MANAGING AND EXPLOITING KNOWLEDGE ASSETS IN THE CONSTRUCTION INDUSTRY

Knowledge-based decision support systems

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Abstract

This paper reviews knowledge-based and decision support techniques in the construction industry with a view to highlighting how construction organisations can exploit knowledge as an asset. It introduces Knowledge Management and Decision Support Techniques and provides information on example applications that demonstrate their use in construction and non-construction sectors. Guidelines for deciding on the suitability of knowledge-based techniques for solving a given problem are provided.

Keywords: artificial intelligence, decision support, integrated systems, intelligent systems, knowledge-based systems

1 Introduction

The success of a construction business in today's competitive market place depends critically on the quality of the knowledge it possesses regarding its markets, products, and technologies. To maintain and improve competitiveness, it is essential to identify, plan, and control knowledge assets with the same priority currently afforded to traditional tangible assets. *Knowledge Management* (KM) techniques offer strategies for identifying and exploiting knowledge assets. *Knowledge-based* (KB) and *Decision Support* (DS) techniques complement knowledge management by enabling the storage of knowledge assets in computer-based systems that can then be used to assist decision making. The recent UK Department of Trade and Industry Intelligent Systems in Business Programme (DTI, 1998) identified the following benefits in a range of industrial sectors resulting from the application of Knowledge Management and Knowledge Based techniques:

- **Organizational Memory** - preservation of knowledge when staff move.
- **Decision Support** - assisting experts by evaluating and suggesting possible options, enabling a wider range of design solutions etc. to be considered
- **Routine Decision Automation** - relieving key staff from trivial but time consuming tasks.
- **Product Improvement** – enabling increased differentiation from competitors' products through the addition of smart features.

Although KB techniques can be applied to create stand-alone applications, they may well be more effective when implemented as part of a wider system accessible throughout the organisation or the project team via networks. Encoding business processes and decision paths in company or project Intra/Extra-nets can provide additional advantages in facilitating Quality Assurance (QA) and recording experience for future re-use. The rapid uptake of such networks and the huge increase in computer processing power and availability, make it important to review this technology at this time.

This paper examines how businesses in the construction industry can obtain the benefits outlined above by embarking on a knowledge management programme. It overviews knowledge management and decision support techniques, provides case-studies to demonstrate their benefits, and recommends steps that a construction business can take now to start realising these benefits.

This paper was authored by The Network of Experts in Knowledge Based Systems hosted by BRE and funded by the UK Government's Department of the Environment, Transport and the Regions (DETR). The Network brought together around one hundred and fifty members from Industry and Academia to assess the Knowledge Management requirements of the construction industry and identify appropriate techniques and tools. The network's Web Site provides complete details of its activities (http://helios.bre.co.uk/kbs/).

2 Overview of knowledge management and decision support techniques

Knowledge management is not a new gimmick. It is common sense. Knowledge can be an organisation's greatest asset. It depends more on the number of connections linking the information rather than on the amount of information (Macintosh, Filby, Kingston & Tate. 1998).

Knowledge management deals with the intangible nature of intellect. It involves much more than technology. We need to understand: what we need to know, where insight and knowledge gets created, how we can best capture it, how it can get us to our destination. (Koulopoulos, 1996)

A conclusion made by researchers in sustainable competitive advantage is that the only thing that gives an organisation a competitive edge is what it knows, how it uses what it knows, and how fast it can know something new.

2.1 Knowledge management

Knowledge management methods guide the identification and analysis of the knowledge used within an organisation and the establishment of a programme to ensure that this knowledge is preserved and developed. Knowledge management methods are generally taken to include the following stages:

- **Identify Your Knowledge Assets**: analyse the knowledge used in the operation of a business: e.g. technical know how, design products, information sent to customers, research and development results and patents, records of company procedures, operating guidelines, management expertise, marketing expertise
- **Document Your Knowledge Assets:** describe each asset in terms of its subject area, quality, and the time and places that it is available. An estimator's knowledge might be documented as follows: "The knowledge is used to generate cost estimates for the installation of wiring in buildings. It is based upon 10 years' experience and has proved accurate. This knowledge is held by an individual in the design department and is available during working hours."
- **Identify Knowledge Management Related Processes**: for each asset identify the processes for developing, updating, using, assessing, and transferring it. For the cost estimation example above, updating processes may include attendance at training courses; reviews of estimates after project completion. A transfer process might include the documentation of estimation best practice to enable other members of staff to perform this task.
- **Identify Opportunities for Developing Knowledge Assets:** issues with assets typically, e.g. bottlenecks, occur when demand upon an asset exceeds supply. In the estimator example, a bottleneck may occur when only one individual can perform this task.
- **Prepare Programme of Actions:** the opportunities for developing knowledge assets are best realised through a programme of focused actions. Knowledge Management methods guide the selection issues that are essential to a business. In the estimator example, relieving the bottleneck would only be recommended if this issue is holding the business back. Example actions include: securing the knowledge from an expert who is about to retire by documenting his knowledge, and sharing knowledge by forming a network of people working in that area.

