A KNOWLEDGE BASED SYSTEM FOR CONSTRUCTION HEALTH AND SAFETY COMPETENCE ASSESSMENT

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ABSTRACT

Organisational and individual Health and Safety (H&S) competence is an essential element to the successful completion of a construction project in a safe way and without hazards to the health of all workforce. Under the Construction (Design and Management) (CDM) Regulations 2007, the client should take reasonable steps to ensure that the appointed duty-holders and engaged people are H&S competent to design, build or co-ordinate the project. Although the CDM Regulations 2007 and its Approved Code of Practice (ACoP) have established 'Core Criteria' to guide the client to assess duty-holders' H&S competence in the outset of a project, it is still difficult for most inexperienced clients to discharge the duty of making the key decisions in H&S competence assessment. In order to help the client implement H&S competence assessment, it is important to develop a tool that can effectively and efficiently support the client to make reasonable decisions in the selection of H&S competent duty-holders.

According to the findings of the case study of existing formal H&S competence assessment schemes undertaken as part of this work, H&S competence assessment was characterised as a subjective, qualitative and non-linear regulation-compliance checking process. In addition, the case study helped identify the latent shortcomings in the 'Core Critiera' and the operational drawbacks in current practice of implementing H&S competence assessment. Based on a review of Information Technology (I.T.) and Artificial Intelligence (A.I.) applications in construction, Knowledge-Based System (KBS) is identified as being a suitable tool to support decision-making in H&S competence assessment, mainly due to its appropriateness to solve regulation-compliance checking problems and support subjective and qualitative decision-making process.

Following a decision-making framework for H&S competence assessment, a KBS decision-support model was developed, applying three mechanisms to support the reasonable decision-making for H&S competence assessment. In order to develop an appropriate and practical KBS for H&S competence assessment, a textual knowledge base was developed, specifying the minimum satisfaction standards and a rating indicator system for 'Core Criteria'. As a result, an online KBS was developed using Java Server Pages (JSP) technology and MySQL. The online KBS applied the textual knowledge base to support the screen, rating, ranking and reporting decision-supporting mechanisms. Simultaneously, the case inquiry and expert inquiry facilities were also included in the KBS for effective decision-making.

Finally, construction experts and practitioners in H&S management evaluated the validity and usability of the KBS through a questionnaire survey. The prototype KBS was borne out to be an effective and efficient decision-support tool for H&S competence assessment and have the potential to be applied in practice.

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LIST OF TERMS/ABBREVIATIONS

ACoP	Approved Code of Practice
A.I.	Artificial Intelligence
ANNs	Artificial Neural Networks
API	Application Programming Interface
APS	Association for Project Safety
ASP	Active Server Pages
CBR	Case-Based Reasoning
CCNSG	Client Contractor National Safety Group
CDM	Construction (Design and Management) Regulations
CHAS	Construction Health and Safety Assessment Scheme
CHSW	Construction (Health, Safety and Welfare) Regulations 1996
CIAT	Chartered Institute of Architectural Technologists
CIBSE	Chartered Institution of Building Services Engineers
CIOB	Chartered Institute of Building
CONIAC	Construction Industry Advisory Committee
CPD	Continuing Professional Development
CSCS	Construction Skills Certification Scheme
DBMS	Data-Base Management System
DP	Data Processing
DSS	Decision Support System

E-R	Entity-Relationship
EU	European Union
FL	Fuzzy Logic
GA	Genetic Algorithms
GDP	Gross Domestic Product
H&S	Health and Safety
HSC	Health and Safety Commission
HSE	Health and Safety Executive
HSG	Health and Safety Guidance
HSWA	Health and Safety at Work, etc. Act 1974
HTML	Hypertext Markup Language
ICE	Institute of Civil Engineering
ICS	Institute of Construction Safety
ILO	International Labour Office
IMechE	Institute of Mechanical Engineering
IPS	Institute of Planning Supervisors
IStructE	Institute of Structural Engineering
I.T.	Information Technology
JDBC	Java Database Connectivity
JSP	Java Server Pages
KBS	Knowledge-Based System
MHSW	Management of Health and Safety at Work Regulations 1999

MIS	Management Information System
MSDs	Musculo-Skeletal Disorders
NEBOSH	National Examination Board in Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PHP	Personal Home Page
RIBA	Royal Institute of British Architects
RICS	Royal Institute of Chartered Surveyors
RIDDOR	Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995
SQL	Structured Query Language
THOR	The Health and Occupation Reporting
UML	Unified Model Language
XML	eXtensible Markup Language

Chapter 1: Introduction

1.1 Research Background

H&S competence refers to the extent of knowledge, experience and ability that enable a group or individual to carry out certain work safely (Hughes and Ferrett, 2005; Carpenter, 2006a; Carpenter, 2006b). It has been widely identified that H&S competence is an important indicator in the development of a positive health and safety culture (Mohamed, 2002; Taylor, 2002; Hughes and Ferrett, 2005; Lingard and Rowlinson, 2005). Qualified and experienced duty-holders and work force who understand their legal obligations as well as the principles and practices of health and safety management can effectively minimise the possibility of accidents in the construction process and maximise the value of project.

Most H&S specific construction legislation has competence requirements or implications for relative practitioners (Carpenter, 2006a). Under Construction (Design and Management) (CDM) Regulations 2007, clients must make reasonable steps to ensure that all engaged duty-holders including the CDM co-ordinator (when the project is Notifiable), designers, contractors and other team members are health and safety competent or work under the supervision of a competent person. In order to standardise the assessing process, the Approved Code of Practice (ACOP) under CDM Regulations 2007 provides 'Core Criteria' to help the assessment of duty-holders' H&S competence. However, assessing duty-holders' H&S competence is a regulation-compliance decision-making process in which the assessor needs to compare the evidence provided by candidate duty-holders with the bespoke standards, and then make a judgment according to his personal knowledge, experience and rule of thumb (Carpenter, 2006a). For many 'one-off' or occasional clients with very little knowledge of construction (Egbu and Robinson, 2005), it could be difficult to deal with such a knowledge-intensive work even with the aid of 'Core Criteria'.

With the development of information technologies (I.T.), a large amount of computer-based techniques have been applied to deal with many construction problems (Heesom, 2004). As one of the major I.T. applications in construction, Knowledge-Based System (KBS) enable people to improve the decision-making process of knowledge-intensive activity by using different advanced artificial intelligent (A.I.) technologies. In order to explore the application of KBS for H&S competence assessment, the following sections introduce the relevant concepts in this research.

1.1.1 Knowledge and decision-making

It is inconceivable that any human activity can be carried out without knowledge. In terms of a pragmatic viewpoint, knowledge is an integration of framed experience, values, contextual information, and expert insight, and can be seen as the most powerful engine of production (Marshall, 1972; Davenport and Prusak, 1998). In the modern world, knowledge is an indispensable basis for making a decision. A decision is a piece of knowledge leading to a choice among alternatives; and decision-making is, thereby, a knowledge-intensive activity which manufactures knowledge about what to do (Holsapple and Whinston, 1996). The decision-making process is also a cognitive activity in which the decision-makers apply their cognitive abilities to generate reasonable decisions through drawing on or altering internal knowledge sources and assimilating external knowledge sources (*ibid.*) Figure 1.1 illustrates the relationship between the knowledge and decision-making process.

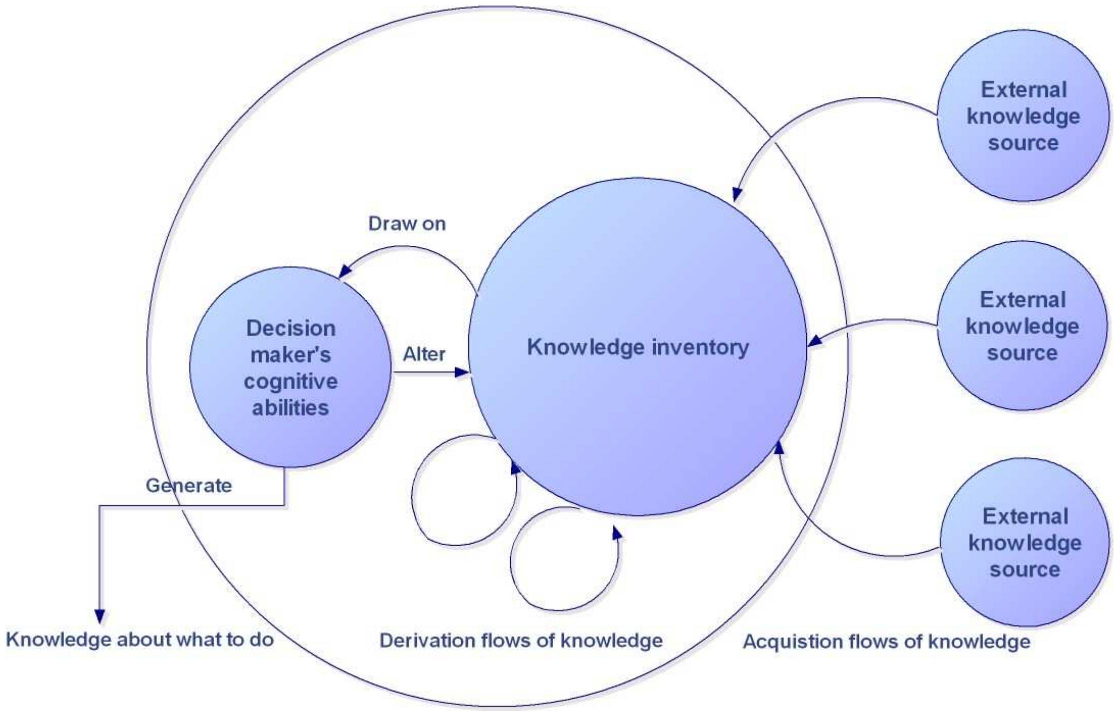


Figure 1.1 The cognitive process of decision-making (adapted: Holsapple and Whinston, 1996)

1.1.2 Knowledge-based system and decision-support system

A Knowledge-Based System (KBS) or expert system can be defined as "…an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution" (Giarratano and Riley, 2005). In literature, the terms of KBS and expert system are used synonymously. One slight difference is that knowledge in expert system may include not only knowledge from books, magazines and knowledgeable people but also more rare expertise (ibid). Figure 1.2 illustrates the basic working concept of a KBS. In general, a KBS can provide end users with expert advice in response to their query in certain knowledge domain. The knowledge base and inference engine are two main components of a KBS. The knowledge base is a database-like knowledge repository storing computerised knowledge, expertise, experience or heuristics elicited from domain experts. The inference engine contains different types of reasoning processes (programmes or algorithms) which can intelligently and automatically draw conclusions from facts or other information supplied by users. Various Artificial Intelligence (A.I.) technologies are usually applied in the inference engine to generate a reasoning process fitting different cognitive characteristics in knowledge-intensive problems.

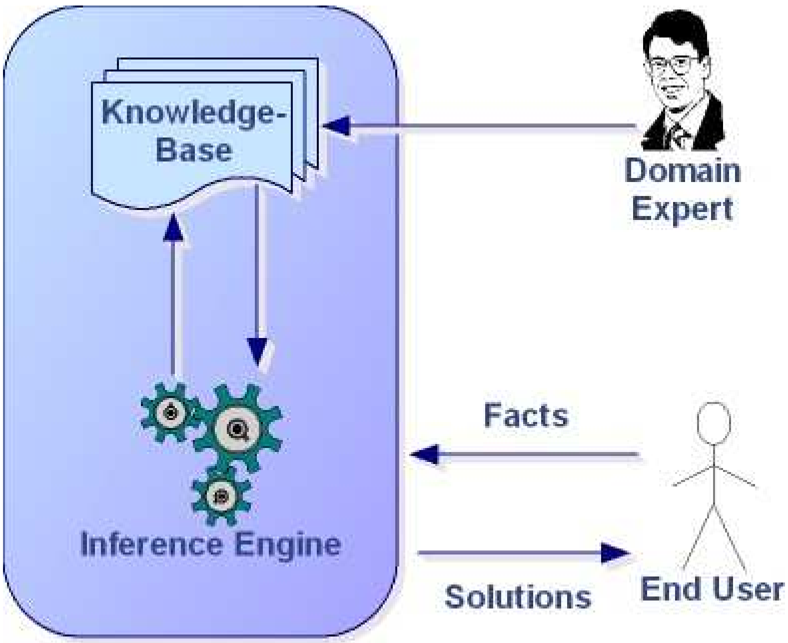


Figure 1.2 The working concept of KBS (Award, 1996; Giarratano and Riley, 2005)

The decision-support system (DSS) derived from data processing (DP) systems and management information system (MIS) can facilitate a decision-maker or a participant in a decision-maker to seek related knowledge from its knowledge repository to support a decision (Holsapple and Whinston, 1996). A typical decision support system can deal with descriptive knowledge (i.e. record keeping), procedural knowledge and reasoning knowledge through its knowledge acquisition ability, knowledge presentation ability and knowledge-selection/derived ability. With the emergence of A.I. technologies, a DSS with the function of managing reasoning knowledge is known as artificially intelligent DSS or expert system (Bonczek et al., 1981). Considering the common point – knowledge reasoning ability in DSS and KBS, a DSS can be seen as a KBS with other decision-support functions including data processing, information communication and reporting to assist decision makers in dealing with knowledge-intensive decisions. Simultaneously, a KBS can become a part of a DSS to improve the knowledge processing ability.

1.1.3 KBS Applications in Construction Industry

Computing and communication technology, commonly known as I.T, have been widely regarded as a key driver for innovation in construction industry (Sun and Howard, 2004). The activities in construction are characterised as information-independent with the transferring of various forms of information such as drawings, specifications, cost analysis sheets, budget reports, risk analysis charts, contract documents, planning schedules and health and safety documents (Tam, 1999). Since the rapid development in computer hardware and software, the increase of I.T. application in construction practices would enhance the competitive advantage, improve productivity and performance, enable new ways of managing and organising, and develop new business (Betts et al., 1991, Betts and Ofori, 1992, 1994, Tan 1996, Sun and Howard, 2004). According to Sun and Howard (2004), six categories of IT application can be identified in construction industry:

1. Business and Information Management
2. Computer Aided Design and Visualisation
3. Building Engineering Applications
4. Computer Aided Cost Estimating
5. Planning, Scheduling, Site Management

6. Computer Aided Facilities Management

As a sub-category in Business and Information Management, KBS is eminently suitable to all stages of the construction process because most construction problems are qualitative and subjective and the problem-solving depends largely on experience and judgment rather than theory and analysis (Dutton, 1997). Rowlinson (1991) listed the KBS application in design, planning, prediction, interpretation, monitoring, fault detection, diagnosis and instruction. Shen and Bradndon (1991) also mentioned a broad range of KBS applications in the construction area including project feasibility study, cost planning and estimation, design and evaluation, contract management, construction planning and operation, maintenance and rehabilitation.

1.1.4 Innovation in Construction Health and Safety Management

As the construction industry is recognised as one of the most dangerous industries (Lingard and Rowlinson, 2005), Health and Safety (H&S) issues have been extensively taken into account in the industry and attempted to reduce accident and occupational illness. Accidents that occurred in a project would not only result in human tragedies, de-motivate workers, disrupt site activities and delay project progress, but rather adversely affect the overall cost, productivity and reputation of the construction industry (Mohamed, 1999). In order to promote the health and safety performance in the industry, I.T. was considered as an innovative mechanism for driving continuous improvement (Lingard and Rowlinson, 2005)..

Knowledge and experience regarding construction H&S issues have been highlighted as vital for delivering good H&S performance through appropriate design, risk assessments and method statements (Mulholland, et al., 2005). Robson and Fox (2000) suggested that KBS can be used in five application areas including regulatory advice, hazard analysis and avoidance, decision support, monitoring and diagnosis and post-accident analysis, to improve industrial H&S. The apparent benefits of applying KBS to construction H&S issues include the easy checking of compliance against regulations, fast delivery domain specific expertise in risk analysis, rapid and timely H&S decision-making and effective capture and analysis of incident information (Lingard and Rowlinson, 2005). With the development of construction I.T., it is envisaged that KBS could be used in more different H&S areas and bring more benefits in future.

As previously presented, H&S competence assessment is a knowledge-intensive decision-making process involving the qualitative and subjective evaluation of duty-holders' H&S culture, management system and former performance in response to the judgment standards of 'Core Criteria' under CDM Regulations 2007. The reasonable assessment of duty-holders' H&S competence relies on the knowledge of regulation requirements and experience in construction H&S management. However, the client, who discharges the duty of taking reasonable steps to assess duty-holders'

H&S competence before they are appointed or engage into the project (HSC, 2007), have little knowledge of H&S regulations and experience in H&S management. It is, therefore, difficult for them to undertake their responsibility in H&S competence assessment. Although the existing formal assessment schemes can help clients undertake H&S competence assessment, the extensive paperwork, non-transparent assessment standards and non-IT based information exchange process of those schemes reduce the effectiveness, practicality and applicability of applying appropriate information and knowledge to support reasonable decision-making. It is hypothesized that a KBS containing relevant information and knowledge such as regulations, examples and cases would significantly improve the decision-making process for the H&S competence assessment. With the emergence of the standardised 'Core Criteria' under CDM Regulations 2007, there is a research aspiration of applying Web technology and KBS to develop a computerised tool to assist clients in assessing duty-holders' H&S competence against the 'Core Criteria'. The KBS can enhance decision-support in H&S competence assessment by reducing time and improving quality. Furthermore, it can improve the development of positive H&S culture in construction by helping the practitioners conduct regulation-compliance checking under CDM Regulations 2007.

1.2 Aim and Objectives of the Research

The aim of this research is to develop a KBS to assist clients in taking reasonable steps in assessing duty-holders' H&S competence under CDM Regulations 2007. In achieving the research aim, the following objectives are specified:

- Review of the research scope in construction H&S management, especially focusing on legal requirements, procedures and current practice in competence assessment.
- Analysis of the knowledge representative nature embeded in the decision-making process of H&S competence assessment
- Exploration of the application of KBS for decision-making support for construction H&S competence assessment
- Development of a decision-support model for H&S competence assessment by applying appropriate I.T. and AI technologies.
- Design and development of a textual knowledge base to appropriately represent the knowledge in the decision-making process of H&S competence assessment
- Prototyping of an online KBS to support decision-making for H&S competence assessment under CDM Regulations 2007;
- Evaluation of the KBS for construction H&S competence assessment.

The KBS (KBS-CHSCA) made use of Java language, Web technology and database to establish three decision-support facilities, including textual rule-based qualitative assessment, case-based querying and online expert support. In addition, the KBS possesses knowledge acquisition ability to capture and store former assessment cases and human expert's advice so that its knowledge base can be enhanced.

1.3 Research Methodology

In the process of conducting the research, the following two research methodologies were used to collect relevant information and analyse the knowledge representative characteristics of the domain problem.

1.3.1 Literature review

At first stage of research, a comprehensive literature review was carried out, focusing on highlighting the importance of assessing duty-holders' H&S competence in the H&S management, introducing the legislation with regards to H&S competence assessment and investigating the feasibility of applying KBS to improve the decision-making process in H&S competence assessment.

A literature review is the bedrock of a study, which can integrate different opinions, criticise previous scholarly works, build bridges between related topic areas, and/or identify the central issues in a field (Naoum, 1998; Fellows and Liu, 2003). In addition, the literature review provides justifications for the research and establishes benchmarks against which the research contributions can be assessed (Gall et al., 1996). The primary objectives of literature review in this research attempts to:

- Emphasise the significance of H&S for the sustainable development of construction industry through introducing the current situation of H&S performance and relative legislations in UK construction industry,
- Discuss the importance of developing H&S culture for the improvement of

construction H&S performance and the relationship between H&S competence and a positive H&S culture,

- Introduce the 'Core Criteria' for H&S competence assessment under CDM Regulations 2007, and
- Explore the KBS technologies and practice to identify effective solutions to develop a KBS for construction H&S competence assessment.

In order to have an in-depth understanding of the knowledge representation mode in the domain problem, two groups of 19 existing H&S competence assessment schemes are investigated to elicit knowledge representative characteristics implanted in the decision-making process of H&S competence assessment.

1.3.2 Case study

A case study is an in-depth data analysis approach focusing on one aspect of a specific problem (Naoum, 1998). The selection of case studies is mainly on the ground of cases' representative with similar conditions to those used in statistical sampling to achieve a representative sample, to demonstrate particular facets of the topic, or to show the spectrum of alternatives (Fellows and Liu, 2003). There are three types of case studies in terms of the analysing approach (*ibid.*):

- Descriptive case study: aims to systematically identify and record a certain phenomenon or process,

- Exploratory case study: is driven by theory to look for specific cases to test established hypothesis, and
- Explanatory case study: tries to explain causality and show linkages among the objects of the study.

The common sources of case study include: documentation, archival records, interviews, direct observations, participant-observations, and physical artifacts (Yin, 2003). With the development of I.T. technologies, information on websites and on-line videos provide dynamic sources for a case study. The analytic method available to undertake a case study has not been well defined so that it is important to define priorities for what to analyse and why (*ibid.*). Miles and Huberman (1994) summarised a set of useful analytic manipulations to conduct case study:

- Putting information into different ways
- Making a matrix of categories and placing the evidence within such categories
- Creating data displays – flowcharts and other graphics – for examining the data
- Tabulating the frequency of different events
- Examining the complexity of such tabulations and their relationships by calculating second-order numbers such as means and variances
- Putting information in chronological order or using some other temporal scheme

Since the case study of this research aims to explore the knowledge representative nature of the decision-making process for H&S competence assessment in current practice, the descriptive method is applied to analyse existing competence assessment schemes. The sources of case study come from the documentation and information from websites of those schemes. After categorising the cases into two groups, the case study concentrates on two representative cases from their groups to make an in-depth analysis. The knowledge representative nature in the decision-making process and drawbacks of applying those schemes are identified in the process of case study to help the development of a decision-making framework and a KBS model for H&S competence assessment.

1.4 Research Programme

Under the general development framework of a KBS, the following research steps were undertaken for the building of KBS-CHSCA.

1. Reviewing of existing knowledge to identify the problem domain. Generic knowledge of construction health and safety issues, H&S management and H&S competence is reviewed to provide a profound knowledge background and significant justification of the research. Primary literature sources (academic research journals, refereed conference proceedings, previous dissertation/thesis, report/occasional paper, and government publications), secondary literature sources (textbooks, trade journals, newspapers and magazines) and reference guides (dictionaries and handbooks) are widely used as three major types of literature sources in the review (Naoum, 1998).
2. Implementation of a case study to investigate the existing formal schemes for H&S competence assessment. The findings of case study help to identify the knowledge representative characteristics in the decision-making process of H&S

competence assessment and reveal the drawbacks in current practice.

3. Formulation of a conceptual decision-making framework to identify the participants of knowledge and information exchange and effective decision-support mechanisms in the decision-making process for construction H&S competence assessment.
4. Development of a KBS decision-support model for H&S competence assessment. The model applies suitable I.T. solutions to appropriately represent knowledge embedded in the decision-making process; deal with drawbacks identified in the current practice and sort out difficulties raised in the framework.
5. Implementation of the proposed KBS to support decision-making of H&S competence assessment. A textual knowledge-base is built up to fulfill the functions of minimum satisfaction checking and subjective and qualitative rating. Java Server Page (JSP), MySql and HTML are used to realise the decision-support model on the Web.
6. Evaluation of the validity and usability of the KBS by analysing and discussing the result of questionnaire survey from industry practitioners for further improvement.

1.5 Contribution to Knowledge

This study has made four primary contributions to the current state of knowledge, within construction H&S management, focusing on the application of KBS to support decision-making for competence assessment under CDM Regulations 2007. The knowledge contributions are presented as follows:

- Developed a KBS decision-support model to enable the client to take reasonable steps to assess duty-holders' H&S competence against the 'Core Criteria' under CDM Regulations 2007. This model established three decision-support mechanisms, comprehensively applying knowledge sources including regulation guidance, existing cases and human experts to effectively support the subjective and qualitative decision-making for H&S competence assessment.
- Established a measurement indicator system to support subjective and qualitative measurement of duty-holders' H&S competence. The measurement indicator system simplified and improved the format and explanation of 'Core Criteria' for H&S competence assessment under the ACoP of CDM Regulations 2007, providing a practical means of assessing duty-holders' H&S competence.
- Enhanced the decision-making process of H&S competence assessment, effectively improving the knowledge acquisition, accumulation and dissemination, breaking the constraint of the lack of assessment knowledge and experience, and furthermore providing a platform to stimulate knowledge exchange and expansion in the problem domain.
- Enriched the application of KBS in construction H&S management, providing a systematical mechanism to effectively support decision-making for subjective and qualitative assessment of regulations-compliance checking problem. The implementation of an integrated inference process would be applied in other

legislation-based assessment problems and provide a concrete example to stimulate further development of the KBS in construction I.T. field.

1.6 Academic achievement

In the process of conducting the study, the following scholarly publications have been accomplished:

Journal Publication:

1. Oloke, D., Yu, H., and Heesom, D., (2006), Developing Practitioner Skills in Construction Health and Safety Management: An Integrated Teaching and Learning Approach, Journal for Education in the Built Environment (JEBE), ISSN: 1747-4205 (Online). (http://www.cebe.heacademy.ac.uk/jebe/volumes_index.php?edition=2.1)

Conference Publication:

1. Yu, H., Oloke, D., Proverbs, D. and Buckley, k. (2005), Improved Health and Safety in Construction: A knowledge-Based Approach. Proceedings of 21th Annual Conference of Association of Researchers in Construction Management (ARCOM),475-487. London UK, September, 2005.

2. Oloke, D. and Yu, H.(2005) Impact of Information and Communication Technology (ICT) on Construction Health and Safety Knowledge Management. Proceedings of the

Third International Conference on Construction in the 21st Century Advancing Engineering, Management and Technology. Athens Greece, September 2005.

3. Yu, H., Heesom, D., Oloke, D., Proverbs, D. and Buckley, k. (2006), Using AI Technologies to Improve Construction Health and Safety Performance: A Conceptual CBR Model for Health and Safety Competence Assessment, Proceedings of World Conference Accelerating Excellence in the Built Environment (WCAEBE), Birmingham, October, 2006

4. Yu, H., Heesom, D., Oloke, D., Proverbs, D. and Buckley, k. (2007), A Knowledge-based decision-support system for health and safety competence assessment, Proceedings of 23th Annual Conference of Association of Researchers in Construction Management (ARCOM),305-314. Belfast UK, September, 2007.

1.7 Guide to the Thesis

As illustrated in Figure 1.3, this thesis consists of 9 chapters.

Chapter 2 provides a review of H&S performance in the UK's construction industry and introduces the legal system of construction H&S. In particular, the importance of establishing a positive H&S culture in construction is discussed and highlighted as the justification of conducting H&S competence assessment.

Chapter 3 reviews the concept and legislation development in H&S competence assessment, and introduces the 'Core Criteria' for H&S competence assessment under CDM Regulations 2007. The latent shortcomings of the 'Core Criteria' are discussed in the review process. Furthermore, a case study of existing formal schemes for H&S competence assessment is presented to explore the knowledge representative characteristics and practical drawbacks embedded in the decision-making process of H&S competence assessment.

Chapter 4 outlines the A.I. technologies and the working principles of KBS, highlighting the adaptability of KBS to deal with various knowledge-intensive problems in construction and investigating the structural and functional feasibility of applying KBS for H&S competence assessment.

Chapter 5 presents a general research framework of the study, introducing knowledge acquisition concepts and applied methods. A decision-making framework of H&S competence assessment is formalised by analysing the assessment process under the 'Core Criteria' and exploring the knowledge and information flow among the decision-making participants. According to the identified knowledge representative nature in the decision-making process and the difficulties revealed in the decision-make framework, the appropriate knowledge representation methods are selected and generalised into a KBS decision-supported model to assist client to reasonably assess duty-holder's H&S competence.

Chapter 6 introduces the development of a textual knowledge base for the KBS, describing a statement indicator system for H&S competence assessment, including the minimum satisfaction standards and qualitative measurement indicators in compliance with the 'Core Criteria'.

