identified as investigating the relationship between knowledge re-use and learning for intelligent decision support. The paper is organised as follows: Section 2 identifies the key issues and challenges of knowledge re-use in decision support. A structural model for knowledge re-use is proposed in Section 3 followed by its evaluation in Section 4. Section 5 discusses further issues and draws conclusions.

2 Key issues and challenges of knowledge re-use

Knowledge re-use can be seen as one of the two major parts of knowledge management, as illustrated in Figure 2. Many publications have addressed the issue of knowledge creation, and various models about knowledge creation have been proposed over the years [16, 4]. However, knowledge creation is not in the central interest of this paper, and this section focuses on knowledge re-use and identifies its issues and challenges in decision support from both knowledge provider's and re-user's views. Knowledge providers regard issues of knowledge repository, classification and retrieval as important to knowledge re-use, while re-users are concerned more about different decision situations that knowledge may be re-used, and how the knowledge is re-used by different decision makers.

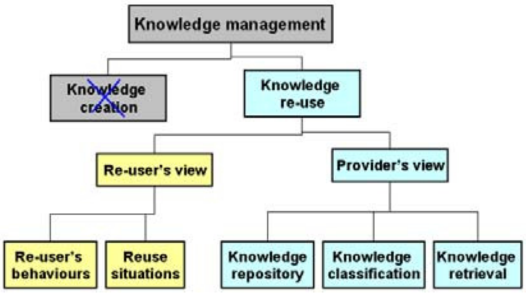

Figure 2 Scope of knowledge re-use

2.1 Challenges from the knowledge re-users' viewpoint

Knowledge re-users refer to those who retrieve existing knowledge and reapply it in some way. As knowledge re-users can be regarded as close to or distant from knowledge producers, where the distance is measured in terms of shared knowledge, four types of knowledge re-users have been defined in literature [7]. They are termed as:

- shared work producers, who create and document the knowledge they later re-use, in this situation, knowledge re-users are the knowledge producers themselves;
- shared work practitioners, who produce knowledge for each other to use, in this situation, knowledge re-users are similar to knowledge producers;
- expertise-seeking novices, who do not have much knowledge or experience in the domain, and differ substantially from the knowledge producers. This situation is also called knowledge transfer, which often involves novices' access to experts and expertise;
- secondary knowledge miners, who attempt to extract knowledge from records that were collected by others, possibly unknown to the re-users, for very different purposes. This situation is also referred to as data mining.

The definition of the above types of knowledge re-users established the understanding that different types of knowledge re-users have varied knowledge about the domain and the knowledge repository. They may have different levels of difficulty in locating, digesting and selecting the knowledge, and may need different degrees of help to successfully re-use the knowledge. This reveals the complexity of knowledge re-use. Therefore, the challenge for knowledge re-use in decision support is to develop a typology of decision maker's role in different situations and to explore how they re-use knowledge when make decisions. For example, what are the purposes of reusing knowledge in decision making? What decision makers need to know, what they actually know, and what they do not know when re-use the knowledge for decisions? How decision makers locate, select experts, knowledge and expertise? How decision makers actually reapply existing knowledge in decision making? To find answers to these questions has been the key challenges from the knowledge re-users' viewpoint.

2.2 Challenges from the knowledge providers' viewpoint

Knowledge providers and producers are the originators and documenters of knowledge, who record explicit knowledge or make tacit knowledge explicit, and prepare the explicit knowledge for re-use by improving knowledge repository design, developing classification schemes to organise knowledge, and providing systems for knowledge retrieval.

Based on the understanding of knowledge re-use situations from previous section, knowledge to be re-used can be from many different producers, held in many different knowledge islands in the form of individual documents, repositories and systems. The questions then arise: how can different decision makers get access to the right knowledge, and how can they interpret it properly (such as collate with the context of the knowledge) and make the most use of it? Existing research has proposed different strategies to solve the problems. Knowledge networking, knowledge integration and knowledge traceability are three popular topics on the researcher's agenda in this regard. Knowledge networking is the process of building up networks of experts and expertise associated with a decision task, finding out where they are and logically connecting them so that they are recognisable nodes of a knowledge map [17]. Once a knowledge network is created, knowledge integration becomes critical, through which fragmented knowledge can be synthesized into systemic knowledge. Prior research shows that lack of integration often leads to misunderstanding among knowledge producers, providers and re-users [18]. Knowledge traceability model has been explored as a common vocabulary recently to avoid misinterpretation of knowledge [19]. However, it is important to remember that knowledge integration cannot ignore the fact that existing knowledge models, repositories and systems work under various software environments. It is often the case that knowledge re-users are forced to switch environments (such as email, MS Word, Rational Rose, live meeting transcripts) to access and re-use the knowledge. It is clear that there is not just one issue but a series of issues that need to be addressed if knowledge re-use can be successfully conducted to support decision making. Therefore, the key challenges from the knowledge provider's view are: is it possible to develop a model or a set of models that can address the whole range of issues regarding knowledge re-use? If yes, what should the models look like? Authors' earlier publication has discussed Knowledge Re-use Model from *behavioural* perspective [20]. But no existing model has been available addressing the issue from *structural* perspective, which identifies the key elements to facilitate knowledge-reuse and how they are inter-related. The following section explores a conceptual model aiming to fill this gap.