Embarking on a knowledge management programme will result in new insights into the knowledge assets critical to the competitiveness of a business and the formulation of a course of actions to maintain and develop those assets. These benefits can be achieved through an investment in time for training in knowledge management methods and the time required to carry out the programme. The Knowledge-based and decision support techniques described in the next section increase the options available for managing assets, but do require some additional investment. The following section introduces these techniques by balancing the benefits they offer against the increased investment required to achieve them.

2.2 Knowledge based and decision support techniques

Knowledge-based and Decision Support techniques enable the storage of knowledge assets within computer systems that can then be used to assist decision-making. At their current level of maturity the techniques have been used to construct systems that possess human level competence over a narrow range of routine tasks. This maturity enables the development of effective decision support systems that in no way replace human decision-making. Rather, by complementing and supporting experts, the techniques offer the following benefits:

- **Addressing Knowledge Bottlenecks:** encoding an expert's knowledge within a decision support system provides wider access to that knowledge. This access enables people to initially pass requests through the decision support system to identify routine problems. Once resolved, the human expert can be used to fully check final requests. This frees the expert to spend more time identifying and resolving more complex problems.
- **Ensuring Knowledge Preservation:** when people are about to retire, their expertise can be captured within a decision support system. This allows others to make use of that expertise after the expert has left. Properly focused on the aspects that are essential to a business, this approach can ensure a tidy transition as other employees develop this expertise themselves.
- **Best Practice:** expertise from experts can be encoded within a decision support system to produce a best practice framework. This approach enables experts to exploit the knowledge of other experts when tackling a complex task.
- **Smart Features:** the use of the complex products supplied within the construction industry can require a high level of knowledge from the customer. Decision support systems offer an opportunity to supply products together with the knowledge required to deploy them. This can both reduce support requests from customers and provide a competitive differential between a business's products and those of its competitors.

Three main groups of techniques are available for building knowledge-based and decision support systems. Each is described below with the emphasis placed on the benefits and complexities of applying the techniques within the group:

- **Explicit Encoding of Knowledge:** these techniques provide a language for recording an expert's knowledge. An expert's knowledge is captured through questions, observations etc. and encoded in the language used by that particular technique. Knowledge acquisition methods and tools are available but require considerable effort. The explicit specification of knowledge enables the system to explain its conclusions.

- **Using Past Cases:** these techniques use records kept on solutions to similar problems to develop a solution to the case in hand. They require access to the design and costing of past projects. While they remove the need to capture expertise from experts, they are dependent upon the quality of information that is recorded on past work and on the similarity to current work.
- **Adaptive Systems**: these techniques entail learning how to solve problems by examining the situations given to experts and the responses they provide. They have proved effective at tackling fault detection problems. While their ability to learn by observation removes the need for a knowledge acquisition process, they cannot explain the conclusions that they reach.

Knowledge-based and decision support techniques complement knowledge management methods. They offer effective approaches to removing knowledge bottlenecks, preserving knowledge, encouraging best practice, and adding a competitive differential to products. AI techniques are now in very common usage but hidden as part of Word Processing packages, drawing tools etc.

The following section presents brief descriptions of actual applications to underline these potential benefits. Section 4 includes a checklist to assist in determining if a knowledge-based system is appropriate.

3 Examples of applications

3.1 Non-construction industry

Bid/ No bid Decision Support System - Each year *Short Brothers* receives many invitations to tender. Owing to the high cost of bidding, inquiries are evaluated and filtered by a Bid/ No bid committee. An intelligent system has been developed that uses a combination of weights derived from previous bids, and the encoded knowledge of several managers to evaluate proposals. The system has resulted in several benefits. It ensures consistent decision making, improves the rationale behind bidding, and speeds up the decision making process. The system has resulted in cost savings because of the speed up in the bid/no bid decision. This results in more time to spend on actual bids - thus increasing the company's bid-to-win ratio. It allows better proposals to be produced and improves allocation of bidding resources. Such a system could have considerable scope within the construction sector. (DTI, 1998).

Procurement - ***EXPERT PROVISIONER*** is a Knowledge Based System that supports Royal Air Force (RAF) Range Managers in the procurement of consumable supplies. The system consists of a graphical user interface to display the procurement item requisition information and a consultation style interface to a knowledge-based system. RAF Wyton houses the central supplies procurement centre for the RAF. 500 Range Managers are responsible for processing orders valued at over £1.2 billion. By linking into existing procurement information and providing a knowledge-based decision aid, Expert Provisioner allows the RAF to know exactly what has been bought, what it has cost and why it is needed. The aim is to reduce the uncertainty of procurement budgets near financial year-ends, wastage through over-ordering, taking advantage of price breaks for large orders and maintaining consistency of order processing. Expert Provisioner was successfully evaluated by end users and a full production system developed.