Chapter 7 describes the implementation of the KBS, discussing the selection of appropriate Web programming language, applying Unified Model Language (UML) and Entity-Relationship (E-R) diagrams to explain the interactions between users and system, the structure of the database management system, and presenting the snapshots of the KBS to illustrate the realisation of the proposed decision-support model.

Chapter 8 introduces the framework and process of conducting the system evaluation. A questionnaire survey was carried out to collect comments regarding the validity and usability of the KBS from the practitioners. All feedback is analysed and discussed to assist the future improvement of the KBS.

Chapter 9 provides a conclusion of the research, summarising the research findings, outlining the fulfillment of research objectives, discussing the limitations of the research and putting forward recommendations for further research.

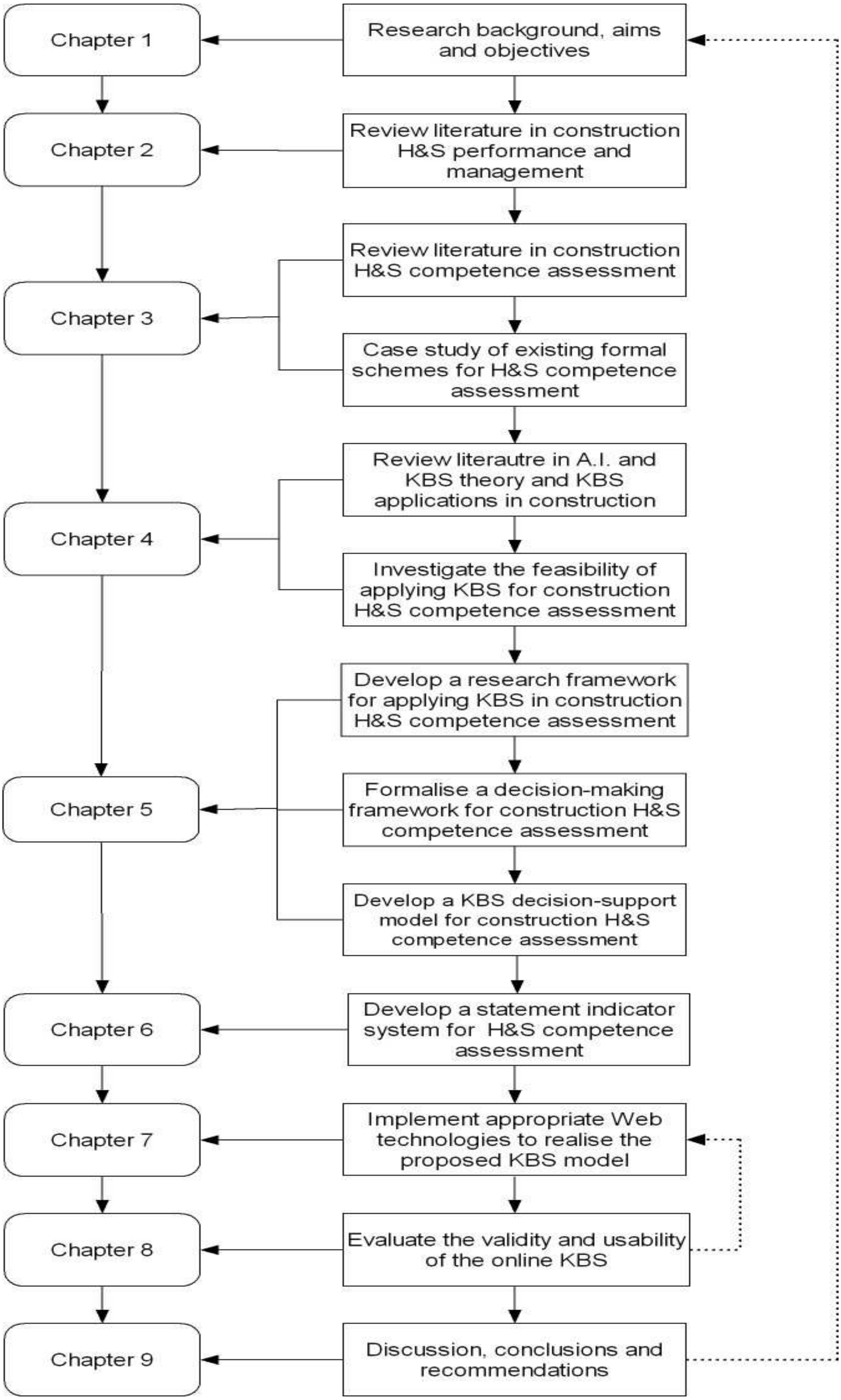


Figure 1.3 Layout of thesis

Chapter 2: Current Status of Health and Safety Management in UK Construction

2.1 Introduction

Workplace Health and Safety (H&S) is a global challenge of the sustainable development of our society and civilisation. According to the International Labour Office (ILO), work-related accidents and illnesses contribute 3.9 per cent of all deaths and 15 per cent of the world's population suffers a minor or major occupational accident or work-related disease in any one year (ILO, 2005). Other than the moral concerns, the economic cost is considerable. The work-related injuries cost the United States US$125.1 billion in 1998 (1.5% of GDP – National Safety Council, 1999) and Britain between £14.5 and £18 billion annually (2.1% - 2.6% of GDP – Health and Safety Executive, 1999) (Smallman, 2001).

When compared with other occupations, construction work is intrinsically hazardous as it is still largely labour-intensive. The construction industry contributed around 60,000 fatalities out of a world total of 355,000, nearly 17 per cent (ILO, 2005). As a major employment generator, the potential rate for serious accidents on and around construction sites is very high. The main causes could be classified as (Kartam, 1997; Fewings, 2005):

- Environmental factor: Many people from different parties such as clients, architects, engineers, equipment suppliers, contractors and others, are usually working close together in an outdoor site packed by different construction plants and material.

- Physical factor: Many activities with unplanned variations in relation to design and construction are unpredictable.
- Behavioral Factor: The tolerance towards risk is traditionally very high.

Furthermore, the structural and cultural characteristics of construction are not in favor of the improvement of H&S performance in the industry. Lingard and Rowlinson (2005) identified 5 barriers to improvement:

- traditional separation of design and construction: seriously limits the identification of innovative solutions to H&S problems at the design stage of a project
- competitive tendering: places a great deal of pressure on contractors, which discourage them to factor into bids the cost of performing the work safely
- a multitude of small businesses: may lack the knowledge and resources to implement H&S management activities and are likely to sacrifice H&S in order to survive in the cutthroat industry
- subcontracting: could bring about inconsistence and even chaos in the H&S management
- emphasis on contractual relationships: often leads to a linear ‘chain’ pattern of communication with a contractual relationship that is characterised by conflict and confrontation, making co-operation on matters of H&S difficult

Each year at least 60,000 fatal accidents occur on construction sites around the world – or one fatal accident every ten minutes (ILO, 2005). The following estimates of ILO reinforce the stark situation of H&S in construction.

1. One in six fatal accidents at work occurs on a construction site.
2. In industrialised countries, as many as 25-40 per cent of work-related deaths occur on construction sites, even though the sector employs only 6-10 per cent of the workforce.
3. In some countries, it is estimated that 30 per cent of construction workers suffer from back pains or other musculoskeletal disorders.

Overall, the UK has one of the best records for H&S performance in the world and the British construction industry is one of the safest in Europe. However, in 2005/2006, the rate of fatal injury to workers is 3.0 deaths per hundred thousand workers while the industrial average is 0.71. Notwithstanding the fatal injury rate is continuing the downward trend of recent years, construction is still a sector associated with a disproportionately high number of job-related accidents and diseases.

In order to improve the H&S performance in UK construction industry, legislative and organisational efforts have been made by government and industry to establish a systematic legal system and preventive strategies. This chapter provides an overview of UK construction H&S performance, the framework of H&S legal system and H&S culture model.

2.2 UK Construction H&S Performance

The significance of UK construction industry to the nation's economy is clear to see. In 2003, the annual output of construction industry is £93 billion, representing 8% of the Gross Domestic Product (GDP). 2.2 million people work in Britain's construction industry, making it the country's biggest industry. As mentioned before, the UK construction industry has one of the lowest accidents rate in the world (shown on Figure 2.1).

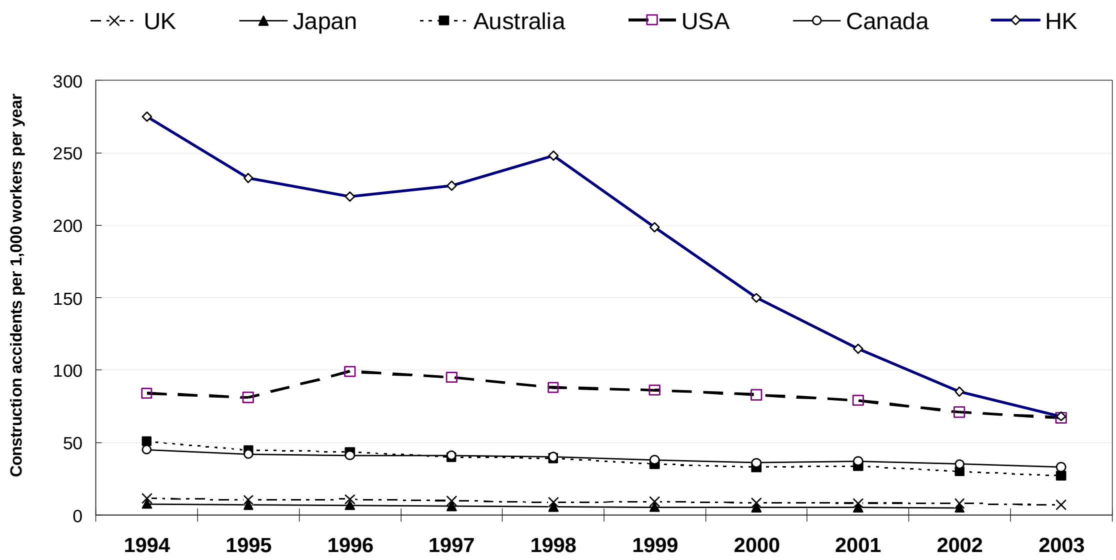


Figure 2.1 The rate of accidents per 1000 workers (UK: over 3 day non-fatal injuries) (Rowlinson, 2005)

Figure 2.2 and Figure 2.3 illustrate that the fatal injuries to construction workers decline steadily since 1994 but still remain unacceptably high when compared to other industries. Although the record of fatal injury accidents in 2005/2006 is the lowest level, each of the 60 fatalities brings endless sorrow to the victim's family, friends and colleagues and radically affects their lives. The higher number and rate of 2006/07 ruins the pattern of continued reduction since 2002/2003 and indicates the stark situation in construction H&S performance.

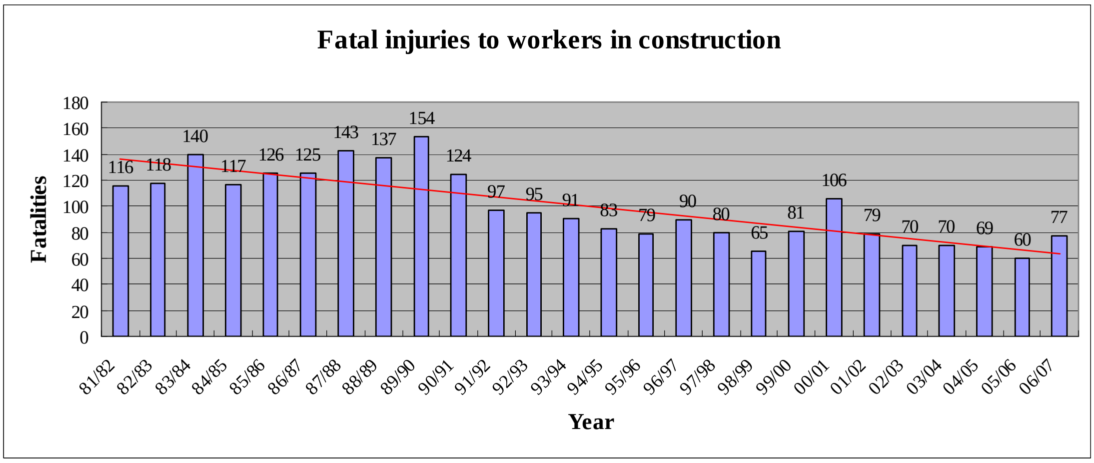


Figure 2.2 Fatal injuries to workers in construction (HSE, 2007)

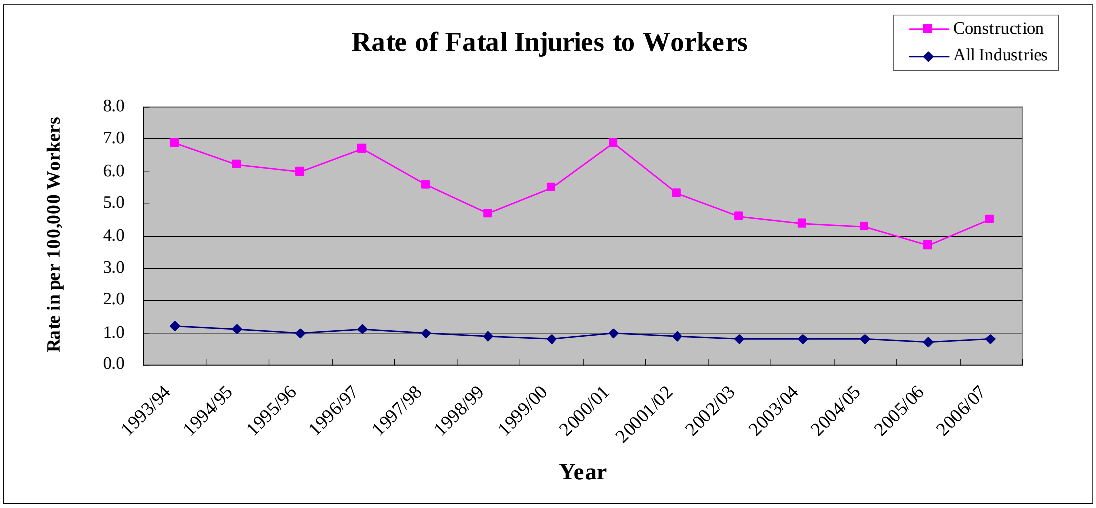


Figure 2.3 Rate of fatal injuries to workers (HSE, 2007)

In addition, a much larger number died prematurely or were disabled due to health problems arising from the construction work (HSE, 2001). In 2004/2005, 3760 employees suffered major injuries and 7509 were reported to experience over 3-day injuries. The main factors contributing to major injures are presented on Figure 2.4.

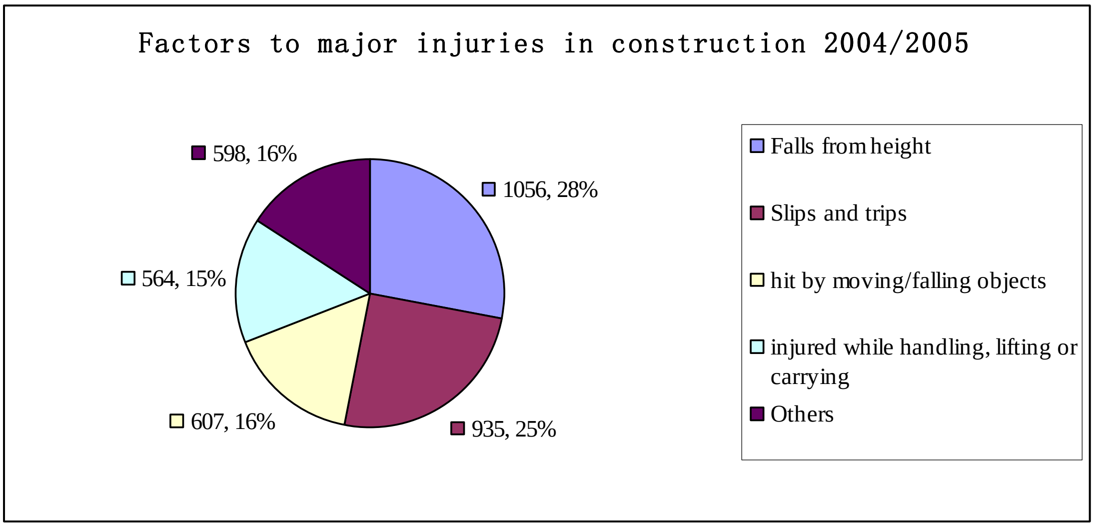


Figure 2.4 Factors to major injuries in construction 2004/2005 (HSE, 2005)

Work-related ill-health in construction also largely affects the well-being of workers. Handling and using tools, materials and substances can result in fractures, strains, musculo-skeletal disorders (MSDs), dermatitis, cement burns, hearing loss, hand arm vibration syndrome and consequent long term disability. Figure 2.5 illustrates that respiratory diseases (Diffused Pleural Thickening and Asbestosis), skin diseases (Dermatitis and Mesothelioma) and physical ill health (MSDs, Upper Limb Disorders, Spine/Back Disorders and Vibration White Finger) are the common occupational diseases in construction and the occurring rates of them are higher than other industries.

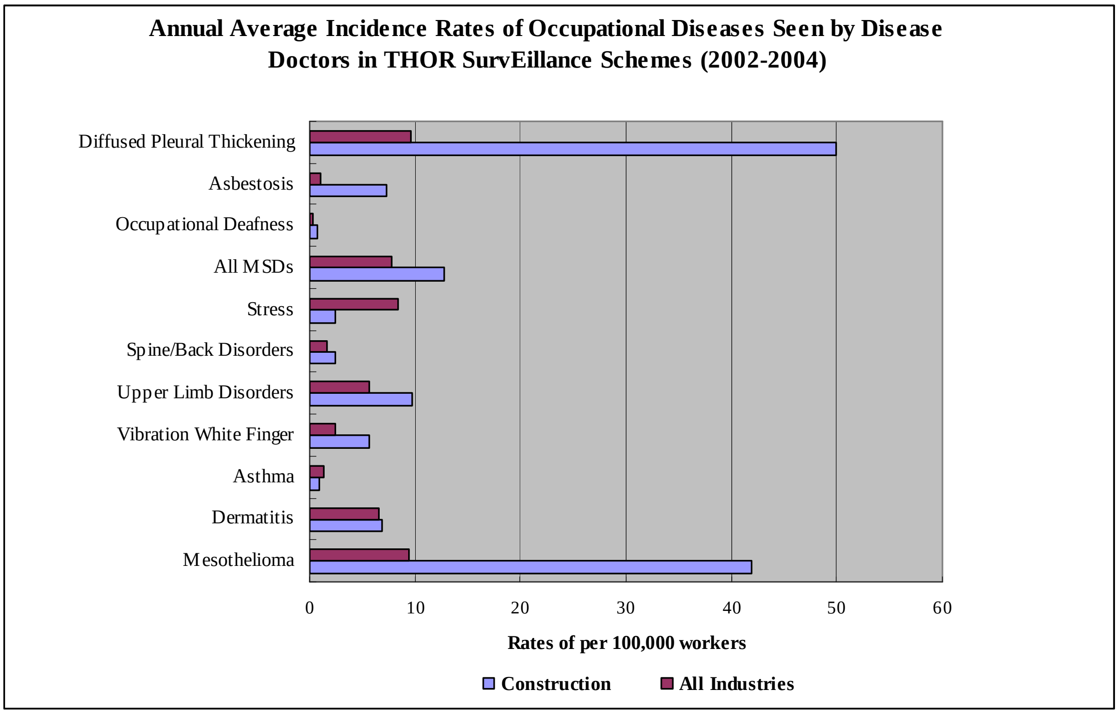


Figure 2.5 Annual average incidence rates of occupational diseases seen by disease doctors in the health and occupation reporting network (THOR) surveillance schemes (2002-2004) (HSE, 2005)

In order to respect the rights of members of a group and ensure that relevant responsibilities are fulfilled, every community has its own rules in relation to various aspects of people's lives. Small or informal groups tend to adopt simple rules, which are not legally binding, while governments of countries and states develop complex and comprehensive rules, which can be enforced (Morries et al., 1996; Lingard and Rowlinson, 2005). Preventing occupational injury and ill-health, ensuring reasonable compensation for victims and rehabilitating workers who suffer injury or ill-health as a result of their work are identified as three objectives of H&S laws (Lingard and Rowlinson, 2005). In relation to construction H&S, a whole raft of legislation has been established to specify H&S responsibilities of different parties involved in construction activities.

2.3 Health and Safety Legislation in UK Construction Industry

In the UK, H&S law is founded in both statue law – law made by Acts of Parliament – and Common Law, determined by judicial precedent (Griffith, et al., 2000). In the context of sub-divisions of law, civil law or criminal law can apply to cases involving H&S under different circumstances. For the vast majority of H&S cases, civil disputes usually follow accidents or illness and concern negligence or a breach of statutory duty, and can be settled "out of court" (Hughes and Ferrett, 2005). However, corporations or individual managers may be prosecuted under criminal law for offences, such as manslaughter or criminal infliction of serious injury, when negligent conduct results in the death or serious injury of a worker. (Lingard and Rowlinson, 2005).

2.3.1 The Health and Safety at Work, etc Act 1974

The Health and Safety at Work, etc. Act 1974 (HSWA) is the milestone in H&S legislation. Prior to 1974, the H&S legislations were prescriptive and expressed in the form of specification standard (*ibid.*). Hughes and Ferrett (2005) commented that those laws were more concerned with the requirement for plant and equipment to be safe rather than the development of parallel arrangements for raising the heath and safety awareness of employees. In addition, those specification-based legislations were criticised as unsuitable for certain types of risk (Bartel and Thomas, 1985; Quinlan and Bohle, 1991; Lingard and Rowlinson, 2005), little incentive to improve beyond minimum standard (Lingard and Rowlinson, 2005) and lacking in flexibility (Gunningham, 1996; Lingard and Rowlinson, 2005). As a result of the review carried out by Lord Robens in 1970, which identified 'apathy' of the construction industry as being the cause of poor H&S performance, the HSWA 1974 was compiled to provide robust principle-based standards unifying all H&S legislations under the same umbrella principles of the Act. The principal recommendations of Robens Report had a major influence on the H&S legislations in Britain and other Commonwealth countries in the rest of the twentieth century (Johnstone, 1999). In addition, HSWA established the Health and Safety Commission (HSC), which is responsible for proposing policy and regulations, and the executive arm of HSC, known as the Health and Safety Executive (HSE), which has the responsibility for enforcing H&S legislation.

As the basis of British H&S law, HSWA 1974 sets out general duties on the employer who should ensure the H&S of its employees and members of public, as far as reasonably practicable. The H&S duties imposed by HSWA 1974 on the employer and other parties are as follows (Griffith and Watson, 2004):

- on employers towards employees

- on employers and the self-employed towards persons other than their employees
- on people in control of premises
- on people who design, manufacture, supply and install plant, equipment and substances
- on every employee
- on everybody

The 'as far as reasonably practicable' statement means that the duty carried out should be considered against inconvenience and cost involved. In other words, an employer does not have to take measures to avoid or reduce the risk if they are technically impossible or if the time, trouble or cost of the measures would be grossly disproportionate to risk (HSC, 2003).

2.3.2 Health and Safety Regulations Influencing the Construction Industry

The HSWA 1974 is the principal legislative Act of Parliament (Enabling Act) under which almost all H&S regulations have been made. Simultaneously, as a member of the European Union (EU), UK has had to adapt all EU legislations into its regulations under the umbrella of HSWA 1974.

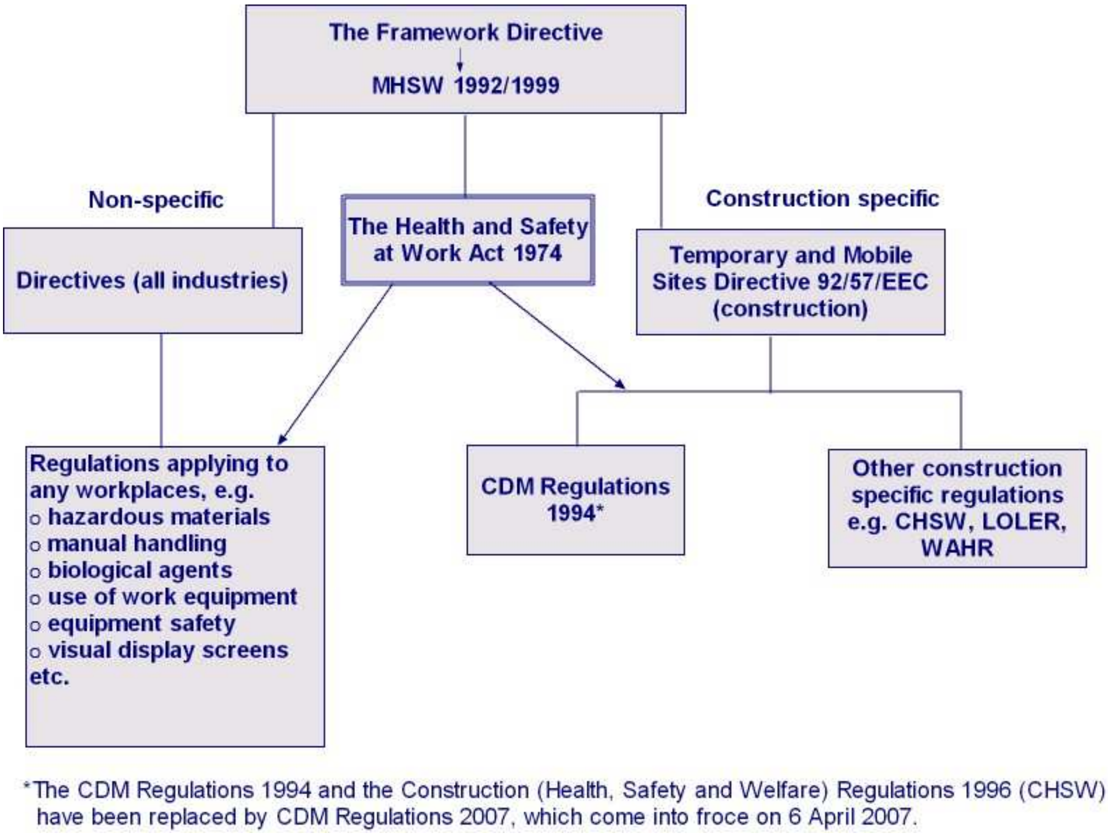


Figure 2.6 The EU directives and UK legislation in health and safety (Adapted from Fewings, 2005, P. 243)

As shown in Figure 2.6, the Framework directive (89/391/EEC) is the result of Article 118A of the Treaty of Rome (1957) encouraging H&S improvements regarding to working place and workers. As a response to the Framework directive, the Management of Health and Safety at Work Regulations (MHSW) was enacted in 1992 and revised in 1999. The MHSW 1999 generally makes more explicit what employers are required to do to manage H&S under HSWA 1974 (HSC 2003). In MHSW 1999, the risk assessment process and generic measures such as training, planning, health surveillance, organisation and monitoring and escape which might be applied to a wide range of more specific regulations, are defined and prescribed

(Fewings, 2005).

In sequence to the Framework directive, other daughter directives were developed to deal with various H&S issues in any workplace. Likewise, each directive has its corresponding regulation in UK. Some regulations can fit all industries, but others are specific to certain industries. The Temporary or Mobile Construction Sites' Directive (92/57/EEC) led to two particular H&S regulations in UK construction industry, they are:

- The Construction (Health, Safety and Welfare) (CHSW) Regulations 1996: The CHSW regulations cover a wide range of health, safety and welfare provision applicable to almost all construction activities except working at height which is covered by the Work at Height Regulations 2003 and lifting operations which are covered by the Lifting Operations and Lifting Equipment Regulations 1998.
- The Construction (Design and Management) (CDM) Regulations 1994: The CDM Regulations is considered as the 'bible' of construction H&S management by construction practitioners. It aims to reduce the incidence of accidents and occupational ill-health arising from construction work by introducing procedures to improve the planning and management of H&S on construction projects of all types, throughout every phase and involving all duty holders in the management of risk (Construction Confederation, 2000).

In order to improve H&S planning, management and performance in the construction industry, after a comprehensive revision, CDM Regulations 1994 and CHSW Regulations 1996 were brought together into CDM Regulations 2007, which came into force on 6 April 2007. The CDM Regulations 2007 aims to improve the planning and management of projects from the inception; identify hazards as early as possible to ensure appropriate measures can be taken to control risks, encourage everyone and apply adequate resources to improve health and safety, and discourage unnecessary bureaucracy which could generate distraction from the real business of risk reduction and management (HSC, 2007).

