A KNOWLEDGE-BASED DECISION-SUPPORT SYSTEM FOR HEALTH AND SAFETY COMPETENCE ASSESSMENT

Hao Yu[1, 2], David Heesom[2], David Oloke[2], Kevan Buckley[3], and David Proverbs[2]

[2] *School of Engineering and the Built Environment, University of Wolverhampton, Wulfruna Street, Wolverhampton WV1 1SB UK*
[3] *School of Computing and Information Technology, University of Wolverhampton, Wulfruna Street, Wolverhampton WV1 1SB UK*

It is believed that standard, generic pre-qualification competence questionnaires can often be irrelevant, create a great deal of paperwork, and be of little benefit to health and safety. Under the Construction (Design and Management) (CDM) Regulations 2007, clients have to take reasonable steps to ensure that all duty-holders to be appointed or engaged are health and safety competent. Since many clients have little knowledge of construction and health and safety, it is difficult for them to make reasonable decision on the selection of health and safety competent duty-holders. In order to assist such clients fulfil their CDM duties, a knowledge-based decision-support model was developed on the basis of the knowledge representation and reasoning features of making health and safety competence assessment. The knowledge-based decision model utilized rule-based reasoning, case-based reasoning and hypertext technology to support three decision-making mechanisms. In order to realize on-line automation, HTML, JSP and MySQL are adopted to develop a dynamic internet-based KBS on a commercial JSP web server. A conceptual architecture of the KBS demonstrated the structure of the system for the future development.

Keywords: CDM regulations, competence assessment, knowledge-based system, health and safety management, web application.

INTRODUCTION

The Construction (Design and Management) (CDM) Regulations 2007 have replaced CDM Regulations 1994 and Construction (Health, Safety and Welfare) (CHSW) Regulations 1996. Under CDM Regulations 2007, Clients must make ensure that all engaged duty-holders including CDM co-ordinator (when the project is Notifiable), designers, contractors and other team members are competent or work under the supervision of a competent person. In order to standardize the assessing process, the Approved Code of Practice (ACOP) of CDM Regulations 2007 provides a guidance of how to assess the competence of organizations and individuals. According to the core criteria in ACOP, assessments are project-related and should be proportionate to the risks, size and complexity of the work. In addition, doing an assessment is a knowledge-intensive process on the basis of mastery of knowledge and expertise in construction health and safety management. However, due to the lack of adequate experience and expertise, most clients are not capable of evaluating duty-holders'

[1] H.Yu@wlv.ac.uk

Yu, H, Heesom, D, Oloke, D, Buckley, K and Proverbs, D (2007) A knowledge-based decision-support system for health and safety competence assessment. *In:* Boyd, D (Ed) *Procs 23rd Annual ARCOM Conference*, 3-5 September 2007, Belfast, UK, Association of Researchers in Construction Management, 305-314.

health and safety competence. Making an unreasonable judgment would bring client prosecutions as a result of accidents caused by the appointed duty-holder who subsequently were proved not competent to carry out the work. However, as the construction industry is dominated by one-off projects', most clients are doing occasional work. It is, thereby, difficult for those one-off clients to equip themselves with sufficient knowledge and experience of making reasonable assessment of duty-holders' health and safety competence.

A Knowledge-Based System (KBS) is a computerized programme which makes use of a range of Artificial Intelligence (AI) technologies to store, retrieve and re-use human knowledge, experience and heuristics (Awad, 1996; Giarratano and Riley, 2006). KBS has been applied in many disciplines to emulate the thought processes of experts to deal with various knowledge-intensive problems. Rule-based reasoning, case-based reasoning, fuzzy logic, decision tree learning, artificial neural networks and evolutionary computation are AI technologies utilized as reasoning processes or knowledge acquisition facilities in KBS (Giarratano and Riley, 2006). The selection of suitable AI technologies to be applied in a KBS depends on the appropriate knowledge representation and reasoning in the process of solving the target problem (Giarratano and Riley, 2006; Yu, *et al.*, 2006).The widely accessible Internet offers a large potential for the delivery of KBS on the World Wide Web. Web-based KBS are 'traditional KBS, using mainly rule-based and case-based reasoning, that have been adapted from organic designs to Internet use by incorporating client-server architectures and Web-based interfaces' (Grove and Arther, 1999).Therefore, an Internet-compatible KBS can offset the difficulty of acquiring knowledge during system development and maintaining knowledge bases over time (ibid.).