3.2 Construction industry applications

3.2.1 Bridge Fabrication error solution eXpert (BFX)

In bridge engineering, fabrication errors occur during the manufacture of elements of the steel assembly. These errors can have deleterious effects on the performance of a bridge if they are not repaired properly. Errors may cause delays in the fabrication process. In the past, Kansas Department of Transportation (KDOT) handled these bridge fabrication errors in a very non-scientific, non-procedural manner on an individual case-by-case basis. Only certain staff members with previous experience in handling these fabrication errors were able to provide repair solutions. The expertise within KDOT was also scattered or scarce, as engineers within different districts were familiar with different types of problems and repair solutions.

A rule based expert system, Bridge Fabrication error solution eXpert (BFX), was developed at the University of Kansas as a joint venture with KDOT. Its objective was to create an expert system for solving the fabrication errors that would provide a standard repair procedure for KDOT. Currently, the system is in operation at the bridge design offices of Kansas Department of Transportation. The system was completed and delivered to the KDOT in January 1994. Over 100 cases were acquired directly from fabrication shops, state inspectors' field notes, and bridge project documents. Of these cases, 77 were used to develop the expert system and 51 were used to validate the system. The 548 rules formulated for BFX's knowledge base were implemented in the expert system development package, Level 5 Object. BFX is capable of handling errors in the areas of tolerances, drilling and punching, cutting, and lamination. (Bocox J, Roddis WMK, 1996)

3.2.2 ELSIE

The ELSIE Expert System is a structured planning tool based on four modules: budget, time, procurement and development appraisal. It was first released in 1985 and runs on a PC, and hence on the machine used by most surveyors. It was initially developed at the University of Salford in an 18-month project funded by the Alvey Programme, after which a company was formed and continued development took place. ELSIE was built using the Savoir Expert System shell, which was selected for its efficiency and its inference net formalism. ELSIE's four modules are integrated around a project database so that information given in one module will be passed to others if required. All modules operate by asking the user a sequence of questions.

The knowledge base contained links that determine the dependencies among the pieces of information held, so that the answers given are propagated 'intelligently' throughout the knowledge base and may affect which questions are asked later on, or in which order. After the main question sequence, the result is declared and the user arrives at a 'What Now' point, at which explanation reports can be obtained, information can be over-ridden, and the information can be archived in the project database for later use. Not only may the answers to the question sequence be overridden but also upwards of a hundred assumptions that the module makes. In practice, the question & answer dialogue would be changed to perform what-if analyses, while the assumptions would be overridden to take account of special or local circumstances. The user interface is relatively simple, comprising ‘windows’ composed of character graphics. To certain questions the user may answer ‘unknown’, in which case the module makes an intelligent assumption (Basden, 1997)

3.2.3 Codes, Regulations, Document/ Product Retrieval

Knowledge based systems technologies can be used to capture knowledge about the structure of documents and the rationale behind information in documents. This was demonstrated in the ***PLINTH*** system developed by AIAI for the Building Directorate of the Scottish Office. The system facilitates the capture of the rationale behind the Building Standards Regulations for Scotland, in addition to the structure of technical documents. This structured knowledge assists the reader whilst navigating the complex interrelationships between sections. The technology may be applied to other types of structured document such as a building's design (Casson, 1992).

3.2.4 BP-Expert

BP-Expert has been developed as part of the COnstruction and Real Estate NETwork (CORENET) programme, which is a key component of the IT2000 Information Technology Masterplan (IT) for Singapore. BP-Expert is an intelligent system, employing AI and CAD, to automate the checking of architectural plans for compliance with the Building Control Regulations. The system will be used to carry out self-checking before submission to the Building Control Division (BCD). It accepts as input building plans prepared with CAD software. It captures knowledge of how to interpret architectural designs as well as how to verify the design against building control regulations. It automatically recognizes the layout of a floor plan, derives spatial relationships between the various building components and checks the design for compliance with the building code. Non-compliances are highlighted, and the architect can correct any design errors until compliance is achieved. The electronic files can then be submitted to Building Control Division (BCD) for final approval.