In addition to the two construction specific regulations, there are other generic regulations affecting health, safety and welfare issues in construction practice. Appendix 1 outlines those regulations usually influencing construction activities.

As a key feature of Robens-style legislation, non-statutory codes of practice are supplemented to provide industry with regulation compliance guidance (Lingard and Rowlinson, 2005). The Approved Code of Practice (ACoP) is produced for most sets of regulations by HSC/HSE and gives details on how to comply with the law. Guidance has two forms – legal and best practice. Legal Guidance series of booklet usually including the Regulations and the ACoP is issued by the HSC and/or the HSE to cover the technical aspects of H&S regulations (Hughes and Ferrett, 2005). Best practice guidance is published by HSE in the title of HSG, such as HSG65 - Successful Health and Safety Management. Notwithstanding, ACoP and best practice guidance are non-compulsory and you are free to take other action, if you do follow them you will be doing enough to comply with the law (HSE, 1995).

2.4 Revitalising Health and Safety

Although the UK has a systematic legal system for construction H&S, construction still contributes significant numbers of fatal accidents and ill-health cases to the statistics. In February 2001, the first construction H&S summit was held to address H&S concerns in the industry. Around 500 company directors, chief executives and other leaders representing all parts of the industry agreed that radical change has to be made in the industry's culture and approach to the control and management of risks (HSE, 2001). In order to focus attention and stimulate action, the Construction Industry Advisory Committee (CONIAC) to the HSC set a series of targets, known as 'revitalising targets' for the industry. These targets include (Hughes and Ferrett, 2005):

- to reduce the incidence rate of fatalities and major injuries by 40% by 2004/05 and by 66% by 2009/10
- to reduce the incidence rate of cases of work-related ill-health by 20% by 2004/05 and by 50% by 2009/10
- to reduce the number of working days lost per 100,000 workers from work-related injury and ill-health by 20% by 2004/05 and by 50% by 2009/10

After 6 years of announcing ‘revitalising targets’, much progress has been made, such as a fall in construction deaths. However, the rebound of fatal injuries in 2006/2007 (see Figure 2.3) reveals that the efforts being put on the H&S is still not sufficient to ensure that the industry’s target will be met in 2010. The industry should put more emphasis on seeking innovative and sustainable ways of working together to achieve the excellence in H&S and meet the ambitious targets punctually.

Since construction is a project-based industry, construction H&S management needs to be systematically arranged and implemented throughout the whole life of a project involving all parts and participants. Furthermore, a positive H&S culture established on mutual trust and confidence between management and workforce is significant for the improvement of H&S performance. The next section will focus on discussing concepts, models and measuring methods of H&S culture in construction.

2.5 Safety Culture in Construction

After years of research and practice, it has been found that techniques used to improve health and safety performance seem to reach a plateau inhibiting the continuing improvement (Taylor, 2002). The lesson learnt from the Chernobyl accident in April 1986 highlighted technological vulnerability and led to the introduction of safety culture (Choudhry, et al., 2007). The International Atomic Energy Agency first developed (IAEA, 1986) and subsequently expanded (IAEA, 1991) the concept of safety culture. In 1993, the Advisory Committee on the Safety of Nuclear Installations provided a definition of safety culture (ACSNI, 1993) which has been referred to in different safety academic literatures. Subsequently, HSC (1993) adopted the definition that is "*safety culture is the product of individual and group values, attitudes, competencies, and patterns of behaviour that determine the commitment to, and the style and proficiency of, an organisation's health and safety programmes. Organisations with a positive safety culture are characterised by communications founded on mutual trust, by shared perceptions of the importance of safety, and by confidence in the efficacy of preventative measures.*"

However, safety culture is a debatable subject and no accepted model of it exists to date (Choudhry, et al., 2007). Despite the numerous definitions of safety culture (Carnino, 1989; Lucas, 1990; Lee, 1993; Kennedy and Kirwan, 1998; Hale, 2000; Glendon and Stanton, 2000; Guldenmund, 2000; Cooper, 2000; Mohamed, 2003; Richter and Koch, 2004; Feng et al., 2006), there is a consensus that safety culture is shared and consistent attitudes, beliefs and perceptions direct organisational members' attention and actions to keep a sustainable safety improvement.

Although it appears to be clear that developing and maintaining a positive safety culture can be an effective means in favorable to good safety performance (Vecchio-Sudus and Griffiths, 2004; Choudhry et al., 2007), seeking an effective method of applying safety culture in practice is a challenge to the whole industry.

2.5.1 Model of safety culture

Guldenmund (2000) suggests that the lack of a unifying theoretical model has hindered the study of safety culture. Lingard and Rowlingson (2005) also argue that models of safety culture can specify desirable attributes related to excellent H&S performance. A safety culture model is defined by Choudhry et al. (2007) as 'a manner in which safety culture is thought to be embedded in the organisation's practices and safety management systems', which is helpful in identifying the key elements for a positive culture.

Different researchers have presented various models (Grote and Kunzler, 2000; Geller, 1994; Geller, 1997; Cooper, 2000) to reflect a positive safety culture. Among those models, Cooper's reciprocal framework is more practical and widely accepted (Glendon and Litherland, 2001; Neal et al., 2000; HSE, 2005; Choudhry, 2007). After analysing former research efforts in accident causation models, Cooper (2000) identified that the interactive relationship (shown on Figure 2.7) between psychological, behavioural and situational factors should be taken into account to developing a safety culture.

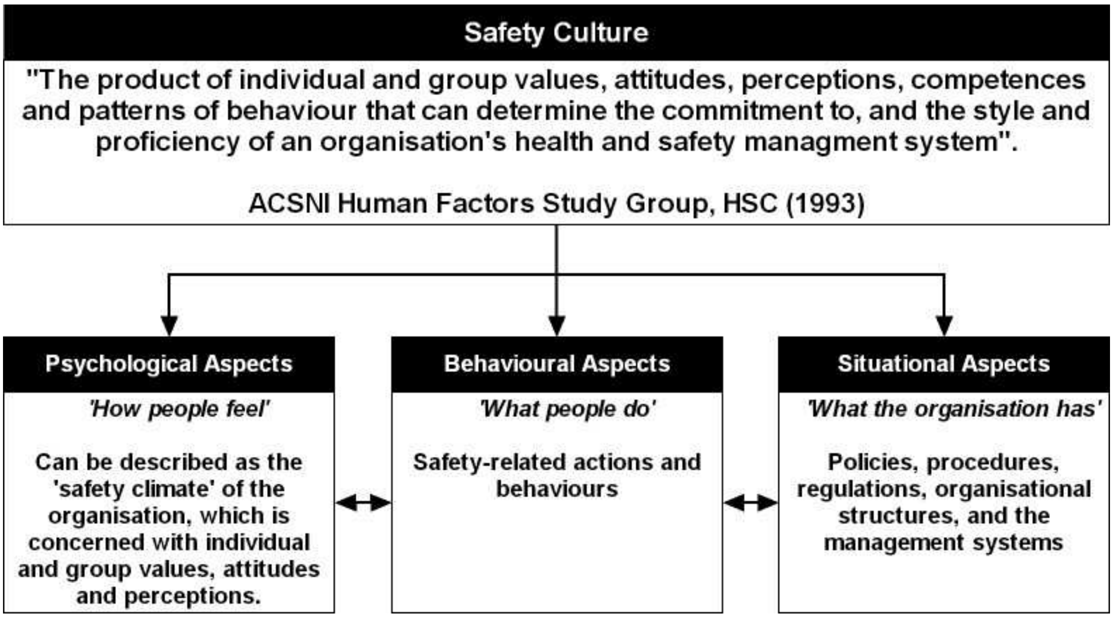


Figure 2.7 Three aspect approach to safety culture (HSE, 2005)

Cooper's model reflects the multiple goal-directed concept of safety culture, which encompasses (Cooper, 2000; Lingard and Rowlinson, 2005; Choudhry, 2007):

- Subjective internal psychological factors: the psychological aspects of safety culture refer to safety climate which represents employee's attitudes and perceptions of H&S in the workplace (Flin et al., 2000; Mohamed, 2003). Since safety culture is top-down core organisational beliefs, safety climate is a bottom-up workforce's attitudes and a useful diagnostic tool and method for measuring the safety culture (Guldenmund, 2000; Mohamed, 2003; Lingard and Rowlinson, 2005).
- Observable ongoing safety-related behaviours: Unsafe behaviour is the major cause of any accident, which accounts for eighty to ninety per cent of all accidents on site (Mohamed, 2002; Lingard and Rowlinson, 2005). As the foci of the model, employee's behaviour substantiates the organisational safety beliefs

and can be influenced and altered by other two aspects of safety culture.

- Objective situational features: The safety management system is the situational aspect of safety culture, which is regarded as the documented and formalised system (policy, procedures, training instructions and resources, etc) of controlling against risk or harm (Kennedy and Kirwan, 1998). Although H&S management systems exist on paper and might not necessarily reflect the way it is carried out in practice (Choudhry, 2007), it can represent the work environment and underlying perceptions, attitudes, and habitual practices of employees at all levels (Kennedy and Kirwan, 1998).

Cooper's reciprocal safety culture model is a process of action and reaction or one of "perpetual dynamic interplay", which provides an integrative way of thinking about the many processes that impact on safety culture (Cooper, 2000; Choudhry et al., 2007).

2.5.2 Measure of safety model

As safety culture is intangible, it should be measured to examine organisational safety attitudes, performance and management systems. The psychological, behavioural and situational aspects of the model also provide a triangulated set of measurement instruments allowing the multi-faceted nature of the safety culture construct to be systematically examined (Cooper, 2000). According to Cooper (2000), the psychological aspects (attitudes and perceptions) can be assessed through safety climate questionnaires; the behavioural aspects (actual safety-related behavioiurs) can be assessed by checklists developed as a part of behavioural safety initiatives, and the situational features can be assess by safety management system audits/inspects (Choudhry et al., 2007).

Despite the fact that the three aspects of safety culture enable it to be measured by a variety of quantitative and qualitative methods (Cooper, 2000), it will take a quite long period to provide a comprehensive picture of an organisational H&S culture. In terms of psychological aspects, the ubiquitous safety climate questionnaire requires to collect data from a considerable number of employee's to measure people's beliefs, values and perceptions for safety culture. Similarly, a thorough assessment of behavioural and situational elements of safety culture can be taken via peer observation and periodical inspections or surveys (*ibid.*), which are also time-consuming processes. Therefore, it is a challenge for a project-based industry such as construction to find a method to evaluate an organisation's safety culture before it engages in a project.

2.5.3 A positive H&S culture

As advocated by Blockley (1995) the construction industry would be better characterised as one with a poor safety culture and that safety record will not be improved until the safety culture is promoted, safety culture is becoming crucial to construction (Fang et al., 2006). Much research (Hinze, 1997; Sawacha et al., 1999; Langford et al., 2000; Choudhry, 2002; Mohamed, 2003) has been done to look into how the safety culture can be established or measured in construction. Furthermore, other prior research (Taylor, 2002; Hughes and Ferret, 2005; HSE, 2005) focus on identifying important components to promote a positive H&S culture. A consistent commitment throughout all levels of management, a clear organisation of management, appropriate procedures, qualified and experienced workforce, an effective communication system, employee involvement and a monitoring and reviewing system are considered as key elements of a positive H&S culture.

A construction project team is usually a temporary unit compromising different organisations that play respective roles throughout the whole life of a project. The maintenance of successful H&S performance in a construction project requires a well-developed administrative and technical management system to ensure a reasonable arrangement for H&S performance. It also requires that each project participant organisation should have a positive H&S culture and good record of H&S performance to ensure the ability to deal with H&S hazards in the current project (Lingard and Rowlinson, 2005; Carpenter, 2006a). It is, therefore essential and significant to identify each participant organisation’s H&S culture and former H&S performance before the organisation comes into the current project.

Although research studies in academia have revealed the importance of a positive H&S culture and indicated some means of developing, maintaining and measuring a positive H&S culture, the industry still appears to lack adequate awareness, knowledge and tools to nurture and evaluate a positive H&S culture in practice. Hughes and Ferret (2005) find that there is concern among some H&S professionals that H&S culture is developed and driven by senior managers with very little input form the workforce. Without an enforced legislation and effective method, it is quite difficult to arouse awareness and commitment of the industry to improve H&S culture.

However, the CDM Regulations 2007 which became effective on 6 April 2007 was introduced to improve this situation. The CDM Regulations 2007 impose a pro-active H&S culture and performance assessment responsibility on the client who is the originator of a project and plays the central role of implementing the Regulations (RIBA, 2008). The client is required to take reasonable steps to assess duty-holders' H&S competence before they are appointed or engage in the project. Any appointed or engaged duty-holder must be H&S competent with a positive H&S culture, effective H&S management system and good former H&S performance to carry out the work assigned. Therefore, the H&S competence assessment under CDM Regulations 2007 can be seen as a legal solution to encourage the development of positive H&S culture in the industry by increasing the competitive advantages of organisations which have already established a positive H&S culture and an effective

H&S management system.

2.6 Summary

H&S issues are increasingly serious concerns to government and industry on the legal, moral and financial grounds. As one of the safest construction industries in the world, UK construction still remains a disproportionate high rate of fatal injuries and ill-healthiness. Although many efforts have been made to establish a systematic and applicable legal system and improve the performance in industry, the current situation has not been as satisfactory as could be hoped.

H&S culture has been identified as a crucial element to overcome the bottleneck of H&S improvement. A reciprocal model of safety culture revealed three aspects of developing and evaluating a positive H&S culture. An organisation with a positive H&S culture can draw on effective management systems to improve H&S performance, mininise the possibility of accident and maxmise the project value.

The H&S competence assessment under CDM Regulations 2007 brings on a new approach which seeks to ensure that the positive H&S culture can be developed and maintained from the outset of a project. As a novice legal requirement, H&S competence should be explored in detail in relation to its concepts, current practice and evaluation method, which will be discussed in Chapter 3.

Chapter 3 Health and Safety Competence Assessment

3.1 Introduction

Chapter 2 provided a broad review of current practice in UK's construction H&S performance, legislations and management, identifying that a positive H&S culture was a significant determinative for an organisation's H&S management and performance. This highlighted that implementing H&S competence assessment under CDM Regulations 2007 brings a systematic method of evaluating an organisation's H&S culture and performance before it comes into the current project. In order to extensively explore the research field of construction H&S competence assessment, this chapter discusses the application of H&S competence assessment in construction in the UK.

Section 3.2 introduces the concept of construction H&S competence, typically identifying the individual competence and organisational competence. In addition, this section extensively reviews the legislations of H&S competence assessment and analytically discusses the influence of applying 'Core Criteria' of H&S competence assessment under CDM Regulations 2007.

Section 3.3 reviews the current practice of H&S competence assessment in UK's industry, introducing the development of assessment criteria prior to the emergence of

'Core Criteria'.

Section 3.4 examines two cases out of 19 existing formal H&S competence assessment schemes for organisation, revealing the knowledge representative characteristics embedded in the decision-making process and identifying the limitations of current H&S competence assessment schemes.

3.2 Construction H&S competence and assessment

According to Wright et al. (2003), competence is commonly defined as 'the ability to perform the activities within an occupation or function to the standards expected in employment'. In the context of construction H&S, competence is a two-faceted concept. On the individual level, a competent person is often regarded to be one that has sufficient training, knowledge and experience of the work related (Construction Confederation, 2000; Taylor, 20002; Hughes and Ferrett, 2005; Carpenter, 2006a). Carpenter (2006a, 2006b) advocates that an individual's H&S competency is the combination of:

- Task knowledge (technical or managerial): Appropriate for the tasks to be undertaken.
- Health and safety knowledge: sufficient to perform the task safely, by identifying hazard and evaluating the risk in order to protect self and others, and to appreciate general background.

- Experience and ability: sufficient to perform the task (including where appropriate an appreciation of constructability), to recognise personal limitations, task-related faults and errors and to identify appropriate actions.

However, the level and development of personal competence within an organisation are determined by the organisational H&S culture. Organisations with a real commitment to improving their H&S culture will go beyond ensuring all members of the workforce have received training and are suitably qualified and experienced in the safety-related requirements of their job (Talyor, 2002). A positive H&S culture can enable an organisation to have clear commitments of H&S management, the promotion of H&S standards, effective communication within the organisation, adequate cooperation from and with the workforce and an effective and developing training progromme (Hughes and Ferrett, 2005). Thus, an organisation with a positive H&S culture can be seen as H&S competent to undertake a project. Therefore, H&S competence on the organisational level can be defined as 'a culture within an organisation that actively considers the health, safety and welfare of its own people, and of those that its work activities affect, with this being achieved through active management and participation of employee' (Carpenter, 2006a).

3.2.1 Legislation of H&S competence prior to CDM Regulations 2007

Prior to CDM Regulations 2007, most construction related H&S legislation encompassed provisions for H&S competence to ensure competent workforce to undertake a work, though those provisions are only on the individual level. Table 3.1 provides a summary of those legislations.

Table 3.1 Summary of competence requirements in relevant construction H&S legislation prior to CDM Regulations 2007

ACT AND REGULATIONS	SUMMARY	REFERENCES
HEALTH AND SAFETY AT WORK ECT ACT 1974	Although this act doesn't specify the requirement for competency, the employers, the self-employed and individuals should have adequate knowledge, experience and skills to discharge their duties.	Carpenter (2006a)
MANAGEMENT OF HEALTH AND SAFETY AT WORK REGULATION 1999	Sufficient training and experience or knowledge and other qualities enable a person as competent to carry out his duties. However, competence requirements could be varied by the situations. Simple situations could just require: a. an understanding of relevant current best practice; b. an awareness of the limitations of one's own experience and knowledge and; c. the willingness and ability to supplement existing experience and knowledge, when necessary by obtaining external help and advice In more complex situations or risks, fully qualified and appropriately experienced practitioners will be required.	Construction Confederation (2000); Hughes and Ferrett (2005); Carpenter (2006a)
CDM REGULATIONS 1994	Section 8 and 9 require those employing Planning Supervisor, Designers or Contractors must ensure that they have the competence to perform their duties. ACoP highlights the principles and main points of assessing competence and resources in order to cut down unnecessary bureaucracy in the standard, generic health and safety pre-qualification questionnaire.	HSC (2001); Carpenter (2006a)
CONSTRUCTION (HEALTH AND SAFETY AND WLEFARE) REGULATIONS 1996	Section 28 emphasises that training, technical knowledge or experience is necessary to reduce risks of injury to any person. People who carry out any relevant construction work should possess those capabilities or be under supervision by competent people.	Carpenter (2006a)

In addition to the above provisions, the ACoP of corresponding regulations provides guidance as supplementary for practical performance. For instance, the paragraph 195 of ACoP in the CDM Regulations 1994 specifies six basic principles for the H&S competence assessment. Paragraph 198 also details the major means by which those competence criteria could be assessed. However, the guidance is still too abstract to provide a thorough and effective method of assessing practitioners' H&S competence for a specific project or task.

3.2.2 'Core Criteria' for H&S competence assessment

According to Regulation 4 of CDM Regulations 2007, H&S competence assessment is a compulsory and major responsibility placed on the client. Any duty-holder including CDM co-ordinator, designer, principal contractor or contractor can not be appointed or engaged in the project unless the client has taken reasonable steps to ensure that the duty-holder is H&S competent (HSC, 2007). In order to assist the client in effectively discharging this duty, ACoP expounds the concept and methods of applying competence assessment.

The duty-holder is a functional definition involving a series of functions in terms of CDM Regulations 2007. Thus, organisations usually act as different duty-holders to take respective responsibilities. The ACoP, thereby introduces a two-stage process, in which the organisation's H&S competence should be assessed according to 14 'Core

Criteria' (Shown in Figure 3.1). Each criterion has specified evaluation standards with examples of evidence that the organisation could use to demonstrate it meets the required standard (Shown in Appendix 2).

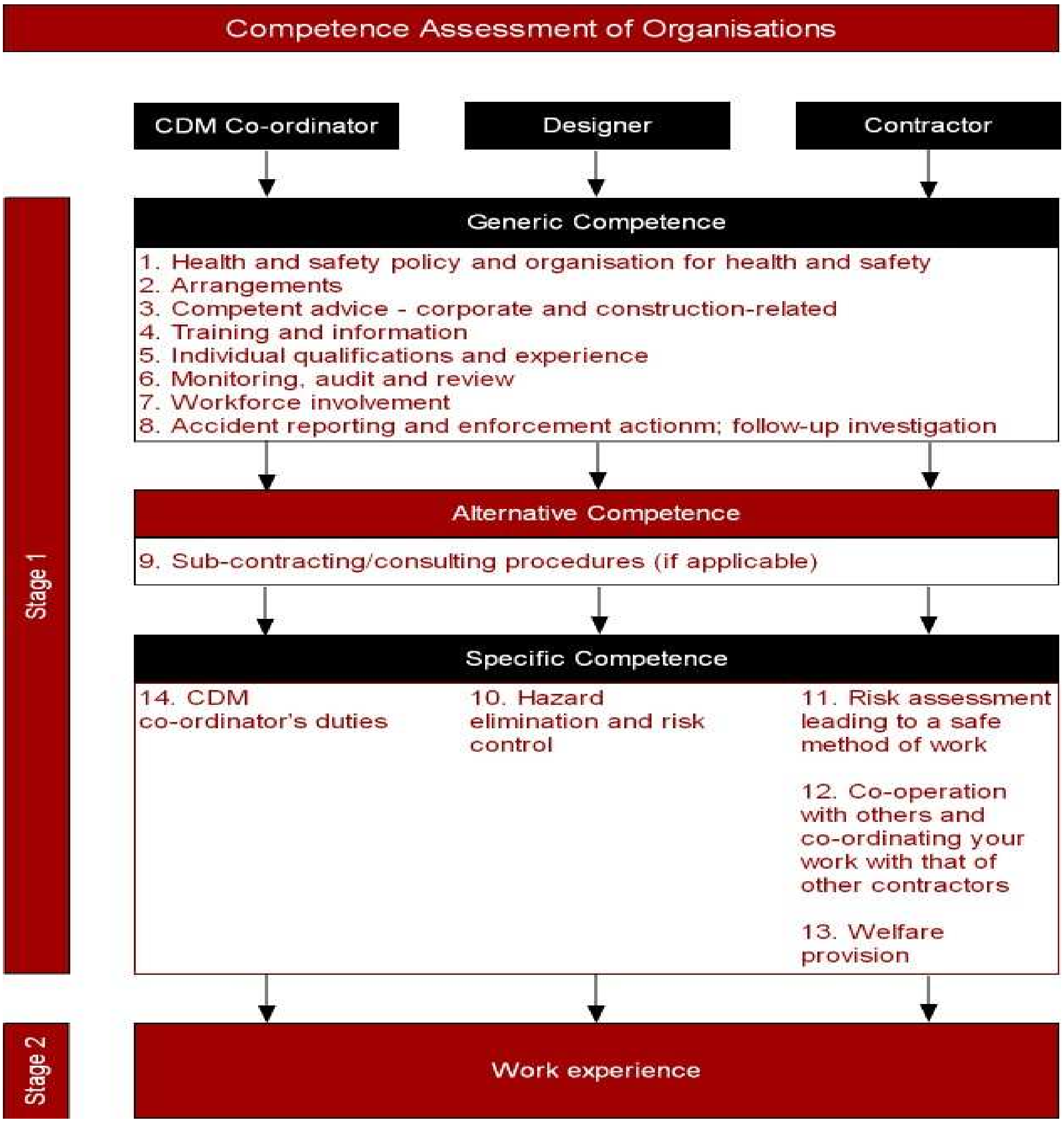


Figure 3.1 Competence assessment of organisations (Yu et al. 2007)

The first stage focuses on assessing the candidate organisation's H&S culture and management system to ensure the future work can be carried out safely and without risk to health. As illustrated in Figure 3.1, all 14 criteria cover two aspects of reciprocal safety model. The ‘Core Criteria’ comprising five key elements of HSE (2002) model for successful H&S management effectively reflect the situational aspects of safety culture (Thompson & Luthans, 1990). As indicated in the reciprocal safety model, the H&S management system is the objective representation of an organisation’s safety culture, showing an over-all arrangement of H&S management and implementation in the organisation. According to HSE’s framework for H&S management (shown in Figure 3.2), a successful H&S management system should include a clearly defined policy, well-defined plans incorporating specific objectives, strong management commitment, the provision of sufficient resources, a systematic training programme, effective monitoring and reporting of performance and a process for reviewing performance and making improvements (Hughes and Ferrett, 2005; Lingard and Rowlinson, 2005). Measuring the 14 ‘Core Criteria’ can effectively provide the client with a retrospective view of an organisation’s H&S management system (Carpenter, 2006a). Thus, the client can select H&S competent duty-holder who has a positive H&S culture and reliable management system to undertake the project.

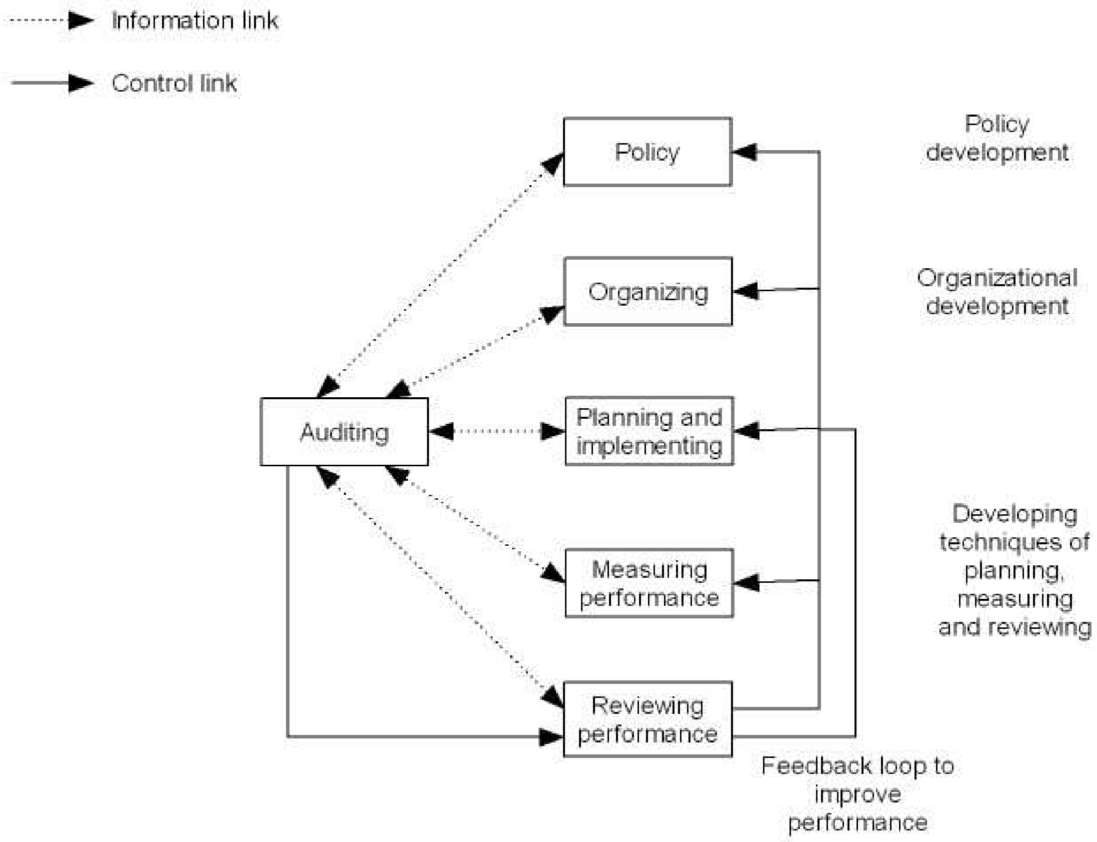


Figure 3.2 Key elements of successful H&S management (Lingard and Rowlinson, 2005)

In addition, criterion 8 is an outcome measure of behavioural aspects of safety culture, demonstrating organisation's former behaviours on H&S performance. Criterion 10 & 11 can also indicate the organisation's routine methods or behaviours on preventing and controlling losses arising from unwanted and unforeseen loss-making events.