In order to assist clients make reasonable judgments on duty-holders' health and safety competence assessment in terms of CDM Regulations 2007, a knowledge-based decision-making model is proposed via the analysing the knowledge representation and reasoning features in the process of undertaking competence assessment. Furthermore, an analytical structure of an on-line knowledge-based decision-making system, which is envisaged to intelligently help clients make reasonable decisions for duty-holders' competence assessment, will be illustrated as an uptake for future research.

A BRIEF REVIEW OF KBS IN CONSTRUCTION HEALTH AND SAFETY

Generally speaking, only few efforts have been focused on the health and safety related KBS development, compared to other areas (Robertson and Fox, 2000). However, interest has appeared to increase the use of KBS for industrial health and safety purposes recently (Lingard and Rowlinson, 2005). Five application areas including the provision of regulatory advice; hazard analysis and avoidance; decision support; monitoring and diagnosis; and post-accident analysis and corporate knowledge, in which KBS can be applied to improve industrial health and safety, have been identified (Robertson and Fox, 2000). Presently, KBS is usually applied to provide regulatory advice and decision support for construction health and safety management, such as Gowri and Depanni's (1998) health and safety expert system for building code compliance checking, Cheung's (2004) web-based safety and health monitoring system for construction management and Davison's (2003) prototype knowledge-based system to assist construction designers to identify hazards, evaluate risks and specify, suitable risk controls in their designs. Although the benefits of KBS

are becoming apparent, the development of KBS is still overlooked in construction health and safety management to date (Yu, *et al.*, 2005). However, it is envisaged that KBS is an effective tool which can enable rapid and timely health and safety decision-making and facilitate the capture and analysis of incident information for future use (Lingard and Rowlinson, 2005).

THE CORE CRITERIA OF CONSTRUCTION HEALTH AND SAFETY COMPETENCE ASSESSEMNT

Health and safety competence is not only a premise of safe performance but also the ability to ensure that an activity can be executed pragmatically and in a value-adding way (Carpenter, 2006a; 2006b). In CDM Regulations 2007, competence is categorized into two levels, namely the organizational and individual competence. In order to aid the competence assessment, ACOP of CDM Regulations 2007 gives various advice which aims to standardize the process. Competence assessment of organizations should be carried out as a two-stage process. The first stage is to assess appointed or engaged company's health and safety arrangements and organization to determine whether the company has positive health and safety culture and management system to ensure the current work can be carried out safely and without risk to health. The second stage aims to appraise the company's experience and track record to ensure its suitability to deal with the key health and accident hazards in the current application. As illustrated in Figure 1, a set of 'core criteria' have been agreed by industry and the HSE to ensure the consistency of the way in which competence assessment of organizations are carried out. Since unnecessary bureaucracy related to competence assessment would obscure the real issues and divert effort away from them, assessments should focus on the needs of the particular project and be proportionate to the risks arising from the work (ibid.). For example, companies employing less than five people may not have to write down their policy, organization and arrangements for health and safety, but need to demonstrate that all those health and safety requirements have been satisfied in relation to the type of work they do.