3 A structural model for knowledge re-use

This section explores a model for knowledge re-use from a structural perspective aiming to capture multiple viewpoints that have been discussed in the previous sections. The aim of defining such a structural model is to establish the foundation for constructing a computer-based knowledge system for decision support at later stage. For clarity, the knowledge type that is to be addressed for re-use and captured is explicit knowledge rather than tacit knowledge. The difference between tacit and explicit knowledge, by definition, is that tacit knowledge exists in the mind of individuals and is acquired through experience, explicit knowledge can be codified and can be acquired through articulation [21, 22].

The process to develop the Structural Model for Knowledge Re-use (SM-KR) consists of three main steps: (1) to identify the important elements that should be considered; (2) to define the attributes and properties of each element; (3) to specify the relationships between the elements. Based on this, an SM-KR is defined and represented with UML class diagrams [23]. In the UML diagrams, the important elements of the SM-KR are modelled as classes, which are abstraction of instances in the reality. Each class can have a set of attributes (to distinguish one class from another) and a set of operations (to define the functions). For simplicity, the attributes and operations are hidden from the view in Figures 3 and 4, so that the attention can be drawn to the classes and class relationships, which provide a bigger picture of the SM-KR.

The top-level of the SM-KR is shown in Figure 3. Five main classes have been identified for knowledge re-use: Re-users, Knowledge Types, Sources, Environments and Integration. The relationships between Knowledge Re-use and all five main classes are specified as an *Aggregation* relationship (represented as a hollowed diamond at the near end of the "whole" class), which means that any of the five classes is only "part of" the SM-KR. The identified relationships between the five classes are modelled as *Association* relationships, represented as a solid line connecting to corresponding classes. To further elaborate the roles of the classes in an association relationship, text labels are placed on the diagram at the near end of the responsible classes. For example, the association relationship between the Re-users and Knowledge Types can be read as Re-users

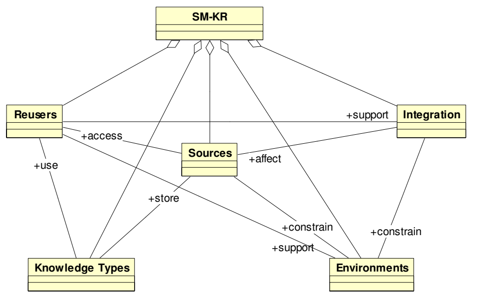

Figure 3 Key elements and their relationships for knowledge re-use with UML

use Knowledge Types. Similarly, Re-users *access* knowledge Sources, and software Environments *constrain* Sources to be used, and so on. In the object-oriented programming, both *Aggregation* and *Association* relationships can be implemented through object references, which keep track of the links between the elements. This top-level structure of the SM-KR presents a clear picture of the main classes and their relationships, i.e. a global view of the structural model for knowledge re-use.

Re-users represent the distance to the knowledge producers. They can be shared work producers, shared work practitioners, expertise-seeking novices or knowledge miners. Knowledge Types can be rationale knowledge (why things were done in a particular way), best practice guide, lessons learned and procedural knowledge (how things can be done) etc. Sources are where different types of knowledge held and maintained, they can be in individual documents, repositories, model bases, or embedded within systems. Specific knowledge sources are often kept and run under specific Environments. For example, common document environment include MS Word and MS Project, common model environment can be Rational Rose or Enterprise Architect. Integration has to take into account the factors of the knowledge Sources, software Environments and their Re-users. As a result, the Integration can be network-based, ontology-based or traceability-based. Figure 4 is the extended class diagram of the SM-KR including the subclasses of all five main classes. The relationships between each main class and its subclasses are modelled as an *Inheritance* relationship, represented as a hollowed arrow pointing to the parent classes. The importance of the inheritance relationship is that all the subclasses will automatically inherit all the attributes and operations from the parent classes. In object-oriented programming, the inheritance relationships can be implemented through code re-use, which is crucial for efficiency and consistency management.