The second stage aims to assess the organisation's experience and track record to ensure its suitability to deal with the key health and accident hazards in the current application (Carpenter, 2006a; HSC, 2007). As advocated by Carpenter (2006a) and also adopted by HSC (2007), the organisations' ability to manage the work and potential harzards can be revealed through contact with previous clients and project teams.

The 'Core Criteria' on the organisational level not only provide a means of systematically assessing the organisation's H&S culture and management system but also standardise the assessment process propitious to making effective judgment. However, the 'Core Criteria' are not practical enough to reduce the bureaucracy and improve the efficiency of decision-making. There are three latent shortcomings which could bring difficulties of implementing H&S competence assessment in practice:

- Non-quantificational judgment standards: although each criterion has concrete judgment standards, the qualitative description of standards is difficult and ambiguous for decision-making.
- Subjective decision-making process: the judgment of each criterion varies on the assessor's knowledge, experience and preference. Such a subjective assessment without structured procedures would result in deviation from judgment standards.
- Knowledge-intensive information processing: the competence assessment requires the verification of evidence and record, involving relative construction and H&S management knowledge. The lack of effective I.T. tool would lead to errors or lapses in the paper work.

The competence assessment of individuals is also a two-stage process. At stage 1, an individual's qualifications and training records should be evaluated to ensure he or she has a basic understanding of the risks arising from the construction work. Stage 2 concentrates on the individual's past experience in the type of work which will be carried out. As criterion 5 of organisation's H&S competence aims at assessing individual qualification and experience, the individual competence assessment can be carried out in the process of organisation's H&S competence assessment. According to HSC (2007), the membership of a relevant professional institution, such as CIBSE; ICE; IMechE; IStructE; RIBA; RICS; CIAT; CIOB; NEBOSH, can be seen as a strong evidence that the person has necessary task knowledge and is capable of dealing with H&S issues in the 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. Although the verification of an individual's qualification or membership is not difficult, the judgment of training records is not easy in practice as the decision-making process is still subjective, qualitative and knowledge-intensive.

In conclusion, although any industry-wide schemes will have shortcomings (Carpenter, 2006a), the 'Core Criteria' for H&S competence assessment provides a robust process to ensure clients appoint H&S competent duty-holders in the inception of project (HSC, 2007). Furthermore, in order to cut off unnecessary bureaucracy in competence assessment, which can obscure the real issues and divert effort away from the client, the competence assessment should focus on the needs of the particular project and be proportionate to the risks, size and complexity of the work (*ibid.*). However, as identified above, the three shortcomings in the implementation of 'Core Criteria' would offset the innovative attempts of H&S competence assessment under CDM Regulations 2007. In order to develop a practical method of effectively applying 'Core Criteria', the following sections will review the current practice of H&S competence assessment and identify the knowledge representative characteristics and limitations of current practice in H&S competence decision-making process after a case study of schemes for H&S competence assessment.

3.3 The current practice in industry

In practice, the contractor's H&S competence is considered as an important factor in the selection process. Construction clients and community are seldom concerned about other duty-holders' H&S competence. Presently, contractor's H&S competence assessment is usually covered by a generic pre-qualification questionnaire or implemented through formal assessment schemes established by both public and private sector sponsors. The general pre-qualification questionnaire is prevalent in the pre-tender process to investigate and assess whether candidate contractors have capabilities of undertaking a contract satisfactorily if it is awarded to them (Hatush and Skimore, 1997). The pre-qualification questionnaire usually comprises a series of criteria to evaluate the overall suitability of contractors. Hatush and Skimore (1997) identified five main criteria (financial soundness, technical ability, managerial capability, safety, and reputation) for contractor pre-qualification and bid evaluation, in which health and safety competence are assessed by four sub-criteria alone with required information:

- Safety: includes experience in handling dangerous substances; experience in noise control; accident book; complied in all respects with health and safety regulations; health and safety information chart for employees; safety record and company safety policy;
- Experience modification rating (EMR): is financially rewarding or penalizing employers according to their accident claims;
- OSHA (Occupational Safety and Health Administration) incidence rate: is the average numbers of injuries and illness, per 100 man-year for a construction firm.
- Management safety accountability: includes who in the organisation receives and reviews accident reports, and what is the frequency of distribution of these reports; frequency of safety meetings for field supervisors; compilation of accident record by foremen and superintendents, and the frequency of reporting; frequency of project safety inspections, and the degree to which they involve project managers and field superintendents and use of an accident cost system measuring individual foremen and superintendents as well as project managers.

Although the above H&S criteria refer to some aspects of H&S culture, management system and performance, such a fragmented assessment can't effectively reflect contractor's H&S competence. Furthermore, the little awareness of the importance of safety criteria, which are treated as secondary importance, plagues the effectiveness of client's autonomous pre-qualification assessment in respect of H&S. Therefore, as argued by HSE (2001b) and Carpenter (2006a), those questionnaires just create a great deal of paperwork, and are of little benefit to H&S.

As many clients don't have any knowledge of construction or may only procure one project in their lifetime, there are a number of formal competence assessment schemes provided by different professional organisations or sponsors to help clients assess contractors and designers' H&S competence (Carpenter, 2006a). Those schemes respectively target the competence of individuals, such as the Construction Skills Certification Scheme (CSCS), and the organisations' competence, like the Construction Health and Safety Assessment Scheme (CHAS).

The individual competence assessment schemes focus on testing an individual's H&S knowledge in respect of site practice. Multiple-choice questions and workplace assessment are usually used in the assessment. The existing formal schemes for an organisation's H&S competence utilise an independent evaluation process in which scheme's in-house assessors need to review organisation's H&S policy, arrangement and performance records, and then determine its H&S competence in terms of the compliance of organisation's H&S documents and records with relevant legislations. Such schemes are to establish an accreditation mechanism, not mandatory but recognised by HSC, facilitating set and maintain professional standards (*ibid.*). However, prior to the CDM Regulations 2007, the H&S competence assessment in the construction industry is organised and implemented separately and ineffectively without unified judgment criteria. Furthermore, since all schemes are sponsored by different public or private organisations and require payment for register or membership, the various assessment schemes could increase overheads on client and duty-holders and even discourage the industry to apply H&S competence assessment. Therefore, the 'Core Criteria' of H&S competence under CDM Regulations 2007 provide the industry with standardised assessment criteria by which the H&S competence assessment can be reasonably implemented and bring value for money to all duty-holders.

3.4 Case study of existing formal H&S competence assessment schemes for organisations

A case study is an empirical data collection approach to investigate the qualitative variables in the context of research problem (Yin, 1993; Fellows and Liu, 2002). The duty-holders' H&S competence assessment under CDM Regulations is a retrospective review process of checking an organisation's H&S culture, management system and performance records against 'Core Criteria'. The existing schemes for organisation's H&S competence can be categorised as a method of measuring the compliance of organisation's H&S management with relevant regulations and specific criteria.

Therefore, the gathering of case study data from the existing H&S competence assessment schemes for organisations will play an important role of eliciting the knowledge representative characteristics in the decision-making process of dealing with regulation-compliance checking problems.

Carpenter (2006a) identified 19 formal H&S competence assessment schemes on the organisation level. As illustrated by Table 3.2, various schemes regarding organisation's H&S are currently operated by a wide range of sponsors from different industries.

Table 3.2 The existing formal H&S assessment schemes for organisation (Adapted: Carpenter, 2006a)

Scheme's Name	**Sponsor**	**Sector Restricted to Construction**
Five Star Health and Safety Management Audit	British Safety Council	No
OHSAS 18001 Compliance Audit	British Safety Council	No
CAPS (The Construction Accredited Partnering Scheme)	National Federation of Builders	Yes
CHAS (The Contractor's Health and Safety Assessment Scheme)	London Borough of Merton	Yes
ConstructiononLine	Department of Trade and Industry	No*
Construction Confederation (CC) Designer Assessment	Construction Confederation	Yes
CORGI	Council for Registered Gas Installers	No
Exor Management Services	Exor Management Services Limited	Yes
CAT (Capability Assessment Toolkit)	Highways Agency	No
LINK-UP	Achilles Group	Railways
MCG Sub-contractor Assessment	Major Contractor's Group	Yes
National Electricity Registration Scheme (NERS)	UK Distribution Network Operators (DNOs)	No
NHBC Scheme	Association of British Insurers	House-building
OCR 1322	Hardaker & Associates	Yes
Safe Contractor	National Britannia Ltd	No
SHEQual	EC Harris	Yes
SEC	Specialist Engineering Contractors Group	Yes
TrustMark	Department of Trade and Industry	Yes
UVDBVerify	Achilles Group	No

*: Yes if registrant is CHAS registered

According to the assessment process, those schemes can be categorised into two groups:

➢ Self-assessment guidance: provides members with a prescriptive judgment criteria and guidance to make assessment by themselves. MCG Sub-contractor Assessment and SEC belong to this group.

- Expert-assessment programme: requires applicants to fill in an evaluation questionnaire or checklist, and then an expert assessor will go through evidence or make a site visit to judge the compliance with legal requirements and determine competence level or validate accreditation. Most of the above schemes are in this group.

In order to facilitate knowledge representation analysis regarding H&S competence assessment decision-making, two schemes from different assessment process will be reviewed to reveal their knowledge characteristics in the decision-making process and drawbacks in the current practice.

3.4.1 Case 1 – MCG MCG Sub-contractor Assessment

(http://www.mcg.org.uk/pdf/MCG_Subcontractor_Pre-qualification_Guidance.pdf)

The Major Contractor Group, representing the interests of major contractors to government and other decision makers, provides member companies with standard H&S pre-qualification criteria for sub-contractors who would be engaged in the project. The H&S pre-qualification criteria enable MCG companies to assess sub-contractor's H&S competence by specifying the requirements of H&S management arrangements, including H&S policy statement, competence of employees, consulting the workforce, risk assessment, H&S advice, accident performance, enforcement action previous experience, CDM, health risk management and H&S planning and improvement. The majority of those criteria are consistent with 'Core Criteria' under CDM Regulations 2007. The judgment requirements, evidence and questions for sub-contractors are also supplied to facilitate the self-assessment by MCG companies. In addition, the requirements together with judgment standards make a prospective sub-contractor clearly understand what H&S criteria they should comply with while working with MCG companies.

According to the evidence and questions suggested by MCG to help pre-qualification criteria assessment, the knowledge representative nature regarding decision-making process can be attributed as non-linear, subjective and qualitative. Most of the evidence the MCG requires to be available is related to documents, records and procedural arrangements. The majority of evaluation questions for evidence checking are started by 'how' and 'what'. Thus, the reasoning process of the H&S pre-qualification assessment can be seen as qualitative evaluation by measuring the satisfaction or compliance between facts (answers) and prescriptive standards. Furthermore, such a qualitative evaluation of H&S documents, records and procedures is subjective because the judgment process depends on the decision-maker's expertise and experience.

However, the lack of measuring scales is the big drawback in the practice. As advocated by Lehtinen, et al. (1996), the effective means of applying subjective performance assessment in terms of behavioral science relies on the construction measuring scales. Without the measuring scales, the decision-making would be inconsistent and non-reasonable due to individual preference. Moreover, the lack of a standard assessment format could bring difficulties to practitioners while keeping the judgment record and accumulating valuable knowledge and experience. In addition, as the vast variations of construction work, size and nature, lack of support from the umbrella association is difficult to assure the effectiveness of applying self-assessment and could even result in unnecessary bureaucracy.

3.4.2 Case 2 - CHAS (The Contractor's Health and Safety Assessment Scheme)

(http://www.chas.gov.uk/)

The Contractors' Health and Safety Assessment Scheme (CHAS) is a client-oriented database consisting of approved contractors who have been validated as H&S competent against the assessment criteria. The aim of the scheme is to avoid duplication of effort by contractors and consultants in H&S pre-qualification and attempts to eliminate a full assessment when tendering for work with its members. Clients subscribing to the scheme will be able to access the database and acquire the information about a company's current status, further information required in the assessment, the outcome of term contract assessment and award of work. In addition, in order to help contractors satisfy the requirements regarding design work under

CDM Regulations 2007, the scheme can be applied to designers.

According to the assessment process, there are at least two stages in assessing competence. The first stage is a fundamental H&S competence evaluation in which the applicant organisation needs to complete a detailed questionnaire which will be assessed by an independent assessor. The questionnaire covers a series of assessment subjects including: General policy statement; Organisation for H&S; Work equipment; H&S training; Consultation arrangements; First aid; Fire precautions; Sub-contractor; Risk assessment; Asbestos, Health surveillance; Accident reporting; Work equipment; and Electrical safety. If a company passes the first stage assessment, it can be considered as having adequate capability of managing H&S and will become a member of CHAS listed in the database. The company that fails in the assessment will receive a written report describing the reasons for failure and can apply again within an agreed timescale after having made suitable changes or improvements. The second stage is carried out when the client requires the scheme to have a project specific check ensuring the applicants have the ability in proportion to the level of risk. However, the scheme only provides guidance on what checks should be done at Stage2. As introduced at the second stage, the third stage is also undertaken by clients to monitor the company's H&S performance when they are doing a work. If the monitor identifies the company have persistent poor safety performance, the client can require the scheme to suspend or remove the company from the approved list.

In accordance with the questionnaire designed by CHAS, the knowledge representative nature in the decision-making process is the same as that of MCG sub-contractor assessment, though the decision in the matter of H&S competence rests with independent assessor. The supporting documentation and evidence together with completed questionnaire are evaluated in terms of the compliance with H&S legislation. The independent assessor's expertise and experience are utilised to support the qualitative assessment, the result of it enabling clients to select H&S competent contractor or consultants in a time and resource saving manner if no specific requirements.

Although the independent assessors are experts in the domain of H&S competence assessment, the non-transparent assessment process without a structured measure system is a main drawback. The subjective judgment result can vary as human's knowledge is perishable and inconsistent (Darlington 2000). Due to the non-transparent evaluation criteria, the qualitative assessment could be doubted by the applicants though they can get written reasons for the failure. In addition, the lengthy questionnaire creates a large amount of paperwork for contractors and consultants. Simultaneously, the end user of the scheme (the client) can't effectively acquire instant knowledge support from the scheme's experts for the project-specific H&S competence assessment (Stage2) and monitoring of performance in the work (Stage3).

3.4.3 Research findings of case study

As a result of the case study for the current formal schemes for organisation's H&S competence assessment, the following characteristics can be summarised:

1. The knowledge representative characteristic of H&S competence assessment can be attributed as a non-linear, qualitative and subjective decision-making process in which relative documents and evidence should be evaluated in terms of the compliance with H&S legislations.
2. Assessment criteria are related to H&S legislation but haven't been standardised in practice.
3. Assessment scale hasn't been established in the practice. Decision-making is in the black-box and depends on individual knowledge and experience.
4. The assessment process is separated and has not been automated. A paper-based questionnaire is still prevalent to collect assessment information, though database (CHAS) has been applied to display the competence status.

The characteristic 2, 3 and 4 identified in the case study are drawbacks of current practice in H&S competence assessment. As discussed in Section 3.3, the emergence of 'Core Criteria' for H&S competence assessment under CDM Regulations can resolve the problem of non-standardisation in assessment criteria. However, the characteristic 3 together with the latent shortcomings of 'Core Criteria' mentioned before are related to the knowledge representative characteristic of H&S competence assessment. The non-linear, qualitative and subjective decision-making process without an effective decision-support tool is likely to be affected by personal knowledge, experience and preference and lead to ambiguous and bias decisions. In addition, the case study reveals the inadequate communication and information exchange between in-house experts of some schemes and those scheme end-users, which result in that knowledge, expertise and experience can not be effectively accumulated, shared and used to support the decision-making process. Therefore, in order to overcome the latent shortcomings of 'Core Criteria' and drawbacks in current practice, it is proposed explore and apply advanced technologies to improve the qualitative and subjective decision-making process.

3.5 Summary

This chapter reviewed concepts, legislation development and current practice in construction H&S competence assessment. Implementing H&S competence assessment can effectively and thoroughly inspect duty-holder's H&S culture, ability and performance before they are appointed or engage the current project. The CDM Regulations 2007 provide the construction industry with 'Core Criteria' to implement H&S competence assessment, which standardises the existing assessment standard.

The case study of current schemes for H&S competence assessment reveals that the knowledge representative characteristic of H&S competence assessment is a non-linear, qualitative and subjective decision-making process. Although the "Core

Criteria'' suggested by ACoP of CDM Regulations 2007 standardise the criteria for H&S competence assessment, the latent shortcomings of the ''Core Criteria'', the subjective and qualitative knowledge representative characteristic in the decision-making process of H&S competence assessment and the identified operational drawbacks in current practice imply a need of developing a tool, supporting reasonable H&S competence assessment.

The next chapter presents a detailed review of the A.I. and KBS technologies. The synthesis of literature reviewed helps to explore the appropriateness of applying A.I. and KBS technologies in H&S competence assessment. The feasibility of developing an online KBS for H&S competence assessment is then presented.

Chapter 4: Knowledge-based system for construction health and safety competence assessment

4.1 Introduction

As discussed in the previous chapter, H&S competence assessment is an evidence-based performance measuring process in which evidence in relation to the organisation's H&S culture, management system and performance is measured against prescribed standards to decide whether the organisation has underlying abilities and knowledge of undertaking the current work (Wright et al, 2003). The decision-making in the measuring process is an analytic review of the compliance between the regulation requirements and candidate's retrospective H&S managerial status in proportion to the risks, size and complexity of the work (Carpenter, 2006a; HSE, 2007). The identified latent shortcomings of 'Core Criteria' and drawbacks in the current schemes has highlighted that it is necessary to develop a tool for improving the effectiveness of subjective and qualitative competence assessment and in favour of information and knowledge communication, acquisition and accumulation. Therefore, it is envisaged that A.I. and I.T. technologies could be applied to develop a task-specific tool improving the effectiveness and efficiency of such a knowledge-intensive decision-making process. This chapter provides a review of relevant A.I. technologies applied in KBS for various decision-support tasks and explores the feasibilities of developing a KBS system for construction H&S

competence assessment.

Section 4.2 describes the basic architecture of KBS for decision-making process, focusing on introducing different A.I. technologies applied in the reasoning process of KBS and identifying advantages and disadvantages of those A.I. reasoning technologies.

Section 4.3 reviews the current application of KBS in construction, identifying the main barriers of developing KBS for construction activities.

Section 4.4 explores the structural and functional feasibility of applying KBS for H&S competence assessment by analysing the reasoning process in the H&S competence assessment and discussing the KBS application cases in construction H&S management.

4.2 A.I. Technologies and KBS for Decision-Making

Chapter 1 introduced KBS as a type of A.I. technology making use of computers to help people deal with complex problems and make decisions in a narrow domain (Awad, 1996; Giarratano and Riley, 2005). According to knowledge representative characteristics in the decision-making, different A.I. technologies can be applied in KBS as knowledge acquisition facility or knowledge reasoning facility to improve the decision-making process.

4.2.1 KBS for decision-making

Decision-making is an intelligent process consisting of three phases (Simon, 1960; Holsapple and Whinston, 1996):

- Intelligence: is an information and knowledge collection period when the decision maker is alert for occasions to make decisions. In the decision-making process for the H&S competence assessment, the intelligence phase represents the information acquisition from the regulations regarding H&S 'Core Criteria' and relative evidence of duty-holders.
- Design: is an information and knowledge processing period in which alternative courses of action will be analysed, compared and evaluated. In the decision-making process for the H&S competence assessment, the design phase involves the subjective and qualitative evaluation of the compliance between the 'Core Criteria' and evidence.
- Choice: is an information and knowledge generation and recycling period when the decision-maker selects an alternative under internal and external decision pressures. The result of selection generates context-based knowledge in terms of the decision-making process and could be utilised in the next decision-making. In the decision-making process for the H&S competence assessment, the choice phase needs to determine the competent duty-holders as a result of evaluation and

accumulate the assessment records and experience not just for further assessment but also as proof of reasonable judgment.

The three decision-making phases represent different knowledge processing functions which can be respectively realised by knowledge acquisition and knowledge reasoning facilities in the KBS. Figure 4.1 illustrates a typical rule-based KBS, in which expertise and heuristics are stored in the knowledge base as production rules (IF-THEN). The inference engine decides which rules are satisfied by current facts or objects and then provides the users with the result of executing the satisfied rules. The knowledge acquisition facility enables the user to enter new knowledge in the system rather than asking knowledge engineer to code the knowledge. Therefore, the KBS is an intelligent decision-support system substituting human experts draws on descriptive and reasoning knowledge to infer advice in response to a decision-maker's request for a recommendation (Holsapple and Whinston, 1996).

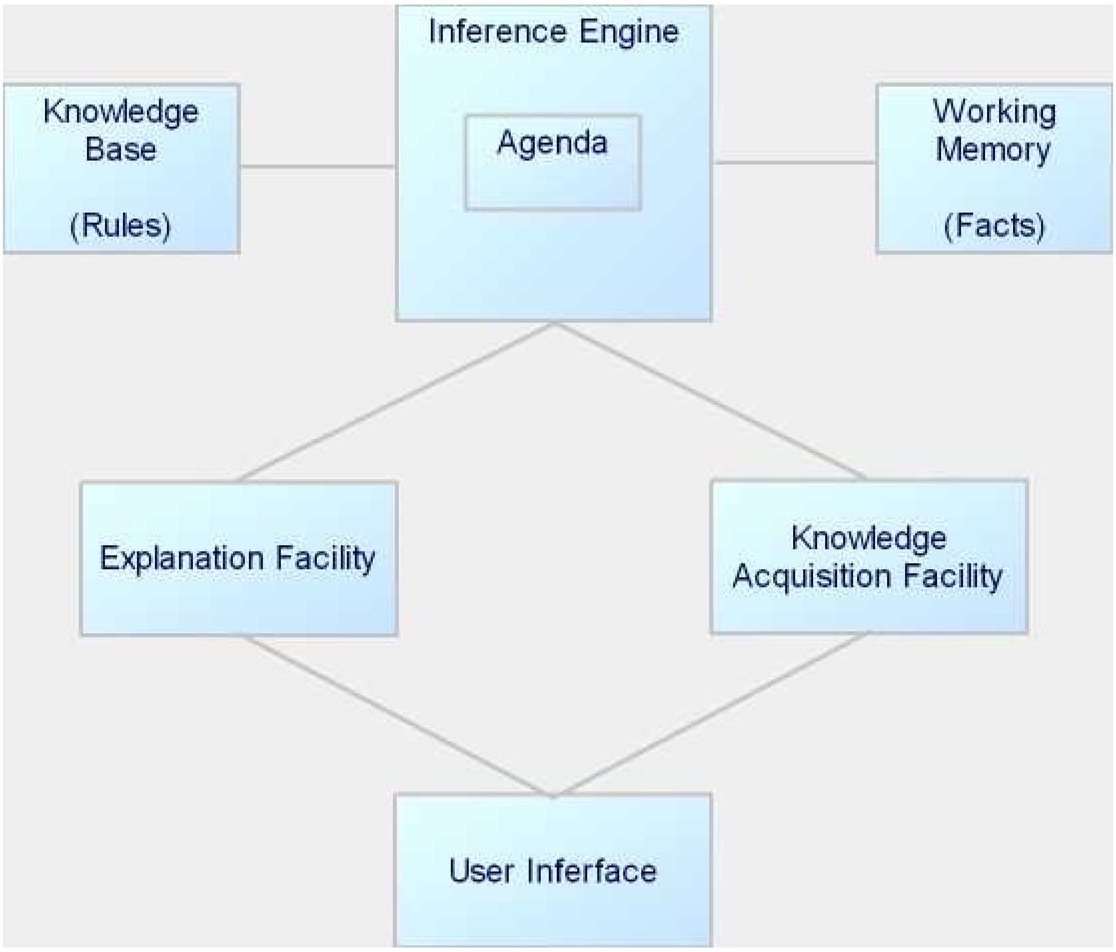


Figure 4.1 Structure of a rule-based system (Friedman-Hill, 2003; Giarratano and Riley, 2005)

4.2.2 A.I. technologies for reasoning process in KBS

An A.I. system basically includes the data structures used in knowledge representation, the algorithms needed to apply that knowledge, and the languages and programming techniques in their implementation (Luger, 2002). In order to process different knowledge, A.I. technologies can be applied in the following reasoning processes:

- Rule-Based Reasoning: is the common method of representing knowledge by using IF… THEN… rules,

- Case-Based Reasoning (CBR): is adapting past experiences of human specialists, represented as cases and stored in a database, to meet current demands when a user encounters a new case with similar parameters (Kolodner, 1993, Laudon and Laudon, 2002),
- Frame-Based Reasoning: is using name and set of attributes, or slots to provide a natural way for the structured and concise representation of knowledge (Negnevitsky, 2002)
- Model-Based Reasoning: is applying a set of rules reflecting the causality and functionality of a physical system to solve predicted or contingent problems (Luger, 2002),
- Fuzzy Logic (FL): is applying approximate reasoning to translate ambiguous and imprecise knowledge into an executable rule set by using imprecisely defined terms called membership function to solve problems (Laudon & Laudon, 2002, Negnevitsky, 2002),
- Artificial Neural Networks (ANN): is employing a distributive machine learning mechanism to formulate a human brain analogous learning algorithm that performs local optimisation (Negnevitsky, 2002),
- Genetic Algorithms (GA): is simulating natural evolution, generally by creating a population of individuals, evaluating their fitness, generating a new population through genetic operations and repeating this process a number of times to come up with better solutions (ibid).

However, different A.I. technologies applied to acquire knowledge and process reasoning have their advantages and disadvantages. Table 4.1 provides a succinct summary of those A.I. technologies.

Table 4.1 A brief summary of A.I. technologies in knowledge acquisition and reasoning process (Mitchell, 1997; Negnevitsky, 2002; Luger, 2002; Shapiro, 2002; Giarratano and Riley, 2005)

A.I. Reasoning Process	Advantages	Disadvantages
Rule-Based Reasoning	✧ Natural knowledge representation ✧ Good explanation facilities ✧ Separation of knowledge from its processing ✧ Dealing with incomplete and uncertain knowledge	✧ Task – dependent knowledge and inability to learn ✧ High heuristic knowledge causes opaque relations between rules ✧ Ineffective search strategy ✧ Omitting theoretical explanation
Case-Based Reasoning	✧ Simplified knowledge acquisition process ✧ A time-saving reasoning process ✧ Avoiding past errors and exploiting past successes ✧ Appropriate indexing strategies	✧ Knowledge may be misapplied ✧ Sometimes the requirement of a large case base ✧ Difficulty to determine good criteria for indexing and matching cases
Model-Based Reasoning	✧ The ability to use functional/structure knowledge of the domain ✧ A robust reasoning process ✧ Providing causal explanations	✧ A lack of experiential (descriptive) knowledge of the domain ✧ The requirement of an explicit domain model ✧ High complexity of constructing the model ✧ High probability of exceptional situation
Frame-Based Reasoning	✧ A powerful tool for combining declarative and procedural knowledge ✧ Can organise knowledge hierarchically	✧ Expressivity limitations ✧ Can not distinguish between essential properties and accidental properties ✧ Difficult to make about the hierarchical structure of the system and its inheritance paths
Fuzzy Logic Reasoning	✧ Inherently robust to represent vague, ambiguous and imprecise terms ✧ Particular well suitable for modeling human decision making	✧ Difficult to construct and tune the fuzzy membership functions and rules ✧ Lack an effective learning capability
Artificial Neural Networks	✧ Strong adaptation to problems that are too complex for conventional technologies ✧ Automatic learning ✧ Good uncertainty and imprecision tolerance	✧ Slow convergence speed ✧ 'Black Box' data processing structure can not provide inference explanation

Genetic Algorithms	✧ Systematic random search ✧ Derivative-free optimisation ✧ Good uncertainty and imprecision tolerance ✧ Good learning ability and adaptability	✧ Difficult to tune ✧ Poor knowledge representation and explanation ability

It is noticed that A.I. technologies are not the panacea of solving all problems. In many real-world applications, not only does knowledge need to be acquired from various sources but also the different reasoning methods should be combined to tackle complex problems. The requirement for such a combination has led to the emergence of hybrid intelligent systems (Negnevitsky, 2002). Ko and Cheng (2003) suggested that an integrated system combined with two or three A.I. technologies could be a promising path towards the development of intelligent systems capable of capturing qualities characterising the human brain. For example, a neural expert system can take advantage of the learning ability of ANNs to offset the "knowledge acquisition bottleneck" of rule-based KBS. Meanwhile, rule-based KBS can provide a facility to explain the reasoning process which appears to be a black-box in ANNs. The combination of different A.I. technologies can offset the demerits of one paradigm by the merits of another (Ko and Cheng, 2003). Other examples include neuron-fuzzy systems (Kasabov, 1996; Lin and Lee, 1996; Nauck et al., 1997; Von Altrock, 1997), evolutionary neural networks (Montana and Davis, 1989; Whitley and Hanson, 1989; Ichikawa and Sawa, 1992), fuzzy evolutionary systems (Ishibuchi et al., 1995) and neuron-fuzzy-genetic systems (Shapiro, 2002).