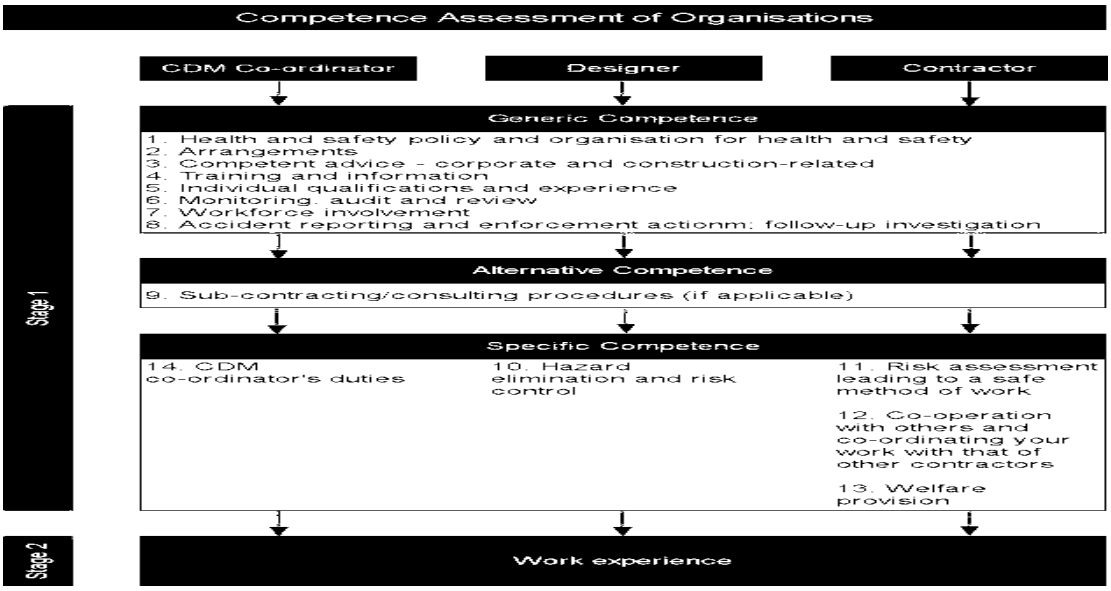

Figure 1: Competence assessment of organizations

As with organizations, the competence assessment of key individuals is a two-stage process:

Stage 1: The task knowledge needs to be assessed to determine whether those individuals are competent to undertake the work safely and without risk to health. The task knowledge can be judged by qualifications and training records, and arrangements which have made for their Continuing Professional Development or lifelong learning.

Stage 2: The individuals' experience and track record needs to be assessed to ensure that those individuals are capable of doing the work. The assessments are suggested to focus on the people past experience in the type of work which will be carried out.

The membership of a relevant professional institution for example CIBSE; ICE; IMechE; IStructE; RIBA; RICS; CIAT; CIOB; NEBOSH provides a strong evidence that the person has necessary task knowledge and is capable of dealing with health and safety issues in current work. In addition, membership of a particular register operated by an institution such as Association for Project Safety (APS); the Institution of Construction Safety (ICS) can be viewed as confirmation that the person has adequate expertise and experience to carry out the CDM duties in current project.

THE SELECTION OF AI TECHNOLOGIES FOR THE KBS OF COMPETENCE ASSESSMENT

Although KBS can help people automate intelligent work, improve productivity and retain scarce expertise, it still has limitations which should be carefully taken into account during planning and development. Awad (1996) concluded the limitations of KBS as:

- KBS knowledge is static;
- KBS doesn't evolve and grow as human knowledge does;
- KBS isn't adaptability, empathy and has common sense.
- KBS can't understand the context of things or learn from experience; and
- KBS doesn't have knowledge of themselves or the environment.

Most of the above limitations are related to the rule-based system which is a typical kind of KBS and can be called as expert KBS. However, with the development of AI technologies, other AI technologies such as case-based reasoning, fuzzy logic, neural networks and genetic algorithms could be added into the rule-based system to circumvent those constraints by improving knowledge acquisition and reasoning process (Giarratano and Riley, 2006).