4 Evaluation of the structural model for knowledge re-use

This section discusses an initial evaluation of the SM-KR in decision support through a ship maintenance case study. The core concept of the case is to generate a work plan to repair a damaged ship through a Support Solution coalition which represents a decision network. The ship is required to be back to service in a certain amount of time period and the damage of the ship has been assessed. The Support Solution coalition is composed of decision makers along the supply chain of the ship maintenance. To evaluate the SM-KR in decision support, we designed three role-play exercises for different types of decision makers to take part in. The purpose of the role-play exercises was to create a decision making situation, by giving the participants a set of tasks to finish for generating the work plan. During the course, they needed to make a series of decisions. All three role-play exercises were videoed, transcripts were then generated from the video and studied. Immediately following the role-play exercises, semi-structured face to face interviews with the decision makers were conducted so that probe questions could be asked to clarify what was observed from the video, and to find out what was behind how the participants made the decisions. As this paper is concerned with knowledge re-use, the following will show how the participated decision makers behaved regarding different aspects of reusing knowledge to support the decisions to generate the work plan for repairing the damaged ship.

The participants selected for the three role-play exercises were substantially different, so that comparison between different types of decision makers could be made. The first exercise was conducted by the researchers who worked on the project and actually planned and designed the role-play event, therefore they were considered as the shared work producers in terms of knowledge re-users. The second exercise was taken part by a group of research staff and students who had not known about the ship maintenance scenario and the documents provided to the exercise. In this sense, they were regarded as expertise-seeking novices in terms of knowledge re-users. The participants of the third exercise were

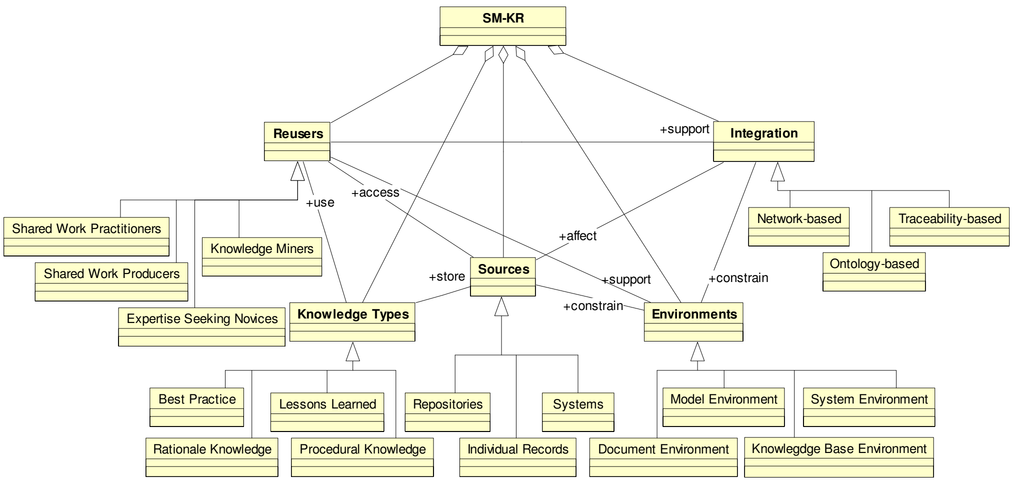

Figure 4 Extended structure of the model for knowledge reuse with UML

experienced engineers and managers directly working in the same areas or similar to ship industry. They were therefore classified into the category of shared work practitioners of knowledge re-users. The following results are based on the study of the three role-play exercises and the follow-on interviews.

Table 1 summarises how decision makers (i.e. the participants in the role-play exercises) responded to relevant elements in the SM-KR, and how they used them to help reach decisions. The example set of critical questions in the column 2 of the Tables were identified at the interviews through probing questions.

From the Table 1, we can see that the decision makers participated in the three role-play exercises used varied knowledge types, sources and environments, as well as different integration strategies. In the first exercise, as the decision makers were shared work producers, they knew how the knowledge were generated and documented for the tasks, and they knew where the knowledge was located. But they pursued like perfectionists and sought for rationale behind each decision to try to justify their decisions. During the process, they tried to keep up with a common vocabulary (a simple traceability model) to maintain the consistency of knowledge. As they knew very well where the required knowledge was in the documents, which they produced earlier, they frequently referred to the paper documents for accuracy rather than just by verbal communication or pure memories. Contrast to the above, decision makers in the third exercise, the shared work practitioners, seemed to make more use of best practise and lessons learnt types of knowledge rather than to seek for rationale, maybe because they were more confident with their past experience. They knew what had worked well in reality and what hadn't. As these shared work practitioners actually were not involved in producing the role-play relevant documents, they could not know what knowledge was in which documents. In fact, they did not even want to search for required knowledge in the documents. Instead they did a lot of talking between themselves and sought for knowledge from the participants (whom were considered as experts). Quite different from the previous two groups, the decision makers in the second role-play exercise, regarded as expertise-seeking novices, tried to search for procedural knowledge (how things can be done) throughout the decision process. Maybe it's because novices did not have experience in the scenario (could not refer to best practice or lessons learned), also did not think rationale knowledge as important as how to get things done. Even though they tried paper documents and drawings provided to them, but they could not integrate knowledge from different sources to reach decisions. In fact, they failed to produce a work plan by the end of role-play session.