In general, A.I. technologies provide different means of building up KBS's for various problems. The key point of selecting appropriate A.I. technologies for knowledge acquisition and the reasoning process in KBS is to understand the knowledge nature of the domain problem and find an effective way to represent relevant knowledge. In addition, it should be noted that A.I. technologies and KBS are not appropriate to every knowledge related task. Sometimes it is difficult to capture even a relatively small, straightforward amount of human expertise because of the rich and complex human knowledge (Davenport and Prusak, 1998). It is, thereby, important to explore the feasibility of applying A.I. and KBS to process certain knowledge-intensive work.

4.3 KBS application in construction

It has been demonstrated by many years of research that knowledge-based systems are one of the most effective methods of managing knowledge if they can be applied in appropriate areas and to appropriate tasks (Kingston, 2004). The construction industry is a knowledge-intensive industry involving various different disciplines (Yu, et al, 2005). Many construction problems are subjective and qualitative, and that much of the industry's expertise is based on experience and judgment rather than theory and analysis (Touran and Briceno, 1990). With the trend of aiming at reducing waste, improve reliability, increasing efficiency, improving the distribution of risk and generally increasing the overall performance of the industry, KBS has been considered as the best tool to help the construction industry realise innovation, though it is not envisaged that KBS will replace human experts but support them (Dutton, 1997, Yu, et al, 2005).

Since diverse KBS at all stages of the construction process from cradle to grave have been developed and reported, construction is an eminently suitable area for KBS (Dutton, 1997). KBS has been widely used in different construction disciplines to support decision-making in:

- Design (Chau and Albermani, 2003; Yang et al., 2003)
- Construction management (Yau and Yang, 1998; Ko and Cheng, 2003; Poon, 2004)
- Planning and Scheduling (Shaked and Warszawski, 1995)
- Site layout (Zouein and Tommelein, 1999; Elbeltagi and Hegazy, 2001; Zhang et al., 2002; Osman et al.,2003; Soltani and Fernando, 2004)
- Cost/Estimating (Li et al., 1998; Perera and Imriyas, 2003; Serpell, 2004; Sutrisna et al., 2004)
- Health and Safety management (Gowri and Depanni, 1998; Davison, 2003, Cheung, 2004)
- Contract management (Cheung et al., 2004; ArA.I.n and Pheng, 2006; Chua and Loh, 2006)
- Contractor pre-qualification (Juang et al, 1987; Lam et al, 2000; Ng, 2001)

Although a number of research have been carried out in attempt to explore and develop prototype KBS for various construction activities, very few KBS appear to be in routine use (Dutton, 1997). The main barriers to the use of KBS in construction could be (Christian and Pandeya, 1995; Duffy et al., 1996; Dutton, 1997; Mukherjee, 2003):

- The fragmentation of industry: Since most of construction projects are one-off, it is difficult to acquire sufficient knowledge, experience and heuristics for the KBS building-up.
- The adversarial nature of industry: The prevalence of traditional procurement methods bring about obstructions for knowledge acquisition and re-use in the industry.
- The complexity of knowledge requirement: Construction is an extremely complex process involving many disciplines. For example, many types of knowledge are required in the design process, such as aesthetics, functionality, legislation, economics, ergonomics and buildability. It is thereby not easy to develop an almighty KBS to deal with such an ill-specified problem.
- The variation of regulations: it will bring large maintenance problems to KBS because building regulations change over time.
- Insufficient reliable knowledge: Some A.I. technologies such as ANNs and CBR, acting as inference engine in KBS require adequate valid data or cases in the system development. However, due to the complexity and inconsistence of the industry some important data is often unreliable or completely missing, which obviously hampers to train and utilise those A.I. technologies dependent upon it.

The five main barriers with other factors such as the lack of investment and ambiguous understanding of some construction processes result in that the application of KBS in construction lags behind other engineering domains such as aerospace and automotive. In spite of technological and industrial limitations, the potential for KBS implementation in construction is huge. The requirement for efficient data and information transfer, collaborative cross-discipline communication between distinct professions, improved record-keeping and effective documentation makes a large development space for sophisticated I.T. including KBS (Sommerville and Craig, 2006). A large amount of complex, ambiguous, imprecise, uncertain, inconsistent and even missing information and knowledge in various construction domains can be elicited, stored, processed and re-used by different KBS. However, it must be acknowledged that KBS provide supports for, rather than automation of, construction tasks (Dutton, 1997). In addition, the reasonable selection of knowledge domain and A.I. technologies for KBS application are crucial for the success of a KBS.

4.4 Feasibility of Using a KBS for H&S Competence Assessment

Compared to other areas in construction, a few studies have been focused on the H&S related KBS development (Robertson and Fox, 2000). Recently, however, interest has appeared to increase the use of KBS for industrial health and safety purposes (Lingard and Rowlinson, 2005). Robertson and Fox (2000) suggested following sub-domains suitable for KBS application:

- The provision of regulatory advice;
- Hazard analysis and avoidance;

- Monitoring and diagnosis;
- Post-accident analysis and corporate knowledge; and
- Decision support.

The H&S management activities usually refer to regulation compliance checking, risk identification and control, and incident information capture and analysis. The advantages of KBS in knowledge acquisition, store, retrieval can effectively deliver domain-specific expertise in H&S activities, such as risk analysis and control, and regulation checking, to people who may not possesses this expertise.

As articulated in Chapter 3, the decision-making of H&S competence assessment is subjective and qualitative, requiring relative knowledge and experience. The drawbacks of current assessment schemes such as the lack of unambiguous and standardised judgment criteria and tedious paperwork, highlight the requirement of a tool with a subjective evaluation indicator system to facilitate assessors undertake reasonable assessment. Furthermore, the separation of clients and assessors in the existing schemes discourages:

- effective information and knowledge exchange;
- effective knowledge acquisition and accumulation; and
- efficient decision-making.

Since the client discharges the duty of making a reasonable assessment under CDM Regulations 2007, it is necessary to develop a client-centered mechanism which can be operated by professional schemes to support subjective and qualitative regulation-compliance checking via available knowledge sources including text, cases and human experts. In addition, the decision-making process can be recorded as evidence in case of the occurrence of prosecution.

Although the KBS is suitable to support decision-making and regulation-compliance checking, attention should be given to the possibility of using KBS to improve the H&S competence assessment and overcome the identified drawbacks in current practice. It is, thereby necessary to investigate the structural and functional appropriateness of KBS for H&S competence assessment.

4.4.1 Structural Feasibility

The takeoff of developing a KBS focuses on finding a suitable problem domain in which the knowledge contains procedures, regulations or heuristics in the form of condition-action statements, a taxonomic hierarchy, or a set of alternatives which need to be searched through (Kingston, 2004). Negnevitsky (2002) identified the following typical problems technically feasible to be addressed by KBS; they are:

- diagnosis: inferring malfunctions of an object from its behaviour and recommending solutions,
- selection: recommending the best option from a list of possible alternatives,
- prediction: predicting the future behaviour of an object from its behaviour in the past,

- classification: assigning an object to one of the defined classes,
- clustering: dividing a heterogeneous group of objects into homogeneous subgroups,
- optimisation: improving the quality of solutions until an optimal one is found, and
- control: governing the behaviour of an object to meet specified requirements in real time.

In addition, the KBS is suitable for problems referring to symbolic reasoning based on concepts, objects or states rather than to calculation based on numerical data; or geometric reasoning based on graphical data; or perceptual input based on textures, shapes, photographs or facial expressions (Awad, 1996; Kingston, 2004).

Construction H&S competence assessment is a regulation-compliance decision-making process, in which the duty-holders' H&S competence assessment is made through subjective condition-action evaluation based on 'Core Criteria'. Figure 4.2 illustrates the inference process of making the decision for one H&S competence criteria. Such a rule-based assessment is structurally suitable for the application of KBS (Awad, 1996; Negnevitsky, 2002; Friedman-Hill, 2003), though the qualitative and subjective nature of the domain problem would require flexible and expert-interactive rule-match judgment.

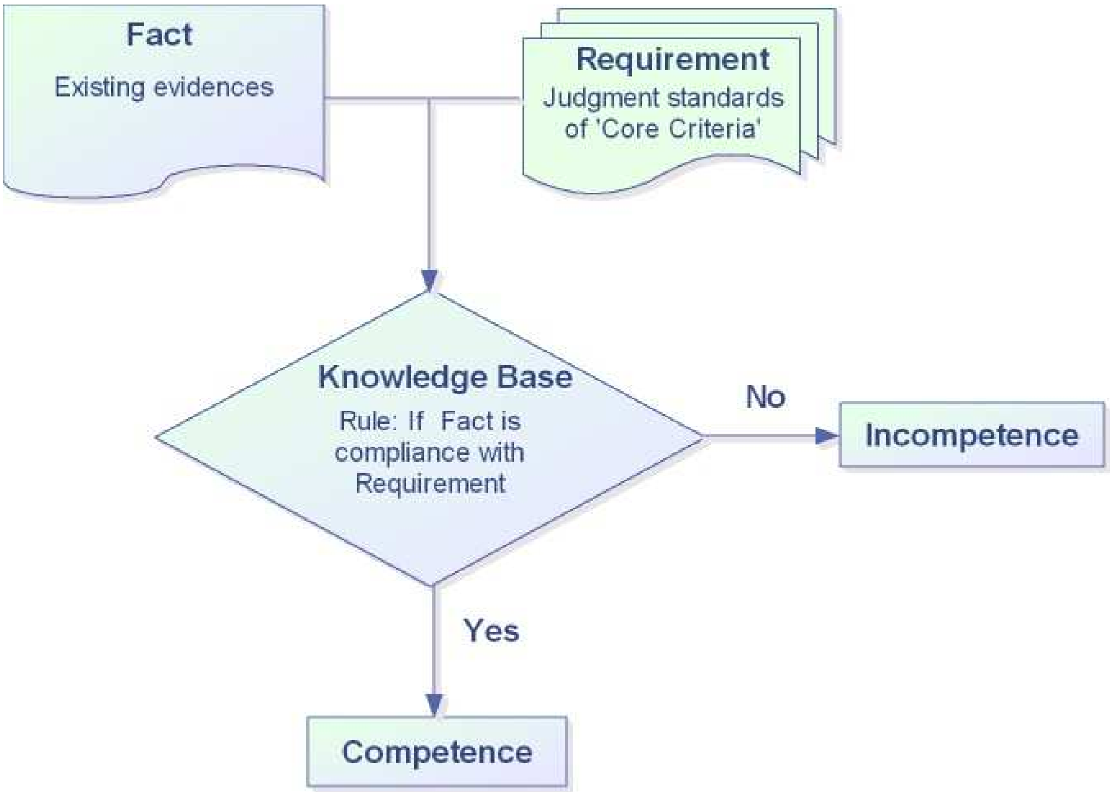


Figure 4.2 Condition-action inference in H&S competence assessment

4.4.2 Functional Feasibility

The condition-action reasoning process in the decision-making process justifies the structural appropriateness of KBS to support H&S competence assessment. The following review of three KBS applications in construction H&S management attempts to justify that KBS is capable of satisfying the functional requirements of H&S competence assessment. Furthermore, the limitations identified from the review would be taken into account in the current implementation.

4.4.2.1 Feasibility for regulation-compliance checking

All regulations are paper-based. In order to automate the process of regulation-compliance checking, KBS must transfer relevant regulations into electronic knowledge base supporting the reasoning process. The following two KBS examples provide possible solutions to store regulations in knowledge base.

- **Example of the KBS for designers' H&S risk identification and control**

Davison (2003) developed a prototype KBS to designers, enabling to identify H&S hazards, diagnose risks and use suitable risk control methods in the design. In order to help designers to carry out their duties under CDM Regulations 2004, the KBS integrates textual H&S regulations, guidance and expertise into a computer aided design (CAD) tool, delivering relevant structured H&S information to designers, enabling them to identify hazardous building attributes within a design and providing appropriate suggestions for risk control. The textual H&S information acquired from regulations, guidance and human experts is transferred into eXtensible Markup Language (XML) format and stored in a database in the connection with a CAD tool. In addition, the relevant H&S hazards to a building property, such as a rooflight are represented as a rule in which the textual hazards are converted into parameters that can be recognised by the CAD tool. The textual H&S information from the database is also attached with the rule to enable designers easily access with important H&S information including the result if the rule fails and reference to relevant H&S publications.

The prototype KBS combines H&S regulation-compliance checking with the design process, effectively improving designers H&S awareness and combating H&S risks in the root. The textual H&S information stored in the database can be connected with the design properties by hyperlink, enabling the efficient information and knowledge retrieval. However, the build-up of an automatic rule-based checking system requires a large amount of work to transform the textual H&S information into parameters identified by the CAD tool. Although the prototype KBS has merits in automation of regulations-compliance checking, effectiveness of risk control and convenient knowledge retrieval, the structured rules constrains the flexibility and adaptability of the KBS as rules are fragile and buildings are diverse.

➢ **Example of the KBS for building H&S inspections**

Gowri and Depanni (1998) developed an expert system enabling building inspectors to carry out compliance checking by providing them with building code text and information regarding commonly encountered code violations. A generic rule base is developed after analysing former violation cases. Meanwhile, the on-line access to code text and case study information is available for cross-referencing. The integration of expert system, databases and hypertext techniques have been proved to be effective to help diagnose the code compliance of existing buildings in Canada (Gowri and Depanni, 1998). However, the expert system for regulation compliance checking is specific for the knowledge which can be represented by quantified attributes because the production system in the compliance-checking relies on the numeric data including occupancy of building, height of building, occupant load of floor, area of floor, travel distance and number of exists. After computing those intermediate values, the expert system can find relative rules and activates compliance-checking by providing a checklist of possible violations. Although, the expert system framework is suitable for knowledge consisting of quantitative attributes, using hypertext technologies to represent text regulations and cases provides a practical solution to represent qualitative data.

The above two examples of KBS application in construction H&S management demonstrate the feasibility of KBS for regulation-compliance checking, highlighting that database and hypertext technology are effective to store and retrieve textual H&S information in the KBS and implying that structured or quantifiable rules are not suitable for the qualitative regulation-compliance checking, such as H&S competence assessment.

4.4.2.2 The Feasibility for Qualitative and Subjective Assessment

As identified in Chapter 3, the criteria for measurement of H&S competence assessment are qualitative and decision-making is subjective. It is necessary to investigate the capability of applying KBS to facilitate qualitative and subjective assessment.

- **Example of the Web-based KBS for construction H&S monitoring**

Cheung et al. (2004) developed a Web-based system (CSHM) to monitor construction

H&S management, facilitating the contractor in detecting potential risks and take corrective action. CSHM uses five categories of parameter including statistics; monitoring and compliance; education, training and campaign; inspection and audit; and complaints and prosecutions, to assess H&S performance in the construction site. For the measurement of qualitative parameters under monitoring and compliance category, CSHM enables the user to rate those parameters such as safe work practices, tools and machinery, personal protective equipment, fire protection, electrical safety, housekeeping, hygiene and first aid facilities and bamboo scaffolding, with a 10-point Likert Scale (1- not achieved, 10- highly achieved). The practitioner can automatically measure and benchmark H&S performance according to the total H&S score. Since CHSM is developed for a H&S manager or specialist, there are no specific rating standards for the qualitative measurement. A knowledge-base containing H&S rules, guidelines and best practice was built in the system to provide practical advice to problems identified in the measurement. In addition, the Web-based interface effectively facilitates data collection and dissemination. However, although CHSM provides a practical solution for the qualitative assessment, the rating scale without a preset scoring standard is likely to generate bias and inconsistency in the subjective measurement.

The example of CHSM indicates the feasibility of applying the qualitative and subjective assessment in the KBS and highlights the effectiveness of using a scoring system to facilitate subjective assessment of qualitative H&S parameters. Furthermore, the Web technologies can efficiently assist remote access, speedy data collection, retrieval and documentation.

The above investigation of three KBS applications in H&S management has revealed that KBS is functionally appropriate to deal with H&S problems in relation to regulation-compliance checking and subjective and qualitative assessment. However, two limitations identified in those examples have highlighted the difficulty and complexity of developing a highly intelligent KBS to automate the subjective and qualitative regulation-compliance checking. The two limitations are:

- It is difficult to develop a fully structured rule-based system to define all possibilities in the regulation-compliance checking.
- It is difficult to completely eliminate the subjectivity of making qualitative measurement for performance-based H&S criteria.

The H&S competence assessment under CDM Regulations 2007 is a unique knowledge problem domain involving subjective decision-making process and qualitative regulation-compliance checking. The non-specialist (client) has the responsibility of ensuring the reasonable judgment process. As a result of the feasibility study, the structural and functional appropriateness of KBS and advancement of I.T. technologies could make the attempt of developing a novel KBS for H&S competence assessment a reality. However, the limitation of structured reasoning rules and the constraint of subjectivity in the qualitative assessment should be carefully considered in the KBS development.

4.5 Summary

This chapter explored the feasibility of using a KBS to support H&S competence assessment. The working theory of KBS is structurally capable of accomplishing three important stages in the decision-making process. The diversity of A.I. technologies can accommodate different knowledge inference processes and deal with various complex problems. The reviewing of different applications of KBS in construction has revealed the selection of appropriate problem domain and suitable A.I. technologies is crucial for the success of a KBS.

The analysis of the inference process in H&S competence assessment reveals the structural suitability of KBS to support decision-making in H&S competence assessment. The feasibility investigation of KBS applications in H&S management validates the appropriateness of KBS for regulation-compliance checking and subjective decision-making process on qualitative judgment criteria. The KBS could satisfy the requirement of supporting the client to make reasonable subjective assessment of duty-holders's H&S competence against qualitative 'Core Criteria' under CDM Regulations 2007. In addition, two limitations for subjective assessment and structured reasoning rules have been highlighted to take into account for the KBS development.

In order to systematically develop a KBS for H&S competence assessment, Chapter five introduces the applied research methodology and the development of decision-making framework and model for the KBS.

Chapter 5 Research Methodology

5.1 Introduction

A review of the method of implementing construction H&S competence assessment and an investigation of the feasibility of applying KBS to improve the decision-making process in H&S competence assessment has hitherto been established. The review of 'Core Criteria' for H&S competence under CDM Regulations 2007 revealed the latent shortcomings of implementation. In particular, a case study of existing formal schemes for H&S competence assessment identified the knowledge representative characteristics embedded in the decision-making process of H&S competence assessment, highlighting the importance of developing a tool to facilitate the client to carry out subjective decision-making of H&S competence assessment against qualitative 'Core Criteria'. The review of A.I. technologies and working theory of KBS identified that KBS was structurally capable to help non-specialists deal with knowledge-intensive problems. The inference rule of decision-making for H&S competence assessment and the investigation of three KBS applications in construction H&S management acknowledged the structural and functional appropriateness of KBS to solve H&S management problems in relation to regulation-compliance checking and subjective decision-making based on qualitative criteria. In addition, the limitations of structured inference rules and subjective measurement of qualitative criteria identified in the investigation should be taken into account in KBS development.

This chapter focuses on presenting a systematic research methodology through the introduction of relevant research definitions, concepts and techniques, leading to a proposed KBS framework and model for the development of a decision-support tool for construction H&S competence assessment.

Section 5.2 presents the general research framework applied in the study.

Section 5.3 introduces the data and knowledge collection concepts and findings of applying relevant research methodologies in the study.

Section 5.4 proposes a conceptual decision-making framework for H&S competence assessment, highlighting the importance of developing a statement indicator system for subjective decision-making.

Section 5.5 describes the selection of knowledge representation method for H&S competence assessment and proposes a KBS decision-support model assisting the client to select H&S competent duty-holders against 'Core Criteria' of CDM Regulations 2007.

5.2 Research Framework

Research is defined by *Concise Oxford Dictionary* as 'careful search or inquiry; endeavour to discover new or collate old facts etc. by scientific study of a subject; course of critical investigation' (Naoum, 1998). Such a voyage of discovery should be guided and controlled by structured research methodology which refers to 'the principles and procedures of logical thought processes which are applied to a scientific investigation' (Fellows and Liu, 2003).

The process of conducting research should be designed systematically to satisfy the requirements for solving a particular problem. Developing I.T. solutions for specific construction management problems usually follows a procedural sequence (Poon, 2001; Oloke, 2003; Sutrisna, 2004; Heesom, 2004) starting from problem identification, followed by I.T. framework or model development, system implementation and ending with system evaluation. Therefore, a four-stage research framework (Figure 5.1) was adopted to guide the research conduction. At stage 1, a literature review of relevant research including construction H&S and KBS technologies was carried out to provide an overview of current theories and methods used for H&S competence assessment and investigate the feasibility of using KBS to support the assessment. Simultaneously, a case study of existing formal schemes for H&S competence was included in the review to explore the knowledge representative (inference) characteristics and operational problems in the decision-making process of H&S competence assessment. According to the inference characteristics and latent shortcomings of 'Core Criteria' identified at stage 1, a decision-making framework was developed at stage 2 to reveal the knowledge and information flow among different participants and effective decision-support mechanism in the decision-making process. Following the framework, a KBS decision-support model was built up, providing a practical I.T. solution to support the client in selecting H&S competent duty-holders under CDM Regulations 2007. At stage 3, a prototype online decision-support tool was implemented after the development of textual knowledge base and database management system. The final stage focused on evaluating the functional reliability and practical validity of the tool through analysing feedback from a questionnaire survey among relevant practitioners.

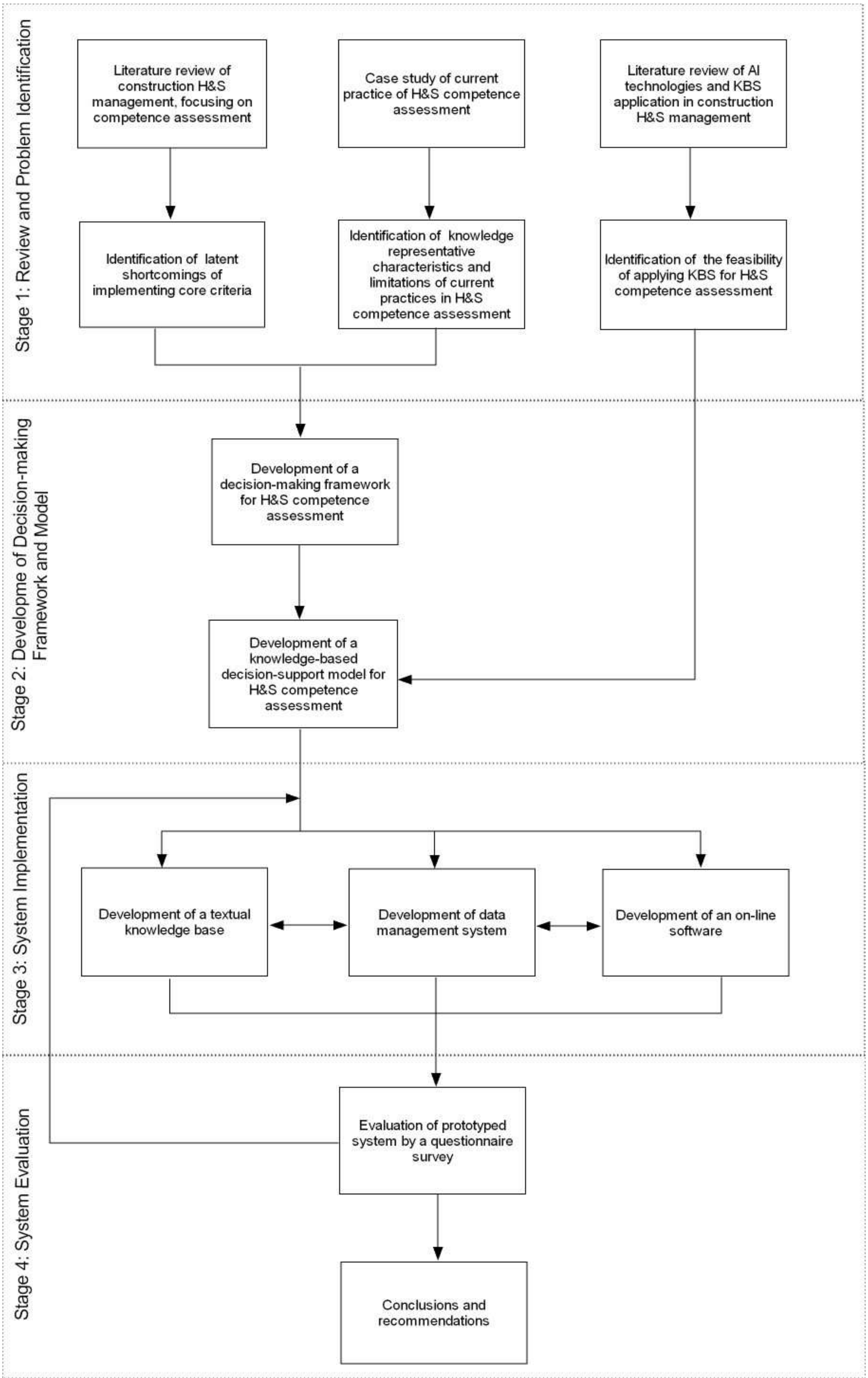


Figure 5.1 Research framework

5.3 Data and Knowledge Collection for H&S competence assessment

The building of a KBS can be viewed as life cycle that begins with a domain problem and ends in a computer-based solution (Awad, 1996). Following the problem identification, relevant data and knowledge need to be collected and interpreted for the further system development. According to the KBS technology, the data and knowledge collection is called knowledge acquisition, which is '*a process by which the expert's thoughts and experience are captured*' (Awad, 1996). Generally speeking, the selection of knowledge acquisition process and techniques depends on the type of knowledge and the nature of reasoning process. Awad (1996) recommended three steps for knowledge acquisition in building a KBS:

- Identify structure of the experts knowledge;
- Discover relative importance of decision criteria;
- Clarify information and elicit knowledge.

In order to facilitate the effective knowledge acquisition, different techniques or tools can be used to tap knowledge from experts, including interview, on-site observation, protocol analysis, brainstorming, consensus decision making, the repertory grid, nominal-group technique and the Delphi method (Awad, 1996; Negnevitsky, 2002; Giarratano and Riley, 2005).

The knowledge acquisition process from human experts can be both tedious and complicated (Awad, 1996). A large amount of resource and time should be spent on manual work to tap the knowledge from experts because most expert knowledge is cognitively complex and tacitly pragmatic (*ibid.*). Furthermore, one of the major difficulties in the development of KBS is called the 'knowledge acquisition bottleneck' - how to extract knowledge from human experts to apply to computers as many human experts are unaware of what knowledge they have and the problem-solving strategy they use, or are unable to verbalise it (Negnevitsky, 2002). Since the major task of knowledge acquisition is determining how experts make decisions for the domain problem, the interview of experts who are experienced in construction H&S competence assessment could be an effective knowledge acquisition method. However, although the current practice of existing assessment schemes use professional assessors to conduct assessment, the confidential conditions of those schemes, limitation of resources in the research and the change of regulations make it difficult to apply interview or other experts-related techniques to acquire relative knowledge. Therefore, in this research, reviewing regulations to appropriately interpret the judgment standards for assessment and conducting case study to analyse the decision-making nature were applied to collect useful data and knowledge for the development of the knowledge representation framework and model in the decision-making process.