It has been recognized that the success of a KBS depends on the selection of appropriate AI technologies to accurately represent and reason the domain knowledge (Giarratano and Riley, 2006; Yu, *et al.*, 2006). Knowledge representation can be defined as an ontological method of analysing the thought process of an expert and then emulating that process in a logic way which can be programmed by computer. According to the judging evidence recommended by the ACOP of CDM Regulations 2007, the decision-making process requires procedural knowledge and semantic knowledge. The procedural knowledge is a shallow and explicit knowledge including procedures, regulations or heuristics in the form of condition-action statements (IF…THEN), a taxonomic hierarchy, or a set of alternatives which need to be

searched through (Awad, 1996). However, the semantic knowledge is a deep and tacit knowledge which is highly organized and represented as knowledge chunks. An expert usually takes a long time to explain or verbalize those chunked knowledge and is likely to recall concrete cases to illustrate them. As illustrated in Table 1, the decision-making process of health and safety competence assessment can be represented by two inference processes.

Table 1: Knowledge representation of health and safety competence assessment

Judgment Task	Inference Process	Knowledge feature
Regulation-compliance checking	Do the candidates have the evidence conforming to the core criteria?	Procedural knowledge
Qualitative assessment of H&S culture, performance and experience	What is the quality of that evidence to satisfy the H&S standards?	Semantic knowledge

In terms of the knowledge features of the two inference processes, appropriate AI technologies have been selected as the reasoning processes in the KBS. Since the procedural knowledge can be represented by production rules, rule-based system is the best choice of the reasoning process in the KBS for the regulation-compliance checking. Assessing the quality of health and safety documents requires semantic knowledge which can be attributed as uncertainty, non-linearity, imprecision, qualitative and subjective. Unlike the procedural knowledge which can be inferred in a set of logic rules, the semantic knowledge is an incomplete causal cognitive process in which former experience and heuristic will be retrieved and adapted to generate a solution for the current problem. Case-based reasoning is such an AI methodology that can help people adapt or refer old solutions to meet new demands. The contextualized cases can represent abstract knowledge and teach people lessons which are fundamental to achieving the goals of the current reasoning (Kolodner, 1993). In addition, case-based reasoning is a suitable means of evaluating solutions when no algorithmic method is available for evaluation (ibid.). Therefore, case-based reasoning is used as knowledge reasoning technology to aid the evaluation of the quality of duty-holders' health and safety documents. In addition, with the advantage of information technologies, the Internet provides KBS with a dynamic platform which can accelerate data transfer, improve knowledge acquisition and reasoning and enhance the maintenance of knowledge base (Wong and Hamouda, 2003; Sutisna, *et al.*,2004;).

A CLIENT-CENTERED KNOWLEDGE-BASED DECISION-SUPPORT MODEL FOR COMPETENCE ASSESSMENT

The client is the originator of a project and is required to be integrated into the selection process of candidate duty-holders. Due to the requirement of CDM Regulations 2007, the client must be capable of doing a reasonable assessment. If a client can take all evidence that has been asked for and provided into account, he will not be criticized if the appointed duty-holder subsequently proves not to have been competent to carry out the work (HSC, 2007). However, many 'one-off' or occasional clients have very little knowledge of construction and thereby cannot make reasonable assessment even with the guidance of ACOP. Presently, although some independent accreditation bodies can be used to assess duty-holders competence, clients still need to make sure that the assessment process is robust and on the basis of the core criteria. It is envisaged that a specific KBS can be developed to help clients make a reasonable decision on candidate duty-holders' health and safety competence and automate the

decision-making process. Furthermore, the KBS can also be used to keep the decision-making record as evidence in case of the occurrence of prosecution.