The results from Table 2 shows us that different decision makers, as shared work producers, practitioners and novices, had very different behaviour when identifying their knowledge needs, locating and selecting required knowledge based on their varied understanding of the knowledge sources and environments. Shared work producers knew very well about the knowledge structure in the sources and environments, they had very little difficulty in locating, integrating and reapplying the knowledge. On the other

Table 1 Elements for knowledge re-use elaborated during the three role-play exercises

<table>
<tr><th>Role-play exercise</th><th>Example critical decisions</th><th>Decision makers as Re-users</th><th>Knowledge Types</th><th>Sources</th><th>Environments</th><th>Integration</th></tr>
<tr><td>1</td><td rowspan="3">- Is the task suitable?
- What's the choice to repair the shaft/ propeller/ hull?
- When to start and finish the tasks?
- How to deal with risk/ uncertainty?</td><td>Shared work producers</td><td>Rationale knowledge</td><td>Paper-based document</td><td>Word document, sketches</td><td>Traceability-based, common lexicon</td></tr>
<tr><td>2</td><td>Expertise-seeking novices</td><td>Procedural knowledge</td><td>Paper-based document,</td><td>Word document, drawing</td><td>-</td></tr>
<tr><td>3</td><td>Shared work practitioners</td><td>Best practice, lessons learned</td><td>Experts</td><td>Verbal communication</td><td>Network of people, talk into agreement to reach consensus</td></tr>
</table>

Table 2 Comparison of decision makers' behaviour between the three role-play exercises

Role-play exercise	Critical decisions	Decision makers as Re-users	Purposes of/needs to re-use Knowledge Types	What they actually know and don't know about the Sources and Environments	Difficulty in locating, integrating and reusing knowledge
1	- Is the task suitable? - What's the choice to repair the shaft/ propeller/ hull? - When to start and finish the tasks? - How to deal with risk/ uncertainty?	Shared work producers	To justify the decisions	Knew details about the knowledge located in the sources and environments	Very little difficulty
2		Expertise-seeking novices	To possibly reach decisions	Only knew physical format of the sources and environment, did not know the structure of knowledge within the sources	Great difficulty in locating, selecting and integrating the knowledge, also in reapplying knowledge without extra help about the context
3		Shared work practitioners	To get the best working decisions	Vaguely knew about the structure of the knowledge in the sources, but not in a great deal	had difficulty with knowledge in documents, but little difficulty with experts and their expertise

hand, novices had great difficulty in searching for knowledge because they only knew very little about the knowledge sources and environments. Shared work practitioners, however, seemed to be in the middle between the two. They had difficulty in seeking for knowledge from documents, but had little problems with locating the experts and their expertise.

In summary, through results from the Table 1, it shows that the five elements (main classes) modelled in the SM-KR are appropriate. Results from the Table 2 approved the defined attributes and operations for main classes, as well as the specified relationships between the classes. Combining results from both tables, it gives the initial validation of the SM-KR defined in Section 3.

5 Discussion and conclusions

Major contribution of this paper is to have defined a model for knowledge re-use from the structural perspective, which considered five main elements, important attributes and operations of the elements, as well as relationships between the elements. The model provides guidance for creation of knowledge re-use schemes, which in turn establishes the foundation for developing knowledge-based decision support systems to achieve better decision support.

The evaluation of the structural model for knowledge re-use has been done in specially created decision making situations, with limited decision makers participating in the process. The authors are aware that a computer-based decision support system or environment needs to be developed using the model, so that the evaluation can be done more widely and in a more convenient way to the participants.

Further work on the topic is to develop such a knowledge-based decision support system and environment to study how knowledge can be re-used for more broad decision situations, and to explore how knowledge re-use and learning can enhance each other [24, 25]. With more insightful understanding of the interdependence between knowledge re-use and learning, investigation of how decision support systems and decision makers can teach and inspire each other through shared learning [26] to achieve intelligent decision support should be researched in the longer term.

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