From the literature review, it has been identified that construction H&S competence assessment is an effective means of evaluating candidate duty-holder's H&S culture and capabilities of dealing with H&S issues. The 'Core Criteria' of H&S competence assessment under CDM Regulations 2007 provide a standardised yardstick to assist clients to discharge their obligations of ensuring all duty-holders are H&S competent before they are engaged into the project. However, the latent shortcomings of 'Core Criteria' imply the difficulties of effectively and efficiently making reasonable decisions in the assessment. The review and analysis of KBS technologies in theory and applications within similar problem domains has justified that the KBS is structurally and functionally appropriate to be applied in H&S competence assessment.

As a result of case review of current practice in construction H&S competence assessment, the knowledge representative characteristics has of the decision-making process been attributed as non-linear, qualitative and subjective. In addition, the non-transparent measurement criteria and process constrains the reasonable decision-making and effective knowledge-sharing in construction H&S competence assessment.

In order to improve the practice of H&S competence assessment under CDM Regulations 2007 and promote a positive H&S culture in the industry, a collaborative decision-making framework is developed to demonstrate a conceptual decision-making process for effective H&S competence assessment.

5.4 A decision-making framework for H&S competence assessment under CDM Regulations 2007

As mentioned in the preceding chapter, the ACoP of CDM Regulations 2007 recommends the use of 'Core Criteria' in H&S competence assessment. According to the evaluation standard and evidence, the 'Core Criteria' can be categorised into three types:

- Procedure-related criteria: Documented procedure of arranging a specific H&S issue, such as H&S arrangement, should be provided as the evidence of a systematic problem-solving process and well-developed H&S culture;
- Example-related criteria: The past examples of dealing with H&S problems, such as design hazard management, are required as the evidence of practical ability; and
- Record-related criteria: Relevant data of important documents, action plan, and performance/qualification record should be in place to demonstrate the consistency of ability in dealing with H&S issues, such as training and information.

As shown in Figure 5.2, most of the criteria should be assessed in terms of documented procedures together with supporting track-records or examples. Such a regulations-compliance checking is a distributed process where multiple participants are involved (Wang et al., 2004) and requires the exchange of information and knowledge among regulations, client and candidate duty-holders.

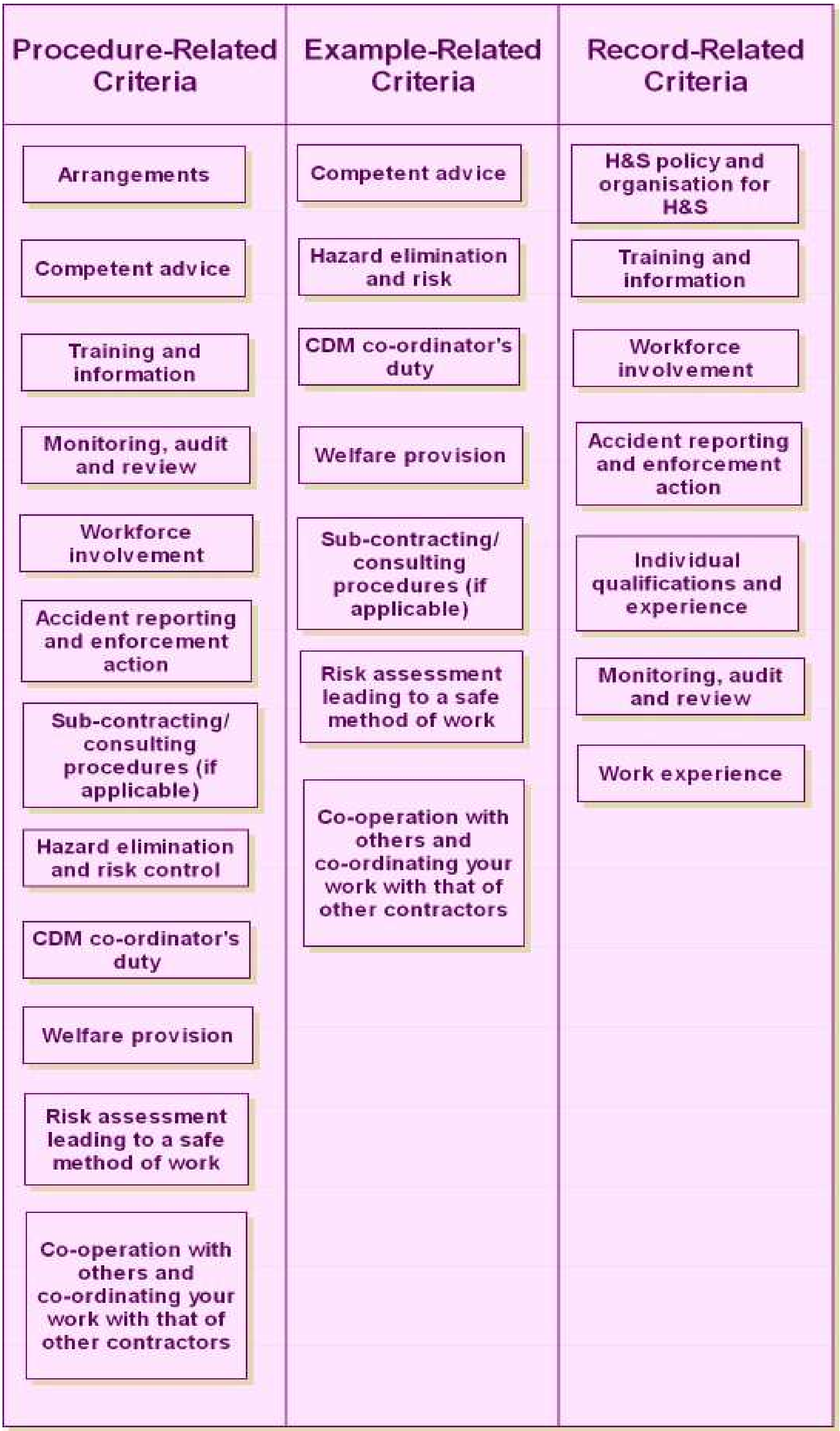


Figure 5.2 Criteria type of H&S competence assessment

According to the interoperation among those participants providing information and knowledge, a decision-making support framework (shown in Fig 5.3) was developed to illustrate the means of effective information and knowledge exchange and support in the decision-making process. In addition, the framework implies difficulties impacting the achievement of reasonable judgment making, which is the important legal requirement of CDM Regulations 2007.

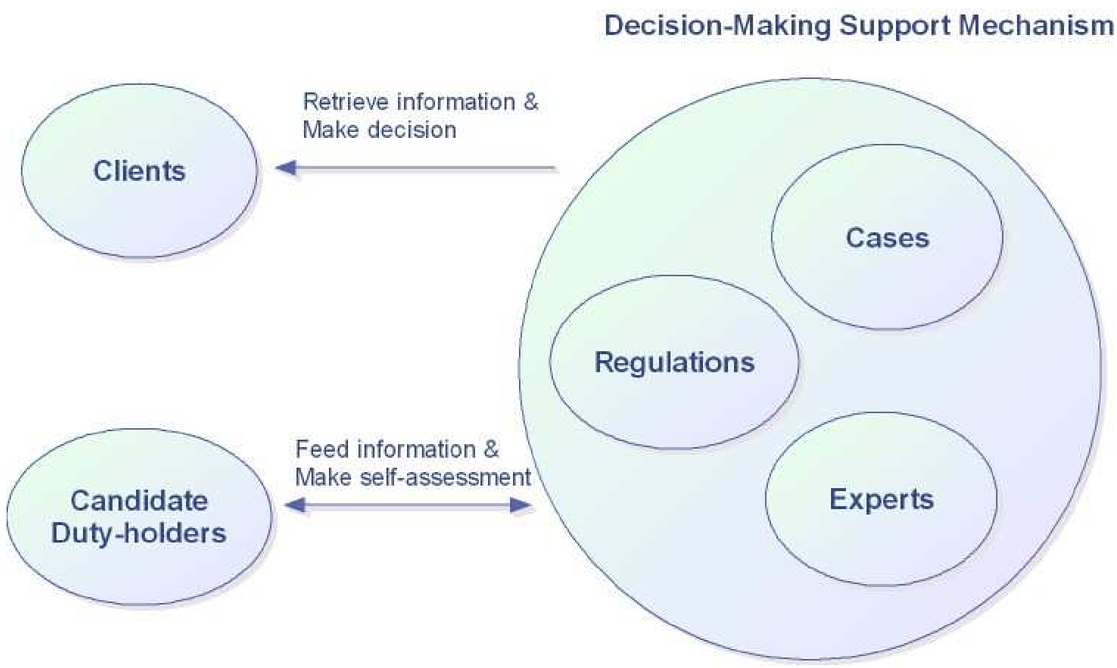


Figure 5.3 A decision-making framework for H&S competence assessment

The client or consultants acting as client should acquire two forms of external information and knowledge sources to support decision-making. One is the regulation codes or requirements for H&S competence; the other is the documented evidence from candidate duty-holders. As most of clients are not specialists in H&S competence assessment, it could be difficult for them to apply the regulation-compliance checking. The decision-support mechanism should provide them with an exhaustive list of regulations and measurement standards or rules. Furthermore, in order to assist clients in making reasonable decision, the decision-support mechanism should be able to accumulate and re-use the knowledge from previous assessment cases and experts who can provide pertinent suggestions. In the decision-making process, it is also important to acquire candidate duty-holders' documented procedures, examples and records based on the 'Core Criteria'. It could be efficient that the decision-support mechanism can help candidate duty-holders make self-assessment before the evidence passed to clients. Simultaneously, the information and knowledge derived from the decision-making process can be stored by the mechanism, helping clients and duty-holders' self-learning. The ideal decision-support mechanism should have the following functions:

- All evidence from the candidate duty-holders can be electronically submitted;
- The submitted evidence can be automatically compared with measurement rules;
- The weakness or the compliance level can be intelligently highlighted.

However, according to the case study findings in Chapter 3 and feasibility investigation in Chapter 4, it is difficult to develop an intelligent rule-based regulation-compliance checking system to support the subjective and qualitative decision-making. Therefore, the current research focuses on the development of an effective subjective assessment indicator to measure the compliance between regulation requirements and duty-holder's documented evidence. Furthermore, the measurement indicator system can also be used to rank candidate duty-holders for the coordination with other selection considerations such as quality, time and cost. In addition, the information and knowledge exchange in the regulation-compliance checking process should be recorded automatically and electronically to improve the productivity and help knowledge acquisition and accumulation.

5.5 A KBS Decision-Support Model for H&S Competence Assessment

According to the suggestion put forward in the decision-making framework, the next stage focuses on applying KBS technologies to appropriately represent the domain knowledge. The knowledge representation is an ontological method of analysing the thought process of an expert and then emulating that process in a logical way which can be programmed by computer (Davis et al., 1993; Awad, 1996, Yu et al., 2007). In other words, knowledge representation is a transition from acquired knowledge to a set of rules, facts and schemes that can be encoded by computer languages to support electronic and automatic problem solutions. The strategies for knowledge representation include semantic nets, frames, rules, formal logic, decision tables and decision trees (awad, 1996; Giarratano and Riley, 2005).

As presented in Chapter four, the H&S competence assessment under 'Core Criteria' can be represented by rules. However, the subjective and qualitative knowledge representative nature of the decision-making process implies that it is unreasonable and unpractical to develop all-around production rules covering all possibilities in the assessment. Further, it would be difficult to debug and maintain the rule base in the prototyping and further improvement process as regulations are changeable. Therefore, it could be more efficient and effective to construct rules in the textual form to support subjective and qualitative decision-making. The textual rules including judgment standards, suggested evidence and rating criteria could assist a client in implementing duty-holders' H&S competence assessment by themselves. Simultaneously, since the textural rules are independent from the logic reasoning, it would be convenient to maintain the rule base at any time.

However, decision-making based on the textual rules is likely to be impaired by the subjectivity of the decision-maker. In order to reduce the subjectivity and improve the accuracy in the H&S competence assessment, it would be useful to apply case retrieval and online expert enquiry facilities to support appropriate decision-making. Compared to the traditional rule-based systems, a case-based decision-support system can represent problem-solving knowledge in a natural way and especially be suitable for the contextual and textural knowledge such as regulation-compliance checking. Simultaneously, the case-based system can provide a reliable and ever-growing knowledge base to enable the efficient knowledge retrieval and re-use for the effective decision-making (Bergmann et al., 2003). In addition to the case retrieval facility, the online expert enquiry facility could help the client acquire timely trouble-shooting support from human experts of some umbrella organisations, such as APS. With the efficient and pertinent help of relative experts, the client can effectively improve the reasonability in the assessment.

In order to realise the above mentioned decision-support facilities, A KBS decision-support model was developed to facilitate the client to take reasonable steps in H&S competence assessment. As illustrated in Figure 5.4, the KBS model contains three decision-support mechanisms, namely:

- screen mechanism: to help clients eliminate the incompetent candidates by evaluating their evidence against the minimum satisfaction standards under CDM Regulations 2007. Since each core criterion has equal importance (HSC, 2007), the failure of satisfying one core criteria will result in the candidate being labeled as 'Incompetent' and can't take part in the work bidding.
- rating mechanism: to facilitate the client in assigning the satisfaction degree in each criterion against the statement indicators. The measurement indicators can enable the client to make a quick qualitative assessment based upon subjective impressions of evidence (Nevis et al., 1995).
- ranking and reporting mechanism: to provide the client with a sorted list of candidates according to their rating results. Simultaneously, the decision-making process with all data and information can be stored, retrieved, revised and printed out.

In the screen and rating process, hypertext technologies are applied to develop the textual knowledge base including minimum satisfaction standards and measurement indicators, to demonstrate the relevant assessment procedure and judgment standards.

A case-based enquiry facility helps clients retrieve former similar assessment cases as cross-reference. In addition, an online expert enquiry facility enables effective information and knowledge exchange between experts and the client.

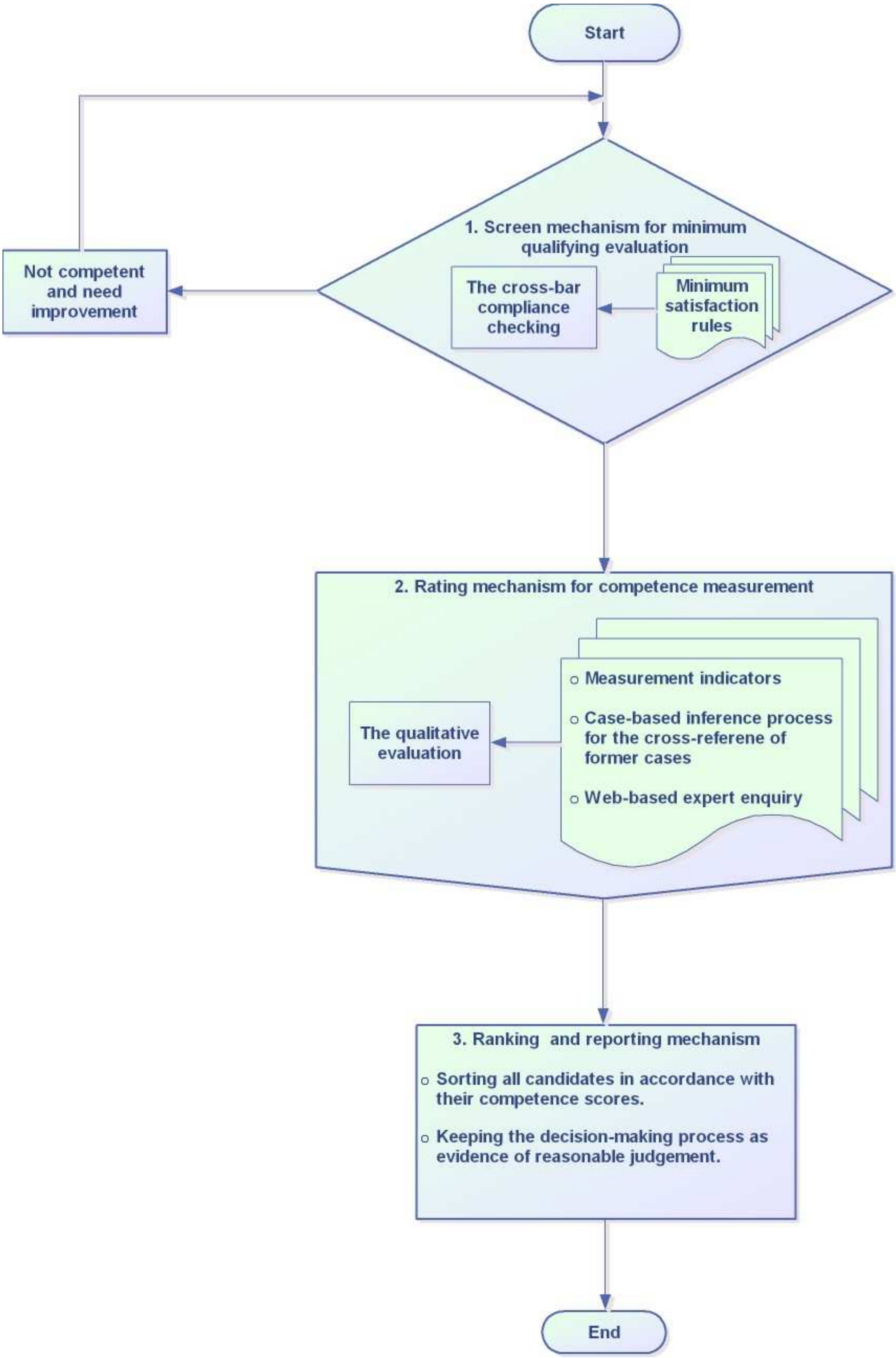


Figure 5.4 A KBS decision-support model for H&S competence assessment (adapted from: Yu et al., 2007)

In order to develop such an online KBS, there are three important steps which have to be accomplished at the research stage 3 & 4, and will be discussed in the following chapters:

- Step 1: Developing the textual knowledge base containing minimum satisfaction standards and measurement indicators to explicitly represent the knowledge for subjective assessment (Chapter six).
- Step 2: Using suitable Web development technologies to develop an online KBS realising the three decision-support mechanisms (Chapter seven).
- Step 3: Evaluating the reliability and user satisfaction of the KBS (Chapter eight).

5.6 Summary

In this chapter, a four-stage research framework has been presented and discussed, providing a systematical methodology of conducting the study. The selection of literature review and case study as the data and knowledge collection methods was discussed and justified.

In accordance with the knowledge representative nature, a decision-making framework was developed to propose the ideal decision-making support mechanism and reveal the difficulties of making reasonable decisions for H&S competence assessment. Further, the description and analysis of knowledge representation in H&S competence assessment led to the development of a KBS decision-support model to appropriately represent knowledge and satisfy functional requirements in the decision-making process. The application of textual knowledge base, case base and Web technologies provided a rational solution supporting the client to take reasonable steps to assess duty-holders' H&S competence against 'Core Criteria' under CDM Regulations.

According to the research framework, the next three chapters present the development of textual knowledge base, the process of prototyping the KBS, and the means of evaluating the KBS.

Chapter 6: Development of A Textual Knowledge Base for Construction Health and Safety Competence Assessment

6.1 Introduction

The previous chapter has described the structure of a KBS decision-support model to assist the client in applying H&S competence assessment. The primary step of developing a practical KBS is to build up an appropriate knowledge base - the heart of a KBS. Since it is difficult and inefficient to develop a precise computerised rule-based reasoning system, the knowledge embodied in regulations can be represented and stored as a textual form convenient for retrieval, inference and maintenance in the decision-making process of H&S competence assessment. As illustrated in the decision-support model of the KBS (Chapter 5), the assessor should firstly decide whether the candidate duty-holder is over the cross-bar of H&S competence criteria, and then make the selection by referring to the quality of those criteria among competent candidates. The main decision-making benchmarks come from the demonstration of core criteria in ACoP of CDM Regulations 2007. However, the paper-based yardstick and guidance are not straightforward enough, especially for some inexperienced clients, to be applied in the online KBS. In the attempt to help the end-users of the KBS understand the core criteria, judgment standards and inference mechanism, an in-depth discussion and explanation of textual rules embedded in the CHSCA-KBS is considered necessary.

In order to effectively represent the judgment knowledge in the KBS, this chapter explores the core criteria in details, demonstrating the contents of textual knowledge base by presenting the key elements of minimum satisfaction standards of core criteria and rating indicators for qualitative assessment.

Section 6.2 describes the assessment method of 15 'Core Criteria' for H&S competence. Following the discussion of developing the principle of minimum satisfaction standard and using a Likert Scale for the qualitative rating indicator, each core criterion is specified in terms of its judgment standard under ACoP of CDM Regulations 2007.

Section 6.3 concludes the development of the textual knowledge base, outlining the measurement standards applied in the rating indicators of 'Core Criteria'.

6.2 The textual knowledge base

As stated by Drucker '*you can't manage what you can't measure*' (HSE, 2001c), thus effective assessment relies on practical measurement. According to the knowledge representative characteristics embedded in the decision-making process of H&S competence assessment (refers to Chapter 3 & 5), it is necessary that a textual knowledge base be developed to demonstrate the minimum satisfaction standards and statement rating indicators for subjective and qualitative assessment in terms of 'Core Criteria. As presented in Chapter 2 and Appendix 2, although the ACoP of CDM Regulations 2007 has explained the core criteria by describing the judgment standards and examples of the evidence that could be used to demonstrate the achievement of requirements, it is not concise and practicable enough to be represented in the textual knowledge base to support decision-making process in the H&S competence assessment. In order to facilitate the effective regulation-compliance checking and subjective rating for the comparison of different candidates, the knowledge base consists of two parts. They are:

- Minimum satisfaction standard: indicates the minimum standard of each core criterion to be achieved, and
- Statement rating indicator: defines a subjective assessment scale to measure the H&S performance in terms of core criteria.

The minimum satisfaction standard is derived from Appendix 4 of ACoP for CDM Regulations 2007 and modified by referring to relative judgment standards applied by existing H&S competence assessment schemes. The standard consists of the key elements and relevant examples to prove the satisfaction, which are designated by the ACoP for the competence assessment.

The rating indicator is developed by applying a Likert scale which measures individual agreement with a statement between being of completely same to completely different opinion (Lehtinen et al., 1996). Likert scaling is a psychometric scaling method, measuring either positive or negative response to a statement (Likert, 1932; Dawes, 2008). A Likert scale is usually developed in a set of ordered categories, implying equidistant response levels that help the measurement of attitudes, preferences and subjective reactions (Bernard, 2005). The Likert scale has been widely used to help the subjective and qualitative assessment of performance in the construction managerial field, such as safety performance assessment (Lehtinen et al., 1996), knowledge management evaluation (Kululanga and McCaffer, 2001), and safety and health monitoring system (Cheung et al, 2004). Due to the effectiveness and practicality of Likert scale in qualitative and subjective measurement, following the assessment of minimum satisfaction standards, a Likert scale with qualitative statements is applied to assist the subjective measurement of the regulation-compliance level of evidence for 'Core Criteria'.

Since the minimum satisfaction standard has specified the fundamental elements which must be included in the relevant documents and policies, the Likert indicator is designed to assess the extent of clarity, understandability and effectiveness of those elements. The Likert indicator system usually applies five-point arithmetic series to represent the ordinal data (Bernard, 2005). However, considering the practicality and effectiveness of qualitative assessment for H&S competence assessment, a three-point geometric series Likert indicator (referring to Table 6.1) has been developed to rate the performance of candidates in each core criterion.

Table 6.1 Likert statement indicator for health and safety competence assessment

Score	Classification	Explanation
1	Acceptable	Evidence meets minimum standard but some areas are not adequate
3	Good	Evidence meets minimum standard and is compliance substantial
9	Excellent	Evidence meets minimum standard and some areas exceed standard

The above table provides a general specification for the Likert rating indicator. Different core criteria have respective rating statements which will be specified in the following sections.

The following sections bring a detail explanation of textual knowledge base (refer to Appendix 3) for H&S competence assessment by highlighting the key elements contained in the minimum satisfaction standards and introducing the development of rating indicator for each core criteria.

6.2.1 Health and safety policy and organisation for health and safety

According to section 2 of HSW Act 1974, if the organisation employs more than five people, it must have a written H&S policy. The key elements of a clearly defined H&S policy and organisation should include (Hughes and Ferrett, 2005; Lingard and Rowlinson, 2005; HSE, 2007):

- a copy of written H&S policy statement (specifying H&S aims and objectives) dated and signed by the most senior person in the organisation, and

- H&S responsibilities for employees at all levels.

In order to carry out an effective qualitative assessment, the rating indicator concentrates on the clarity, comprehensibility and adaptability of the policy context. The rating indicator for organisations more than five persons is designated as:

- Acceptable: The health and safety policy contains statements of the organisation's commitment to H&S and is reviewed regularly.
- Good: The health and safety policy contains the organisation's statement to H&S, specifies the H&S principles in which the organisation believes and identifies the general responsibilities of employees.
- Excellent: The health and safety policy contains the organisation's statement and principles to H&S, and clearly sets out the responsibilities for health and safety management at all levels within the organisation in relation to the nature and scale of the work.

It is not necessary if the organisation employs less than five people to display a written copy of H&S policy and organisation. However, it should demonstrate the appropriate policy and organisations for H&S. The demonstration could be carried out through interview or other communication forms. The rating indicator is slightly changed to adapt to the means of the demonstration. The following is the rating indicator for organisations less than five people:

- Acceptable: The demonstration of health and safety policy can explain the organisation's commitment to H&S.

- Good: The demonstration of health and safety policy can explain the organisation's commitment to H&S, H&S principles in which the organisation believes and general H&S responsibilities of employees.
- Excellent: The demonstration of health and safety policy can explain the organisation's commitment to H&S and clearly identifies the H&S responsibilities of all employees in relation to the nature and scale of the project.

As suggested by the ACoP, the HSE leaflet INDG259 (An Introduction to Health and Safety) is hyperlinked in the knowledge base to provide a guidance and reference of the format and contents of company's health and safety policy.

6.2.2 Arrangements

Arrangements for H&S comprise details of the means applied to realise the company's H&S policy. The following items normally included in the arrangements (Hughes and Ferrett, 2005):

- Employee health and safety code of practice
- Accident and illness reporting and investigation procedure
- Fire drill procedure
- Electrical equipment (maintenance and testing)
- First aid
- Machinery safety (including safe systems of work)

- Permits to work procedures
- Health and Safety inspection and audit procedures
- Procedures for contractors and visitors
- Catering and food hygiene procedures
- Terms of reference and constitution of the safety committee

According to the guidance in ACoP, a construction organisation with more than five employees should display a written copy of arrangements for H&S, which includes:

- details of means used to arrange health and safety management;
- rules of discharging its duties under CDM 2007; and
- the way of communicating these arrangements to the workforce.

The above three points are key elements designated in the minimum satisfaction rule for this criterion.

As the clarity and understandability of the arrangements is the measurement standard (HSC, 2007), the rating indicator could be demonstrated as:

- Acceptable: The general arrangements which the organisation has made for putting its H&S policy into effect, discharging its duties under CDM 2007 and communicating to the workforce are in place.
- Good: The arrangements which the organisation has made for putting its H&S policy into effect, discharging its duties under CDM 2007 and communicating to the workforce are clearly specified.
- Excellent: The arrangements which the organisation has made for putting its H&S

policy into effect, discharging its duties under CDM 2007 and communicating to the workforce are clearly specified. Besides the general arrangements, there are specific H&S rules, procedures and the provision of facilities to fit the nature and scale of current project

Similar to the first criterion, a construction organisation with less than five employees does not need to display a written copy of the arrangements. The candidate duty-holder can meet the minimum satisfaction rule by demonstrating its arrangements to realise the H&S policy and discharge the duties under CDM 2007 in other forms, such as an oral presentation. The rating indicator should also focus on assessing the clarity and understandability of the arrangement context, and the correlation between the contents and current work in the demonstration, which is presented as:

- Acceptable: The general arrangements which the organisation has made for putting its policy into effect, discharging its duties under CDM 2007 and communicating to the workforce can be demonstrated.
- Good: The arrangements which the organisation has made for putting its policy into effect, discharging its duties under CDM 2007 and communicating to the workforce can be demonstrated in a clear and understandable manner.
- Excellent: The arrangements which the organisation has made for putting its policy into effect, discharging its duties under CDM 2007 and communicating to the workforce can be demonstrated in a clear and understandable manner. There

are also details and specific arrangements to fit the nature and scale of current project.