According to the knowledge representation and reasoning process of making competence assessment, a knowledge-based decision-support model was developed by applying appropriate AI technologies facilitating clients to take reasonable steps of decision-making on duty-holders' health and safety competence. The knowledge-based decision-support model utilizes rule-based reasoning, case-based reasoning and web technologies to effectively and intelligently support client's decision-making for competence assessment. As illustrated in Figure 2, the model includes three decision-support mechanisms, namely:

- The screen mechanism: In order to avoid unnecessary bureaucracy, the filtering mechanism helps clients eliminate the incompetent candidates by checking the existence of a set of documents or the adequacy of knowledge (for company employing less than five people) in compliance with the requirements of ACOP. A set of rules are developed for the dichotomy evaluation via a checklist.
- The rating mechanism: The competence assessment is a type of retrospective appraisal of organizational and individual health and safety performance. The rating methods relying on the construction measuring scales are usually applied for the subjective performance assessment in terms of behavioral sciences (Lehtinen, *et al.*, 1996). The five-point likert rating scale is the most simple indicator system to catergorize health and safety performance into certain classes (Lehtinen, *et al.*, 1996; Trethewy, 2003). In order to assess the core criteria on the base of subjective measurement of qualitative evidence, the five-point likert rating scale is used to help client classify candidate duty-holders' health and safety competence. Table 2 is the method of rating core criteria of competence. As mentioned before, many clients are not capable of making competence assessment because they don't have adequate knowledge in relation to construction and health and safety management. In order to facilitate clients to fulfill the task, a hypertext system provides assessment guidance including standards of judgment, examples of evidence or best practices. Furthermore, case-based reasoning is applied to enable clients to get cross-reference of cases selected by experts and stored in a case base. Simultaneously, applying web technologies can facilitate client to get on-line help from remote experts.

Table 2: Likert rating indicator for health and safety competence assessment

Score	Classification	Explanation
1	Poor	Evidence does not meet standards
2	Fair	Evidence partly meets standards
3	Acceptable	Evidence meets standards but is not adequate
4	Good	Evidence meets standards and is compliance substantial
5	Excellent	Innovation exceeding standards

- Ranking and reporting mechanism: The candidates are sorted not only by the total rating scores but also the number of criteria scored over 3 (acceptable). The more criteria over acceptable classification, the better competence of a candidate. According to the ranking, clients can select the reasonable candidates to undertake the work after taking other considerations such as cost, quality and time into account. A report is generated automatically to illustrate the selection process to meet the requirement of CDM Regulations 2007. The report also would be seen as an evidence of reasonable judgment in case of future prosecution.