Further information can be obtained from the following Web site, which has been used as the source for the above description:
http://www.gov.sg/mnd/pwd/bpx/index.htm

3.2.5 Operation

The use of knowledge-based systems is well established in the process and manufacturing industries. Techniques developed for those industries can be transferred to the monitoring of the structural behaviour of buildings. A monitoring system has been developed by BRE to study the in-service behaviour of two steel trusses in a large hall located in Neasden. In addition to the sensors on the truss, two temperature gauges record the ambient temperature in the zone around the trusses. These data are used for system development and a knowledge based monitoring system currently under development is directly linked to the logger.

3.2.6 Property valuation

The University of Portsmouth developed a system for valuing properties using property details from surveys and records of actual auction prices. This system used a neural network and demonstrated that non-experts could give effective valuations. This was very necessary as the introduction of the UK Council Tax required millions of properties to be assigned into bands (DTI, 1998).

3.2.7 Predicting defects in housing construction

The majority of building defects are avoidable and relate to design and construction problems, in addition to poor quality maintenance work and general negligence and abuse by the users. It has been estimated that the annual cost of such problems is around £1000 million in the UK and represents about 95% of all defects. The current techniques employed to predict defects in housing do not offer a facility to construction professionals and workmen for the intelligent application of information at both design and construction stages.

A prototype KBS system was developed at the Sheffield Hallam University. The system incorporates all knowledge related to design specification and codes of practice, materials and components workmanship considerations and procedures. The knowledge collated allows the KBS to be used before or during the construction process. The system may be used during the sketch design and detailed design stage of the construction process (Ahmed and Stephenson, 1997).

3.2.8 Subsidence – diagnosis and management

SCAMS is a KBS developed at the University of Teeside to provide guidance to engineers in the engineering management of subsidence cases (Scott and Anumba, 1996; Scott, 1997). It offers intelligent advice and addresses three key aspects - diagnosis of a subsidence case, choice of an appropriate course of investigations, and specification of effective remedial measures. The knowledge encapsulated within the system has been obtained from literature, domain experts, case studies and an industry survey. The system:

- serves as a decision support system for experienced engineers and provides guidance for inexperienced engineers;
- leads to reduced repair costs due to more appropriate investigations and more effective remedial measures;
- aids understanding and ensures greater consistency in evaluation and management;
- ensures all relevant geotechnical and structural engineering considerations are taken into account;

SCAMS has been evaluated by domain experts and is being developed into a commercial product.

4 How to decide on suitability of a knowledge-based solution for a problem

Many attempts to develop knowledge-based systems have failed. The reasons for failure are normally the same as those for conventional information systems. Failure is not normally due to technical aspects of the knowledge-based technologies used. The most common reasons for failure are: insufficient business justification; lack of support from project stakeholders; and organisational issues.

AIAI at The University of Edinburgh has developed a methodology for determining the feasibility of a given knowledge based system application (Filby 1997). This comprises an assessment of:

1. **Business Feasibility (e.g. improvements in the quality of decision making; a reduction in staff costs; preserving knowledge which was vulnerable to loss; etc.)** weighted against the possible costs that will be incurred e.g. hardware and software costs; running cost (backups and maintenance); etc.
2. Project Feasibility e.g. the commitment, availability and skills of all the project stakeholders should be considered.
3. Organisational Feasibility e.g. whether the organisation is currently undergoing any organisational changes; what impact the system will have on tasks preceding and following the task supported by the system; a full understanding of the main functions/processes along with their associated information; training staff within the organisation to install, maintain and manage information and the proposed technology; existence of a champion to lead the introduction of such systems.
4. Technical Feasibility e.g. the type of task - synthesis tasks are often harder than analysis tasks; risks - tasks with major risks should be identified and their impact on the development determined; these should be implemented first to reduce the overall risk to the project; the type of reasoning –if it is primarily symbolic reasoning based on expertise then a KBS should be suitable; requirement for common-sense knowledge - if this is required to solve the problems, it is likely to be infeasible; etc.

5 Conclusions

- KB/AI techniques can successfully be used to capture and re-use best practice ‘knowledge’. This has been demonstrated most clearly in non-construction industry sectors. Consideration should be given to refocusing construction research on to practical industry needs.
- The precise techniques used are of less importance than the industry needs – decision support systems capturing experience can be constructed in many cases using more traditional IT techniques. A methodology to allow the assessment of

an organisation's existing skills and knowledge and to identify the key gaps and opportunities for improvement is needed.

- The small market size for software in the construction industry and other factors make the development of many stand-alone DSS problematic. A more promising approach would be to develop a library of Web-based tools that could be shared. The incorporation of common sense 'intelligence' into Classes of Objects through the IAI is one way forward. The development of tools, which could be used by individual companies or interest groups to add additional, specific and possibly proprietary knowledge, would also be very helpful.
- There is a need for documented Case Studies that demonstrate concrete benefits.
- Means need to be established to allow industry to obtain advice on feasibility of decision support systems to address their needs. This could be a role for a network of experts

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