6.2.3 Competent advice – corporate and construction related

This criterion refers to the accessibility of H&S expertise or consultation. The organisation should provide evidence including the following elements to satisfy the minimum satisfaction rule:

- name of the source of advice, for example a safety group, trade federation, or consultant who provides H&S information and advice.
- competency details of the source of advice. The advisor must be able to provide general H&S advice, and also advice relating to construction H&S issues.

Since the H&S advisors within the organisation have closer knowledge of the practical aspects of the work and are more accessible than those outside the organisation, the in-house consultation is preferable (Lingard and Rowlinson, 2005; Carpenter 2006a; HSC 2007). In addition, the former example of using the advice provides a strong evidence of the effectiveness of the consultation resource. Thus, the rating indicator of this criterion focuses on assessing the readiness of acquiring professional advice and the effectiveness in former practice, which is:

- Acceptable: The organisation and employees have ready access to competent H&S advice from outside the organisation.
- Good: The organisation and employees have ready access to competent H&S

advice from within the organisation.

- Excellent: The organisation and employees have ready access to competent H&S advice from within the organisation. Evidence showing that advice was given and action was taken in last 12 months.

6.2.4 Training and Information

H&S training of employees plays an important role in the management system of H&S and is a significant representation of organisation's H&S culture. A systematical training programme covering all levels in the organisation and containing life-long learning plan can effectively prevent accidents, improve H&S performance and promote a positive H&S culture (Hughes and Ferrett, 2005). Therefore, the key elements in the minimum satisfaction standard for this criterion should include (HSC, 2007):

- training arrangements to provide employees with knowledge and skills to perform their job safely and understand the necessary information to discharge their duties. One or some of following examples can be seen as evidence to satisfy this element:
  - Headline training records
  - Evidence of a H&S training culture including records, certificates of attendance and adequate H&S induction training for site-based workforce.
  - Sample 'toolbox talks'

- a programme for refresher training. An active Continuing Professional Development (CPD) programme can be seen as an evidence for this element.

As advocated by Lingard and Rowlingson (2005), the effectiveness of a training programme relies on the extent to which learning is put into practice. The rating indicator of this criterion focuses on the extent of practicality and effectiveness of the training programme, which is:

- Acceptable: A general training programme is sent out for all levels of employees from Board to trainees.
- Good: A detailed training programme including induction training, job-specific training and supervisory and management training is adequately sent out for all levels of employees from Board to trainees.
- Excellent: A detailed training programme including induction training, job-specific training and supervisory and management training is adequately sent out for all levels of employees from Board to trainees. There is solid evidence or record showing the effectiveness of the training programme, such as the improvement of H&S performance on site.

6.2.5 Individual qualifications and experience

As discussed in Chapter 3, this criterion is special for the individual H&S competence assessment. The employees’ qualification and experience should be assessed according to the following key elements of the minimum satisfaction rule:

- Employees of the organisation who will engage in the project should have the appropriate qualifications and experience for the assigned tasks.
- Employees who don't have appropriate qualifications and experience should be under controlled and competent supervision.

The examples of appropriate qualification and experience for different duty-holders listed in the ACoP of CDM Regulations 2007 include (HSC, 2007):

- Contractor organisations:
  - Details of number/percentage of people engaged in the project who have passed a construction health an safety assessment, for example the ConstructionSkills touch screen test or similar schemes, such as the CCNSG (Client Contractor National Safety Group) equivalent.
  - For site managers, details of any specific training such as the ConstructionSkills 'Site Management Safety Training Scheme' certificate or equivalent.
  - For professionals, details of qualifications and/or professional institution membership.
  - For site workers, details of any relevant qualifications or training such as S/NVQ (National and Scottish Vocational Qualifications) certificates.
  - Evidence of a company-based training programme suitable for the work to be carried out.
- Designer organisations:

- Details of number/percentage of people engaged in the project, who have passed a construction H&S assessment, for example ConstructionSkills touch screen test or affiliated schemes, such as the CCNSG (Client Contractor National Safety Group) equivalent.
- Details of any relevant qualifications and/or professional institution membership and any other specific qualifications such as ICE (Institute of Civil Engineer) construction H&S register, NEBOSH (National Examination Board in Occupational Safety and Health) Construction Certificate, APS (Association for Project Safety) Design Register.

- CDM Co-ordinator:
  - Details of number/percentage of people engaged in the project who have passed a construction health an safety assessment, for example the ConstructionSkills touch screen test or affiliated schemes, such as the CCNSG equivalent.
  - Evidence of health and safety knowledge such as NEBOSH Construction Certificate.
  - Details of professional institution membership and any other specific qualifications such as member of the CDM co-ordinators' register administered by the APS or ICS that is formerly the IPS (Institute of Planning Supervisors), or the ICE construction health and safety register etc.
  - Evidence of a clear commitment to training and the Continuing Professional Development of staff.

For a large or complex project, or one with high or unusual risks, the CDM Co-ordinator needs more competence. According to Appendix 5 of CDM ACoP, the competence assessment standard for the CDM Co-ordinator engaging in the large, complex or high-risk project include:

- Appropriate task knowledge for the tasks to be undertaken,
- Sufficient H&S knowledge to perform the task safely, and
- Sufficient experience and ability to perform the task.

The examples of attainment of the above standards are provided in the textual knowledge base (refer to Appendix 3).

People with appropriate qualification or experience should have adequate knowledge or skill to deal with the assigned tasks safely and without risks to health. Thus, the percentage of employees at different levels with appropriate qualification or experience is considered as the rating indicator for the qualitative assessment. The rating indicator for this criterion is stated as:

- Acceptable: Specific corporate post holders (for example Board members and health and safety advisor) and other key roles have the appropriate qualification and experience. Some of the other employees have the appropriate qualification and experience and others are controlled or supervised by those competent employees.
- Good: Specific corporate post holders (for example Board members and health and safety advisor) and other key roles have the appropriate qualification and

experience. Most of the other employees have the appropriate qualification and experience and others are controlled or supervised by those competent employees.

- Excellent: All employees have the appropriate qualification and experience.

6.2.6 Monitoring, audit and review

Monitoring, audit and review constitutes a systematical process to measure the achievements of H&S policy and objectives; inspect the efficiency, effectiveness and reliability of the H&S management system; and assess the adequacy of performance of the H&S management system (Lingard and Rowlinson, 2005). Monitoring, audit and review are key activities in making sure that the organisation's H&S management system is working properly and collecting practical information for the further improvement. According to the ACoP, an organisation which wants to meet the minimum satisfaction rule of this criterion should have a system that can:

- Monitor the procedures of H&S performance
- Audit the them at periodic intervals, and
- Review them on an ongoing basis.

For the convenience of assessing, the following examples can be seen as the evidence of satisfaction (HSC, 2007):

- Evidence of formal audit or discussions/reports to senior managers.
- Evidence of recent monitoring and management response.

- Copies of site inspection reports.

Since this is a procedure-based criterion, the qualitative assessment is based on the extent of detail and practicality of the system. The rating indicator is demonstrated as:

- Acceptable: Documented evidence (at least one type of the above evidence for minimum satisfaction checking) shows that general monitoring, audit and review system has been in place.
- Good: Documented evidence (at least two type of the above evidence for minimum satisfaction checking) shows that structured monitoring, audit and review system has been established.
- Excellent: Documented evidence (at least two type of the above evidence for minimum satisfaction checking) shows that structured monitoring, audit and review system has been established. Furthermore, evidence shows that the system can identify limitations or drawbacks in the performance of H&S management and develop corrective methods to improve the effectiveness of H&S management.

6.2.7 Workforce involvement

Since the workforce has first-hand experience of site conditions and is often the first to identify potential problems, involving the workforce in decision-making of risk identification and control is crucial to prevent the accident in construction work (HSC, 2007). Further, the cooperation of all employees is important for an organisation to establish a successful H&S culture (Hughes and Ferrett, 2005). As the key feature of Robens-style legislation, the workforce involvement is a consultative process to ensure worker participation in H&S decision-making (Lingard and Rowlinson, 2005). In addition, according to an important principle of industrial democracy, people have right to be involved in making decisions that affect them, particularly when those decisions can have an impact upon their health and safety (Industry Commission, 1995). Therefore, the organisation should have, and implement, an established means of consulting with its workforce on H&S issues. One or some of following examples can be seen as evidence to meet the minimum standard (HSC, 2007):

- Evidence showing how consultation is carried out.
- Records of H&S committees
- Names of appointed safety representatives (trade union or other).

The effectiveness of work forces involvement depends on whether recommendations from the employees can be implemented and both management and employee concerns are freely discussed (Hughes and Ferrett, 2005). Therefore, the rating indicator focuses on measuring the practicality of the means of workforce involvement, which is stated as:

- Acceptable: There is a general workforce involvement system i.e. Safety committee or safety representatives.
- Good: There is a structured workforce involvement system, i.e. evidence showing

that the system is working in the organisation and is helpful to improve H&S performance and management.

- Excellent: There are routine procedures of ensuring that the workforce is involved in the H&S management, i.e. evidence showing the monitoring and review of H&S publicity and communication throughout the organisation.

6.2.8 Accident reporting and enforcement action; follow-up investigation

According to the RIDDOR (the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995), all employers, no matter has large or small, should report certain more serious accidents and incidents to the HSE or other enforcing authority and to keep a record (*ibid.*). In addition to the compulsory external incident reporting system, the organisation should establish an internal system to report and investigate all incidents including 'lost time' injuries, 'no lost time' injuries and near miss. The reporting of an incident can help to evaluate the effectiveness of prevention strategies and is an essential first step in future incident prevention (Lingard and Rowlinson, 2005). In order to assess the system for incident reporting, the key elements of minimum satisfaction for this criterion include (HSC, 2007):

- The organisation should provide records of all RIDDOR (the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995) reportable events for at least the last three years.

- A system should be established to review all incidents and recording the action taken as a result.
- The organisation should record any enforcement action taken against the organisation over the last five years, and the action which the organisation has taken to remedy matters subjective to enforcement action.

One or some of following examples can be seen as evidence to meet the minimum standard:

- Evidence showing the way in which the organisation record and investigate accidents and incidents.
- Records of last two accidents/incidents and action taken to prevent recurrence.

  Records of any enforcement action taken over the last five years, and what action was taken to put matters right.
- For larger companies, simple statistics showing incidence rates of major injuries, over three-day injuries, reportable cases of ill health and dangerous occurrences for the last three years. Records should include any incidents that occurred whilst the company traded under a different name, and any incidents that occur to direct employees or labour-only sub-contractors.

The measurement of an organisation's accident reporting and investigation system could focus on the integrity of its incident track-record and the effectiveness of the investigation system for further accident prevention. The rating indicator for the qualitative assessment of this criterion is presented as:

- Acceptable: All RIDDOR reportable events in the recent three years are in the place. The records including last two accidents/incidents and follow-up actions, and any enforcement actions if occurred in last five years are available.
- Good: Besides the evidence listed at acceptable level, other documented evidence is provided to show that the accident investigation system has been established and can work effectively.
- Excellent: Besides the evidence listed at acceptable level, other documented evidence showing that the accident investigation system can work effectively and the corrective or preventative recommendations resulted from the investigation can be implemented and have positive impact on the organisation's H&S performance.

6.2.9 Sub-contracting/consulting procedures (if applicable)

Sub-contracting/consulting is a prevalent and economical method of acquiring expertise, skills, labourers and plants in the modern construction process. In order to maintain a controllable H&S management, the main contractor/consultant must take the responsibility of H&S for the multiple-layer subcontracting/consulting, as it is unreasonable and ineffective to subcontract H&S obligations to those other organisations (Lingard and Rowlionson, 2005). If there are sub-contractors/consultants involved in the project, the main contractor/consultant should make sure the satisfaction of the following elements:

- Arrangements for appointing competent sub-contractors/consultants and ensuring their arrangements for appointing competent sub-contractors/consultants,
- Arrangements for monitoring sub-contractor performance.

The assessment of the above minimum satisfaction standard can be carried out by checking the following examples (HSC, 2007):

- Evidence showing how the lead organisation ensures sub-contractors are competent.
- Examples of sub-contractor assessments the lead organisation has carried out.
- Evidence showing how the lead organisation requires similar standards of competence sub-contractors.
- Evidence showing how the lead organisation monitors sub-contractor performance.

For the measurement of this criterion, it would be reasonable and practicable to evaluate how the organisation is performing sub-contracting/consulting. An organisation with a structured sub-contracting/consulting system would be better than one using casual approaches in selecting H&S competent sub-contractors and consultants and monitoring their H&S performance and further appointment. The rating indicator for sub-contracting/consulting procedures is stated as:

- Acceptable: Some forms of pre-qualification H&S assessment such as questionnaire responses, meeting minutes or audit records, have been applied to select competent sub-contractors/consultants and monitor their work and further appointment.

- Good: A general selection and monitoring system for different layer's sub-contractors/consultants has been in the place with practical evidence (at least three samples) showing that sub-contractors/consultants can be appropriately selected and effectively monitored.
- Excellent: A general selecting and monitoring system for different layer's sub-contractors/consultants has been in the place with substantial evidence (a record of projects in recent three years) showing that sub-contractors/consultants can be appropriately selected and effectively monitored.

6.2.10 Hazard elimination and risk control (designers only)

As pointed out by Wright, et al. (2003), the best opportunity of eliminating H&S hazards is in the design process. The poor H&S record can be improved by encouraging designers to give more consideration to H&S matters at the design stage (Davison, 2003). According to the ACoP, the minimum satisfaction rule of hazard elimination and risk control should include the following key elements (HSC, 2007):

- There are arrangements for meeting the duties under regulation 11 of CDM 2007.
- Those arrangements should be implemented.

In order to make an assessment, the following examples can be seen as the satisfying evidence:

- Evidence showing how the organisation:

  - ensure co-operation of design work within the design team and with other designers/contractors;
  - ensure that hazards are eliminated and any remaining risks controlled;
  - ensure that any structure which will be used as a workplace will meet relevant requirements of the Workplace (Health, Safety and Welfare) Regulations 1992.
- Examples showing how risk was reduced through design.
- A short summary of how changes to designs will be managed.

Since the ACoP of CDM 2007 emphasizes that the assessment of this criterion should focus on practical measures which reduce particular risks arising from the design, not lengthy procedural documentation highlighting generic risks, the rating indicator is developed to evaluate the practicality and effectiveness of implementing hazard elimination and risk control, which is demonstrated as:

- Acceptable: Evidence is provided to show the detail arrangements to meet designer's duties, i.e. hazard assessment and risk control forms or report.
- Good: A documented hazard assessment processes and practical samples (at least three) are provided to show the arrangements to meet designer's duties.
- Excellent: A detailed record of projects in recent three years is provided to show the structured method and arrangements to meet designer's duties.

6.2.11 Risk assessment leading to a safe method of work (Contractors only)

Risk assessment is an essential part of the planning and implementation stage of H&S management system and an important duty of contractors under CDM Regulations 2007. A systematic risk assessment procedure can effectively identify and prioritize different levels of risk and provide appropriate risk control methods. HSC (1997) developed a five-step procedure to help organisations implement risk assessment. The five steps are:

1. look for the hazards
2. decide who might be harmed, and how
3. evaluate the risks and decide whether existing precautions are adequate or more should be done
4. record the significant findings
5. review the assessment and revise it if necessary.

However, since the generic procedures can bring little value to H&S, it is important to ensure the risk assessment procedures are practical and effective. Therefore, the key elements of the minimum satisfaction rule for risk assessment should include (HSC, 2007):

- procedures in place for carrying out risk assessment
- procedures in place for developing and implementing safe systems of work/method statements. (The identification of H&S issues is expected to feature prominently in the safe system in terms of the nature of the work.)

The following examples can be seen as the evidence for the minimum satisfaction:

- Evidence showing how the organisation will identify significant H&S risks and how they will be controlled.
- Sample risk assessments / safe systems of work / method statements.

If the organisation employs less than 5 people and does not have written arrangements, it should be able to describe how it can implement risk assessment.

Similar to the criterion for hazard elimination and risk control, the rating indicator focuses on measuring the practicality and effectiveness of the procedures, which is demonstrated as:

- Acceptable: Evidence is provided to show the process of doing risk assessment in practice.
- Good: A documented procedure and practical samples (at least three) are provided to show the arrangements for the risk assessment and control.
- Excellent: A detailed record of projects in recent three years is provided to show the structured method and arrangements for the risk assessment and control.

6.2.12 Cooperating with others and coordinating your work with that of other contractors (Contractors Only)

Cooperation between parties and coordination of the work are important to the successful management of construction H&S (HSC, 2007). Regulation 5 & 6 under

CDM 2007 impose the duty of cooperation and coordination on every person concerned in the project. In order to maintain effective and efficient cooperation and co-ordination, contractors should keep good communication between all parties and encourage the engagement of workers. The key elements of minimum satisfaction for this criterion are:

- The organisation should be able to illustrate how cooperation and coordination of its work is achieved in practice; and
- How it involves the workforce in drawing up methods statements/safe systems of work.

The following examples can be seen as evidence to demonstrate the organisation meeting the minimum satisfaction standard (HSC, 2007):

- Evidence could include sample risk assessments, procedural arrangements, and project team meeting notes.
- Evidence of how the organisation coordinates its work with other trades.

As stated in the minimum satisfaction rule, the method of implementing cooperation and coordination in practice is the focus of assessing this criterion. The contractor should show its capability and experience in cooperating and coordinating with workforce and other parties. The measurement of this criterion should concentrate on the effectiveness and efficiency of the methods applied in cooperation and co-ordination by contractors. The rating indicator is presented as:

- Acceptable: Evidence is provided to show the process of cooperating and coordinating with other parties and workforce in projects.

- Good: A documented procedure and practical samples (at least three) are provided to show the arrangements of cooperation and coordination with other parties and workforce in projects.
- Excellent: A detailed record of projects in recent three years is provided to show the structured procedures and arrangements for cooperation and coordination with other parties and workforce.

2.6.13 Welfare Provision (Contractors Only)

The welfare issues concern the standard of welfare facilities on the construction site. The arrangements for welfare include the provision of sanitary conveniences and washing facilities, drinking water, accommodation for clothing, facilities for changing clothing and facilities for rest and eating meals (Hughes and Ferrett, 2005). The Schedule 2 of CDM Regulations 2007 provides particular requirements on welfare facilities. The client, principal contractor and contractor have the duty of ensuring the compliance with the requirements of Schedule 2 throughout the construction phase.

The key element of minimum satisfaction rule for welfare provision is straightforward, requiring the appropriate welfare facilities be in place before the commencement of work on site. One or some of following examples can be seen as evidence to meet the minimum standard (HSC, 2007):

- Health and safety policy commitment;

- Contracts with welfare facility providers;
- Details of type of welfare facilities provided on previous projects.

The qualitative measurement of contractor's arrangements for welfare facilities focuses on the technical capability and former experience of providing welfare facilities in a proportion to the size of the workforce. The rating indicator is stated as:

- Acceptable: Evidence is provided to show that the organisation has the ability to arrange the workforce facilities, but lacks experience of dealing with the same size of workforce before as in the current project.
- Good: Evidence is provided to show that the organisation has the ability to arrange the workforce facilities and some experience (at least one project) of dealing with the same size of workforce before as in the current project.
- Excellent: Evidence is provided to show that the organisation has the ability to arrange the workforce facilities and sufficient experience (at least five projects) of dealing with the same size of workforce before as in the current project.

2.6.14 Co-ordinator's duties

Working as a CDM co-ordinator, the organisation has the duties of ensuring good working relationships, clear communication and sharing of relevant information among different parties (HSC, 2007). According to the ACoP, the demonstration of the ability of encouraging cooperation, co-ordination and communication between designers should concentrate not only on the generic procedures but also on the actual examples. Therefore, the key elements of the minimum satisfaction rule for co-ordinator's duties include:

- generic procedures of encouraging cooperation, co-ordination and communication between designers are in place.
- examples of implementing the procedures in practice.

Since the actual examples are more important than the generic procedures, the measurement of co-ordinator's duties should focus on the effectiveness and practicality of encouraging cooperation, co-ordination and communication. The rating indicator is stated as:

- Acceptable: Generic procedures are in place with at least one practical sample showing the effectiveness of implementing the procedures.
- Good: Generic procedures are in place with at least three practical samples showing the effectiveness of implementing the procedures.
- Excellent: Generic procedures are in place with a record of projects in recent three years showing the effectiveness of implementing the procedures.

2.6.15 Work experience

Previous work experience is a useful evidence of an organisation's ability to deal with the key H&S hazards in the current application (Carpenter, 2006a). The key element of minimum satisfaction rule of work experience requires the organisation to display details of relevant experience in the field of work for which it is applying. One or some of following examples can be seen as evidence to meet the minimum standard (HSC, 2007):

- A sample record of recent projects / contracts should be kept with the phone numbers / addresses of contracts who can verify that work was carried out with due regard to health and safety.
- Evidence showing that the organisation should have sufficient ability to deal with key health and safety issues arising from the work it is applying for.
- Where there are significant shortfalls in the organisation's previous experience, or there are risks associated with the project which it has not managed before, an explanation of how these shortcomings will be overcome should be provided.

As the assessment refers to capability of dealing with relevant projects, the measurement will focus on the amount of previous projects in a similar field and the performance in those projects. The rating indicator is:

- Acceptable: The organisation shows previous experience in at least one similar project with good recommendations from former clients, or evidence of good H&S performance. If there is any shortcoming in that project, detail explanation of improvement methods should be provided.
- Good: The organisation shows previous experience in at least three similar projects before with good recommendations from former clients, or evidence of good H&S performance. If there is any shortcoming in those projects, detail

explanation of improvement methods should be provided.

- Excellent: The organisation shows previous experience in at least five similar projects before with outstanding recommendations from former clients, or evidence of perfect H&S performance. If there is any shortcoming in those projects, detail explanation of improvement methods should be provided.

6.3 Summary

This chapter presented the development of a textual knowledge base for decision-support in H&S competence assessment, explaining a three-point Likert measurement standard for the indicator rating system of ‘Core Criteria’. Further, it highlighted the key elements of minimum satisfaction rules for each ‘Core Criteria’ and described the measurement standard of each rating indicator in detail. The following table is a summary of measurement standards applied in the rating indicators for ‘Core Criteria’:

Table 6.2 Summary of measurement standards applied in the rating indicators for 'Core Criteria'

Core Criteria	Measurement standard
1. Health and safety policy and organisation for health and safety	the clarity, comprehensibility and adaptability of the policy context
2. Arrangements	the clarity and understandability of the arrangements
3. Competence advice – corporate and construction-related	the readiness of acquiring professional advices and the effectiveness in former practice
4. Training and information	the extent of practicality and effectiveness of the training programme
5. Individual qualifications and experience	the percentage of employees at different level with appropriate qualification or experience
6. Monitoring, audit and review	the extent of detail and practicality of the system
7. Workforce involvement	the practicality of the means of workforce involvement
8. Accident reporting, and enforcement action; follow-up investigation	the integrity of incident track-record and the effectiveness of the investigation system for further accident prevention
9. Sub-contracting/consulting procedures	the structure of the procedures
10. Hazard elimination and risk control	the practicality and effectiveness of implementing hazard elimination and risk control
11. Risk assessment leading to a safe method of work	the practicality and effectiveness of the procedures
12. Cooperation with others and coordinating your work with that of other contractors	the effectiveness and efficiency of the methods applied in cooperation and co-ordination by contractors
13. Welfare Provision	the technical capability and former experience of providing welfare facilities in a proportion to the size of the workforce
14. Co-ordinator's duties	the effectiveness and practicality of encouraging cooperation, co-ordination and communication
15. Work experience (Stage 2 assessment)	the amount of previous projects in similar field and the performance in those projects

Based on the developed textual knowledge-base, the following Chapter presents the implementation of a prototype on-line KBS, discussing the selection of appropriate

Web programming technology, and describing the development of database management system and the Web-based interface.

Chapter 7: Development of The KBS

7.1 Introduction

In Chapter 6, the textual knowledge base, including the minimum satisfaction standards and qualitative measurement indicators, was developed to assist the reasonable decision-making process. In order to realise the principal research aim, an online KBS for construction H&S competence assessment is developed, in which the client can apply the decision-support model to select H&S competent duty-holders by reasonable steps. This chapter presents the implementation of the online KBS, entitled KBS for Construction H&S Competence Assessment (KBS-CHSCA).

Section 7.2 outlines the structure of the database-driven Web system and briefly analyses Web application technologies, highlighting that the suitability of Java Server Page (JSP) as the Web application technology for KBS-CHSCA.

Section 7.3 introduces the basic concepts and working theory of JSP technology.

Section 7.4 outlines the Data-Base Management System (DBMS) and explains the reason for selecting MySQL as the DBMS for KBS-CHSA. Following the discussion of DBMS and MySQL, an Entity-Relationship (E-R) diagram is used to illustrate the structure of the database for KBS-CHSCA. In addition, the approach of connecting

MySQL with JSP is briefly introduced.

Section 7.5 presents the application of Unified Model Language (UML) to analyse the structure of KBS-CHSCA, describing the use case model of the functional requirements of KBS-CHSCA and the activity diagrams of the interactions between users and the system.

Section 7.6 describes the applied technologies in the KBS implementation and introduces the main functionality and usability of KBS-CHSCA.

7.2 The Database-Driven Web System and Web Application Technology

In an attempt to realise the KBS through a Web interface, an interactive database-driven Web application is applied to support efficient data exchange between users and the KBS. The Web application uses Hyper Text Markup Language (HTML) to collect input data from the Web browser and submit them to the Web server. For a database-driven Web system, a programme runs on the Web server to process the input data, interacting with the database, and thus dynamically composing a reply to the browser as HTML, or other forms of data that the browser can render (Zahir, 2003).

As illustrated in Figure 7.1, the typical dynamic Web system contains three main functions of service delivery: HTTP (HyperText Transfer Protocol) interface, the application (or business) logic and the database. The front-end layer, acting as the interface of the Web system, receives the request from the clients (users), processes the static content from its local file system, and connects with the application logic of the middle layer (Conallen, 2003; Andreolini et al., 2005).