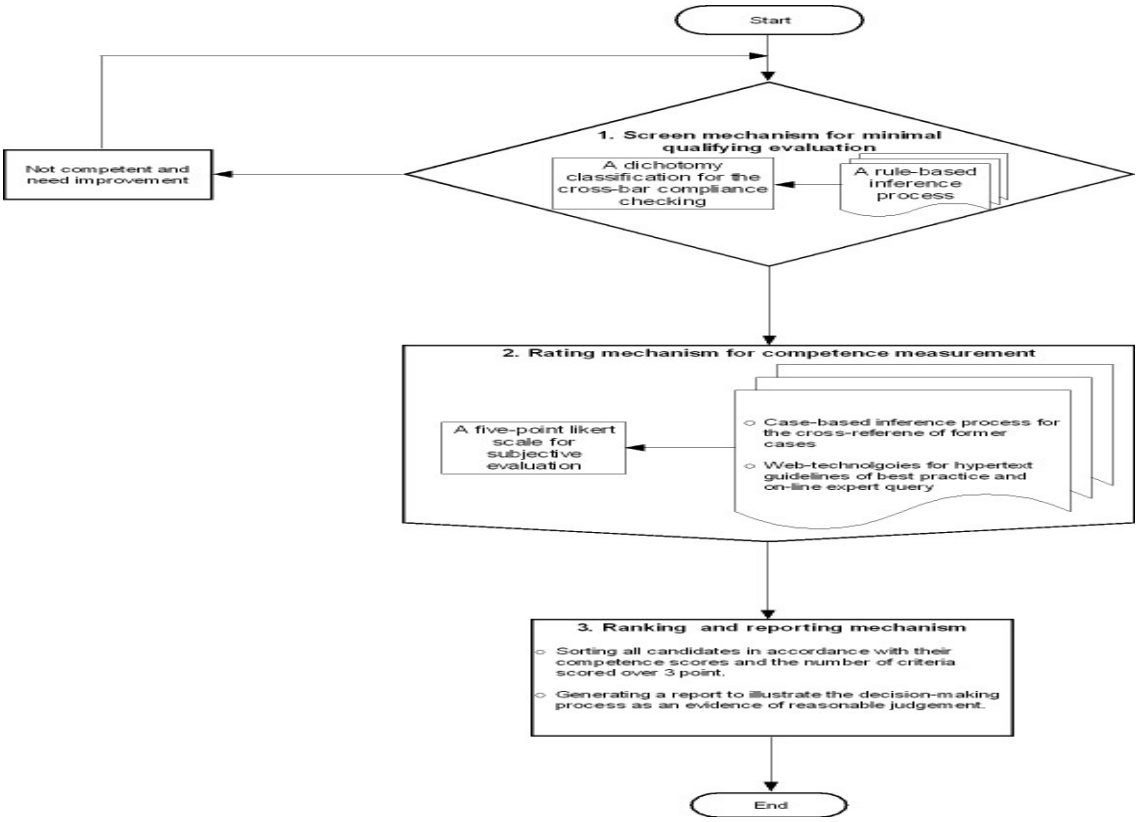

Figure 2: A knowledge-based decision-support model for health and safety competence assessment of organizations

THE CONCEPTUAL FRAMEWORK OF THE WEB-BASED KNOWLEDGE-BASED DECISION-SUPPORT SYSTEM FOR COMPETENCE ASSESSMENT

In order to develop an online decision-support tool, the first task is to select a dynamic web development programming language which can provide database support, friendly interface, a security system, and a stable internet connection (Cheung *et al.*, 2004). JavaServer Pages (JSP), a state-of-the-art dynamic web programming language enabling rapid development and easy maintenance, was adopted as language for the development of online KBS. For the efficiency of date and case collection and retrieval, the world's most popular open source database – MySQL is applied because of its superior performance, scalability and reliability (MySQL, 2007). A commercial JSP web server using Tomcat 5.0, the most effective Java server solution for Java Server Pages applications, has been rented to host the KBS. Figure 3 is the conceptual architecture of the web-based KBS. Hypertext Markup Language (HTML) was applied for the creation of webpages to deliver information and contents. JSP was used to deal with data entry and support three decision-support mechanisms. A Java Bean (a Java class), was developed to provide connectivity to a MySQL database by using Java Database Connectivity (JDBC) technology. The application of Java Beans can clean up page code and simplify its maintenance and development (Mcgrath, 2002).

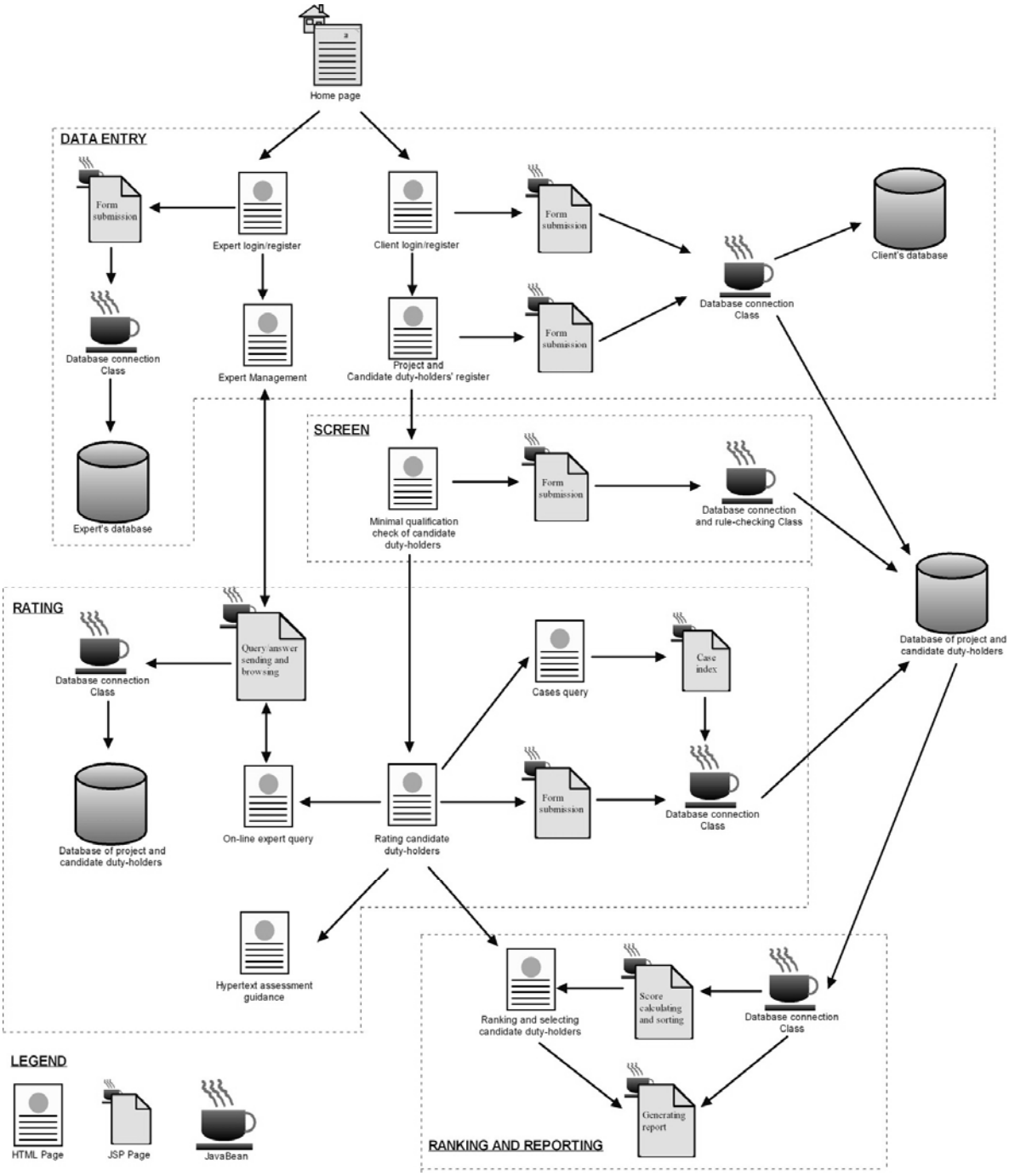

Figure 3: Conceptual architecture of web-based KBS for health and safety competence assessment

RECOMMENDATIONS FOR FUTURE RESEARCH

In order to develop a practical on-line KBS that can effectively help client deal with health a safety competence assessment under CDM Regulations 2007, future research will focus on:

- The collection of relevant data and knowledge for effective hypertext guidance;
- The development of rule base for efficient rule-based screen process;
- The development of web pages for a user-friendly interface; and

- The verification and validation of the KBS for a reliable and correct decision-support tool.

CONCLUSIONS

The health and safety competence assessment has been acknowledged as the first and important task of ensuring safe and healthy performance in construction. Under CDM Regulations 2007, clients have to discharge the duty of taking reasonable steps to assess duty-holders' health and safety competence against the core criteria before they are appointed or engaged. However, such a decision-making process is knowledge-intensive and difficult to be accomplished satisfactorily by many clients without any knowledge and experience in construction. The development of a knowledge-based decision-support model provides a scientific approach of facilitating clients to assess duty-holders' health and safety competence against the requirements of CDM Regulations 2007. The application of advanced web technologies could automate the decision-making, improve knowledge acquisition and retrieval, and facilitate health and safety management. The recommendations of further research indicate several important tasks that should be accomplished for the success of applying KBS in construction health and safety competence assessment.

REFERENCES

Awad, E. M. (1996). Building Expert Systems: Principles, Procedures and Applications. St. Paul, West Publishing Company.

Carpenter, J. (2006a). Developing guidelines for the selection of desingers and ontractors under Construction (Design and Management) Regulations 1994. Norwich, Health and Safety Executive.

Carpenter, J. (2006b). "Managing safety risk through whole-life competency." Civil Engineering 159: 57-61.

Cheung, S. O., K. W. Cheung, *et al.* (2004). "CSHM: Web-based safety and health monitoring system for construction management." Journal of Safety Research 35: 159-170.

Darlington, K. (2000). The Essence of Expert System. London, Pearson Education Limited.

Davison, J. (2003). The development of a knowledge based system to deliver health and safety information to desingers in the construction industry. Norwich, HSE.

Giarratano, J. C. and G. D. Riley (2005). Expert Systems Principles and Programming Fourth Edition. Canada, Thomson Course Technology.

Gowri, K. and S. Depanni (1998). "The Health and Safety Expert System (HASES): an expert system framework for building inspections." Engineering Construction and Architectural Management 5(1): 92-102.

Grove, R., F. and C. H. Arthur (1999). An Internet-Based Expert System for Reptile Identification. The First International Conference on the Practical Application of Java, London.

HSC (2007). Managing health and safety in construction: Construction (Desingn and Management) Regulations 2007 Approved Code of Practice. Norwich, Health and Safety Commission.

Kolodner, J. (1993). Case-Based Reasoning. San Mateo, Morgan Kaufmann Publishers, Inc.

Lehtinen, E., B. Wahlström, *et al.* (1996). Management of Safety Through Performance Indicators for Operational Maintenance. IAEA Specialist Meeting on Methodology for Nuclear Power Plant Performance and Statistical Analysis. Vienna.

Lingard, H. and S. Rowlinson (2005). Occupational Health and Safety in Construction Project Management. Abingdon, Spon Press.

Mcgrath, M. (2002). JavaServer Pages in easy steps. Southam, Computer Step.

MySQL. (2007). "MySQL Expands Partner Program to Support Growing Market for MySQL-Related Products and Services." Retrieved 05/May, 2007, from www.mysql.com/news-and-events/press-release/release_2004_13.html.

Negnevitsky, M. (2002). Artificial Intelligence: A guide to Intelligent System 2nd Edition. Beijing, Pearson Education Limited.

Robertson, D. and J. Fox (2000). Industrial use of safety-related expert system. Norwich, HSE.

Sutrisna, M., D. Proverbs, *et al.* (2004). "A Knowledge Based System for valuing variations in civil engineering works: a user centred approach." International Journal of IT in Architecture, Engineering and Construction **2**(4): 285-302.

TRETHEWY, R. W. (2003). "OHS Performance-Improved Indicators for Construction Contractors." Journal of Construction Research **4**(1): 17-27.

Wong, S. V. and A. M. S. Hamauda (2003). "The development of an online knowledge-based expert system for machinability data selection." Knowledge-Based System 16: 215-229.

Yu, H., D. Heesom, *et al.* (2006). Using AI Technologies to Improve Construction Health and Safety Performance: A Conceptual CBR Model for Health and Safety Competence Assessment. World Conference Accelerating Excellence in the Built Environment (WCAEBE), Birmingham, University of Wolverhampton.

Yu, H., D. A. Oloke, *et al.* (2005). Improving Health and Safety in Construction: A Knowledge-Based Approach. Twenty First Annual Conference of Association of Researchers in Construction Management, London, ARCOM.