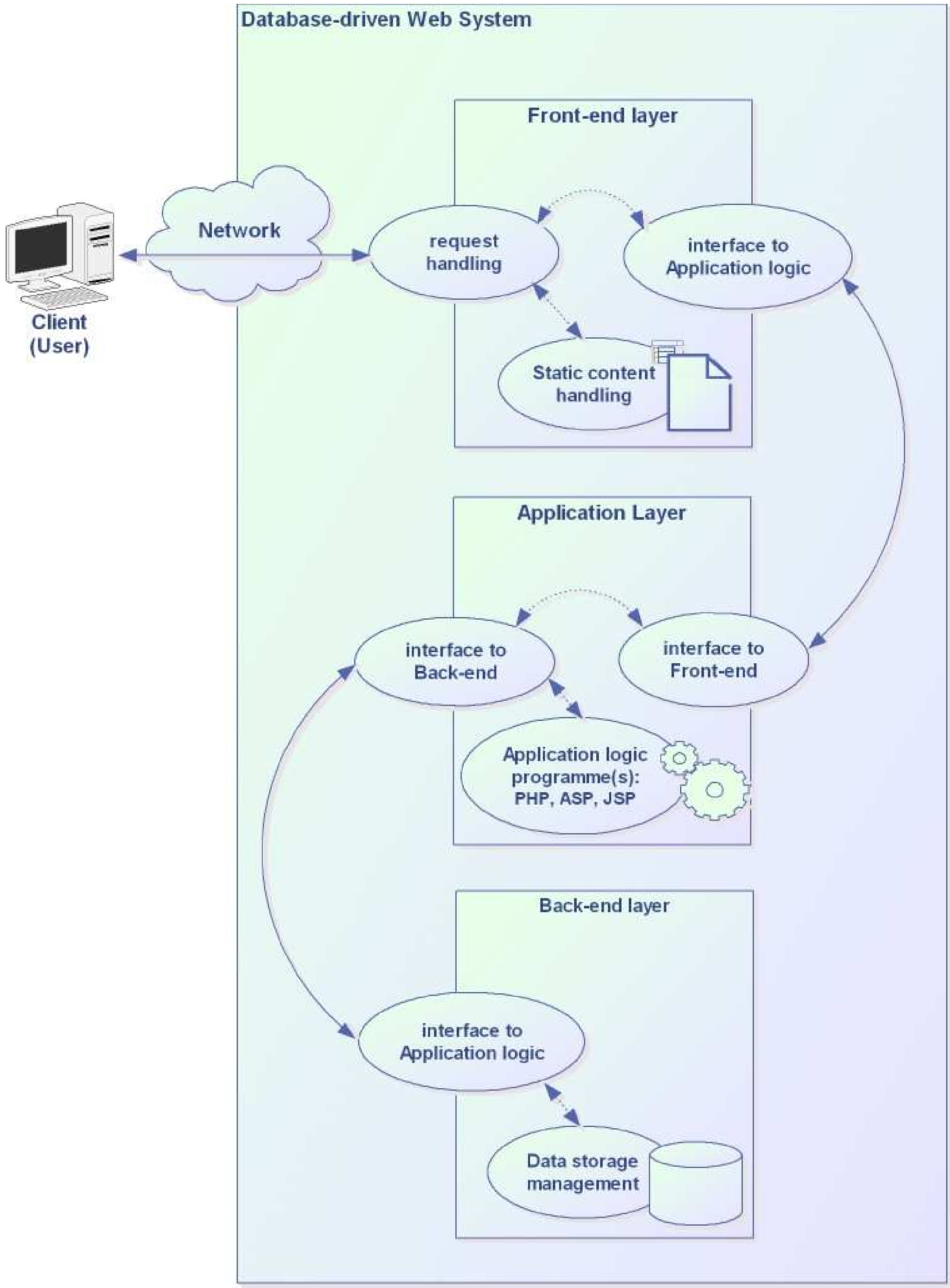


Figure 7.1 Architecture of a Database-Driven Web system (adapted from: Andreolini et al., 2005)

As the heart of a Web system, the application layer focuses on dealing with the logic operation and computing the information from the requests. Simultaneously, the application layer interacts with the back-end layer, which consists of a database server storing and managing the persistent data and information of the system. The result of operations in the application layer and interaction between the application and back-end layers generate the dynamic responses to be returned back to the clients.

In order to process the logic operation and interact with the database, it is necessary to select appropriate Web application technologies which must be capable of processing business logic on the application layer of a Web system. Presently, PHP (Personal Home Page: a Hypertext Preprocessor), ASP (Active Server Pages) and JSP (Java Server Pages) are three widely-used Web application technologies for the Web system development (Robbins, 2006). PHP and ASP are both server-side scripting languages and quite popular for medium size dynamic websites. Compared to ASP and PHP, JSP is a server-side component-based programme providing more advantages including: platform independence, efficient processing, solid performance, reliable security and highly scalable (Mcgrath, 2002; Hall and Brown, 2004). In addition, as JSP can separate logic from other content, page maintenance becomes simple (refer to 7.3). Considering this modularity and scalability of JSP, JSP was selected as the Web technology to develop the KBS.

7.3 Outline of Java Server Pages

JSP, developed by Sun Mircosystems, is a technology based on the Java language and enables the server-side development of dynamic Web systems. JSP files usually contain HTML or XML markup elements and a number of JSP elements, and have a .jsp file extension. JSP elements containing Java scriptlets (small sequences of Java code) are used to present the logic content of a Web page. Alternatively, the logic content can reside in a server-based resource, such as a JavaBean component, that can be accessed by a JSP tag to generate the dynamic content of a page (Mcgrath, 2002). The independence of the logic operation in the Web pages is convenient for the system maintenance.

The JSP pages have to be compiled by a JSP-enabled Web server and converted into executable code (Java Servlet) to process the logic operation and deliver the results to the browser. As illustrated in Figure 7.2, a JSP request made by a user who hits a Web page ending with .jsp comes into the Web server from a browser. The Web server recognizes the JSP file and transfers it to the Servlet Engine (Container). The JSP file is then converted into a .java servlet file, containing Java source code. Further, the servlet file is compiled into a .class file. The servlet class is instantiated and executed by the Container. If the JSP processing requires access to a database, the JDBC (refer to 7.4) is used to make the connection and handle the SQL (Structured Query Language) request. Eventually, the servlet output is sent back to the browser usually in the form of HTML. In the JSP processing, if the corresponding class file already exists, the Container automatically skips the previous steps and re-use the existing class file to save the operation time.

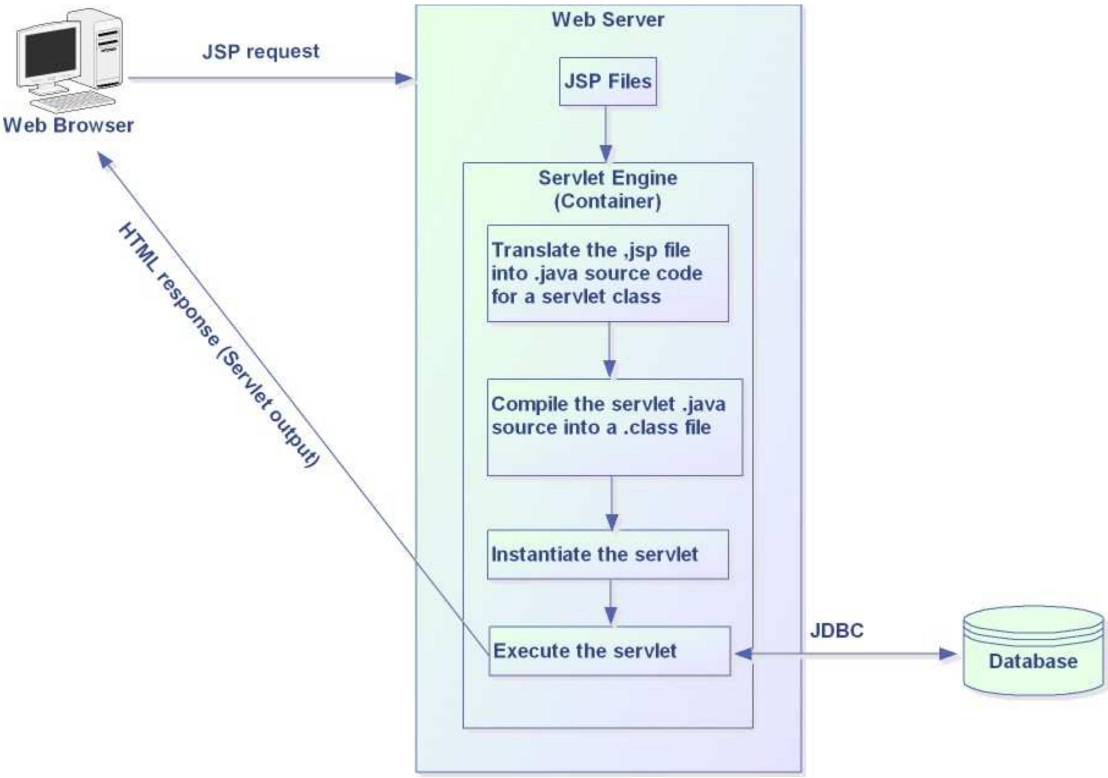


Figure 7.2 Architecture of Java Server Pages (adapted from Turner, 2002; Mathews et al., 2003; Basham et al., 2004)

7.4 Database Management System

According to the KBS decision-support model for H&S competence assessment, the case retrieval facility is important to facilitate reasonable decision-making. In order to collect the assessment case and record the decision-making evidence and steps, a database management system (DBMS) is required to store and manage the assessment data and cases. The DBMS is a software system that is used to control the organisation, storage, management and retrieval of data in a database (Beynon-Davies, 2004; Hoffer et al., 2008). A DBMS can accept requests from the application programme and return the result of operating the requests. A bridge, thereby, is needed to set up the connection between an application programme and a DBMS. The bridge connecting a DBMS with a Java application is known as JDBC (Java Database Connectivity) technology, which is an Application Programming Interface (API) providing access to a wide range of DBMSs from the Java programming language (Mcgrath, 2002). As illustrated in Figure 7.3, the JDBC can be divided into three functional parts. The JDBC API defines the Java interfaces and classes that can be used to connect with databases and send queries. The JDBC DriverManager is a class to define objects which can connect Java applications to a JDBC driver. The role of the JDBC DriverManager is to provide a means of managing the different types of JDBC Drivers. A JDBC Driver is provided by a DBMS vendor to perform the interface between Java application and the database. By working with the JDBC, a Java programme can manipulate a database, including (Matthew et al., 2003):

- establish a connection to a database;
- send SQL statements; and
- return the results.

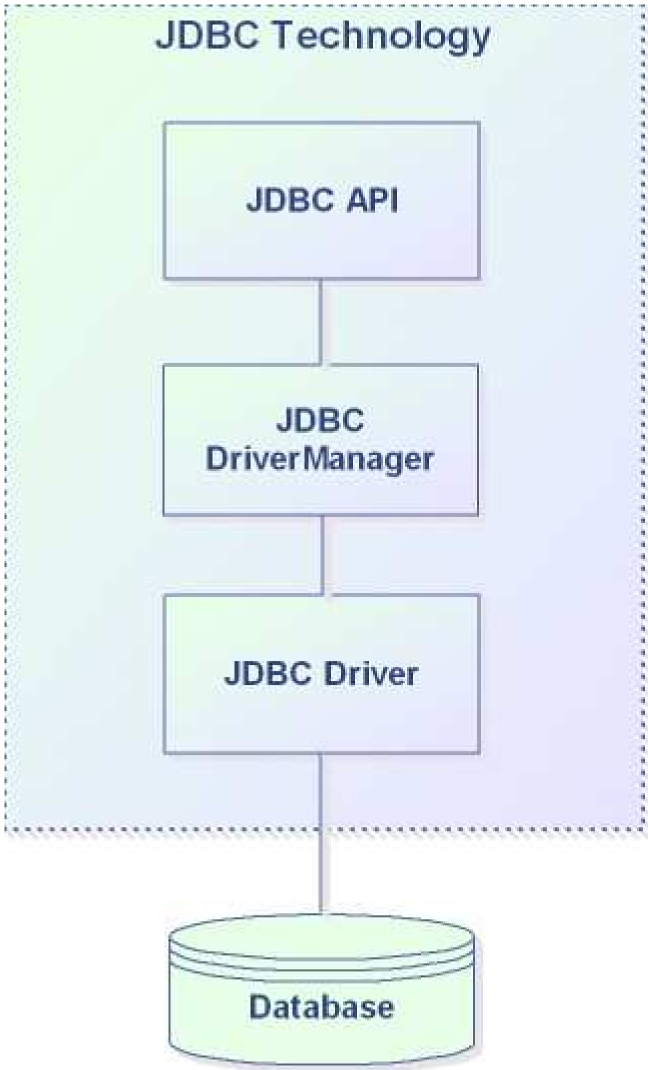


Figure 7.3 Architecture of JDBC

Presently, a large amount of DBMS are available to help different users share data and process resources. MySQL is the world's most popular open-source SQL database because of its consistent fast performance, high reliability and ease of use (Cheung et al., 2004). Considering MySQL provides fast data access, built-in database management tools and a very flexible storage and retrieval mechanism (Bell, 2007), MySQL was selected as the DBMS for the KBS development. In addition, MySQL is a relational DBMS applying tables to systematically manage different types of data.

The relational DBMS can efficiently represent data relationships by common values in related tables; such a feature enabling the effective data and information management which is important for the case inquiry facility of the KBS for H&S competence assessment. Simultaneously, the interoperability of relational database with SQL standard makes MySQL easily setup connection with JSP. MySQL is in widespread use on Web servers running JSP (Mcgrath, 2002). The official JDBC driver for MySQL is known as Connector/J, which is a pure Java-based driver supporting efficient performance with the database (Matthew et al., 2003).

7.4.1 E-R Diagram of the Database

As the database is the centre of a DBMS, it is important to establish a database supporting the KBS. A database is '*an organisd collection of logically related data*' (Hoffer et al., 2008). A well designed database structure can improve the efficiency of data manipulation and ensure the integrity and security of stored data. The core stage of database development is to elicit the initial set of data and process requirements from users (Beynon-Davies, 2004). Such a conceptual modeling process can be illustrated by using Entity-Relationship (E-R) Diagram which is a semantic data modeling tool applied to accomplish the goal of abstractly describing or portraying data (Bagui and Earp, 2003).

An E-R diagram is built up of entities, attributes and relationships between entities.

An entity was described by Chen (1976) as '*a thing which can be distinctly identified*'. Since the name of an entity represents a type or class of thing (Bagui and Earp, 2003), eight entities are identified in terms of their functionalities in the KBS. In addition, each entity includes some attributes describing properties or characteristics for the entity.

As illustrated in Figure 7.4, the eight entities include two users of the KBS (client and expert); four types of duty-holder (designers, CDM co-ordinator, principal contractor, and contractor); project and question. Between two entities, one verb word is used to describe their association. The client and expert entities contain the attributes of their personal information, part of which including username and password are unique and used to login to the KBS. The attributes included in the four types of duty-holders represent each candidate's personal information, the involved project, the provided evidence, qualitative rating and assessment comment of each core criteria, the competence status, and the total score of the qualitative evaluation. Each candidate duty-holder should have a set of assessment records for the project he/she has bid for. The assessment records could be used as the evidence of taking reasonable steps in the decision-making. The attributes of the project entity describe the general information of a project and the username of the involved client. Since the question entity should record the question related information, its attributes include the unique client information (username), the project information (name, type, and procurement type), the related duty-holder information (name and type), question information (related core criterion, provided evidence, type, contents and answer from expert). In addition, each entity contains an ID attribute that works as a primary key to keep the data separate. The ID attribute is also used to establish the relationship between relative tables to ensure the consistency and integrity of data record.

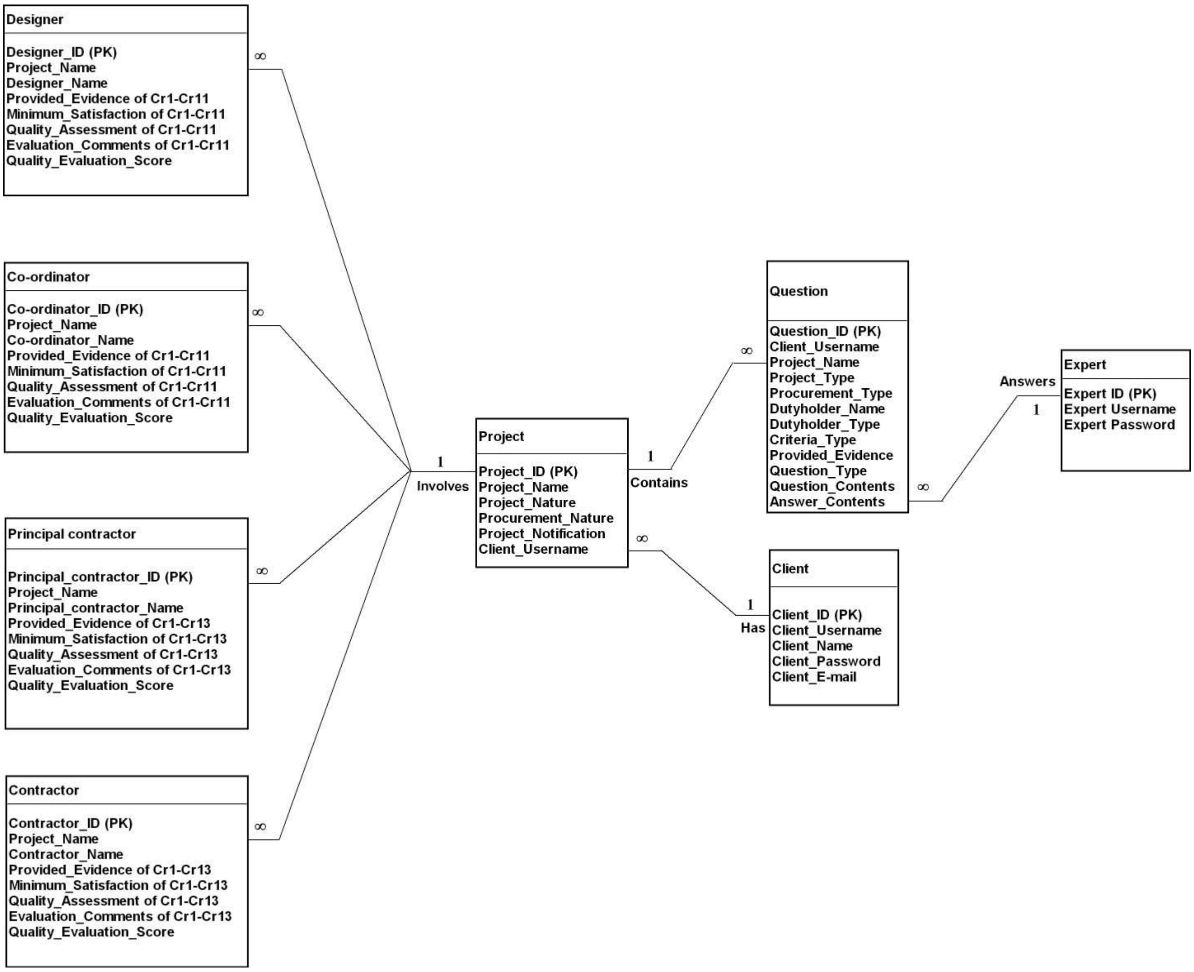


Figure 7.4 E-R Diagram of the KBS

7.5 Structure Analysis of the KBS

In the process of implementing the KBS, the UML (Unified Model Language) was applied as a tool to assist the KBS development. The UML is the software industry standard and a modeling language for visually expressing the models of software-intensive systems (Conallen, 2003). A graphic notation is applied in the UML to enable system builders to create blueprints that capture their visions in a standard, easy-to-understand way, and provide a mechanism to effectively share and communicate these designs with others (Schmuller, 2002). The UML contains 13 types of diagrams to express the different views of a system model. According to the KBS decision-support model for the H&S competence assessment, the online KBS is envisaged to facilitate the client to select appropriate duty-holders through three decision-support mechanisms. In order words, the three decision-support mechanisms are the functional requirements for the KBS.

7.5.1 The Use Case Model of the KBS

In UML, use cases are models for capturing the functional requirements of a system (Fowler, 2004). Thus, a use case model was developed to illustrate the functional structure of the KBS. As shown in Figure 7.3, clients and experts are two actors, making up the stakeholders in the KBS. The oval notation in the diagram indicates a use case (a system requirement from a user’s point of view) that the system can provide. The relationship between use cases is expressed by an arrow-headed dashed line. The <<extend>> notation indicates a type of dependency relationship between two use cases. In the Figure 7.5, the uses case Process Assessment extends the use case Process Expert Enquiry and Process Case Enquiry. This means that clients assessing duty-holders' H&S competence might decide to extend dialogue with the KBS to include the activities described in the Process Expert Enquiry and Process Case Enquiry use cases.

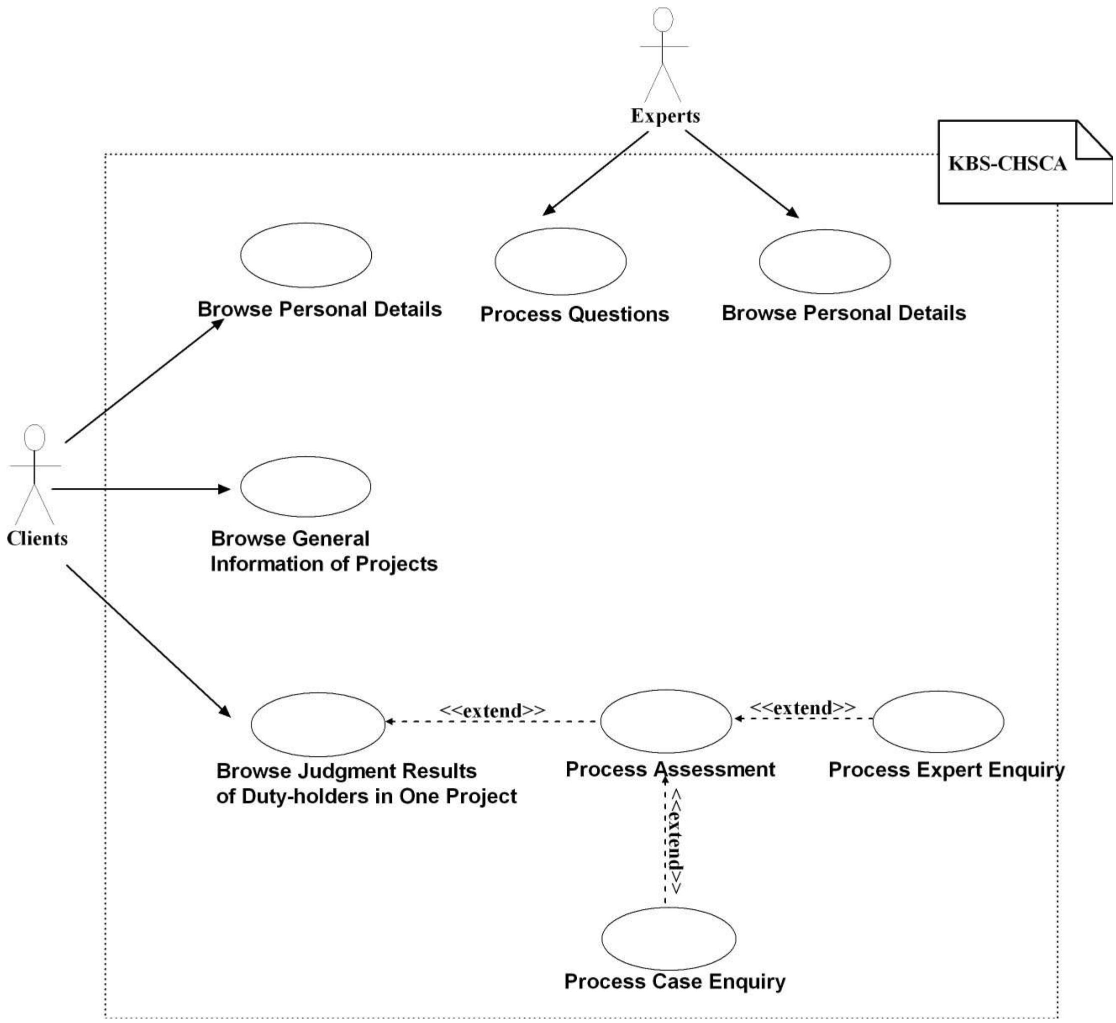


Figure 7.5 Use Case Diagram for the KBS

7.5.2 Activity Diagrams of the KBS

Although the use case diagram shows major activities of the business workflow and the structural relationships between use cases, it does not show workflow which specifies the basic operational flows included in a use case (Conallen, 2003). It is, therefore, necessary to develop activity diagrams to clearly identify the concrete activities and logical workflows for the realisation of use cases. Since the Browse Personal Details use case is straightforward, including activities of viewing and modifying clients' or experts' username, password and E-mail address, the activity diagram is used to specify the following significant use cases:

- Browse General Information of Projects (refer to Figure 7.6);
- Browse Judgment Results of Duty-holders in one project (refer to Figure 7.7);
- Process Assessment (refer to Figure 7.8);
- Process Expert Enquiry (refer to Figure 7.9);
- Process Case Enquiry (refer to Figure 7.10); and
- Process Questions (refer to Figure 7.11).

As illustrated in Figure 7.6, the Browse General Information of Projects use case is decomposed into several optional activities enabling clients to view, modify and input projects. Furthermore, the KBS can identify the involved duty-holders and provide relevant explanations according to the project's notification status and CDM Regulations 2007. In addition, the KBS can guide new users into the Process Assessment use case.

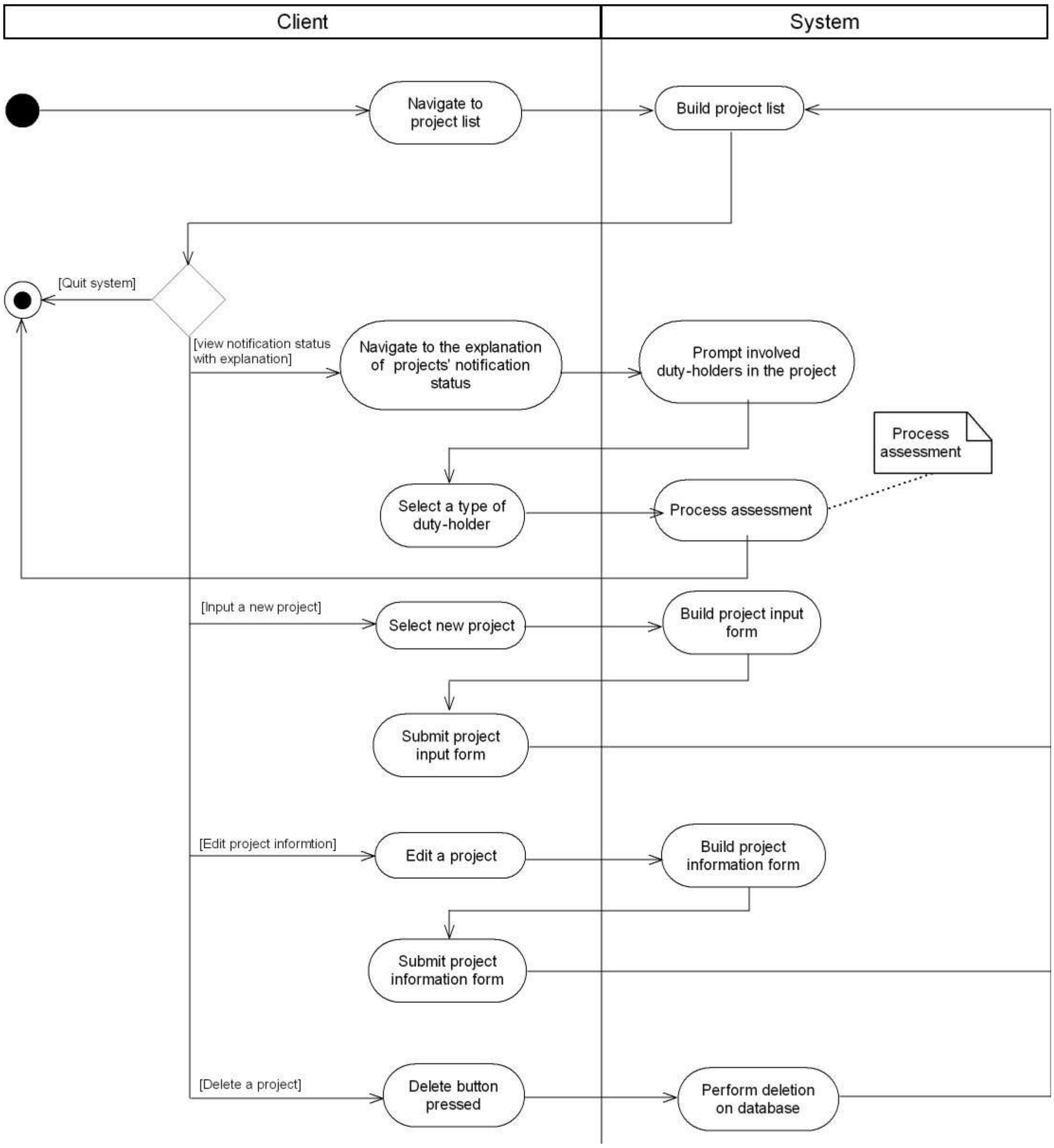


Figure 7.6 Activity Diagram of the Browse General Information of Project Use Case

Figure 7.7 demonstrates the activities and their relationships included in the use case Browse Judgment Results of Duty-holders in One Project. Clients can view the judgment results of all candidate duty-holders in terms of the type of duty-holder. Simultaneously, the KBS enables clients to view and modify the assessment process, add and assess a new candidate, delete a candidate, and print out the judgment result and assessment process.

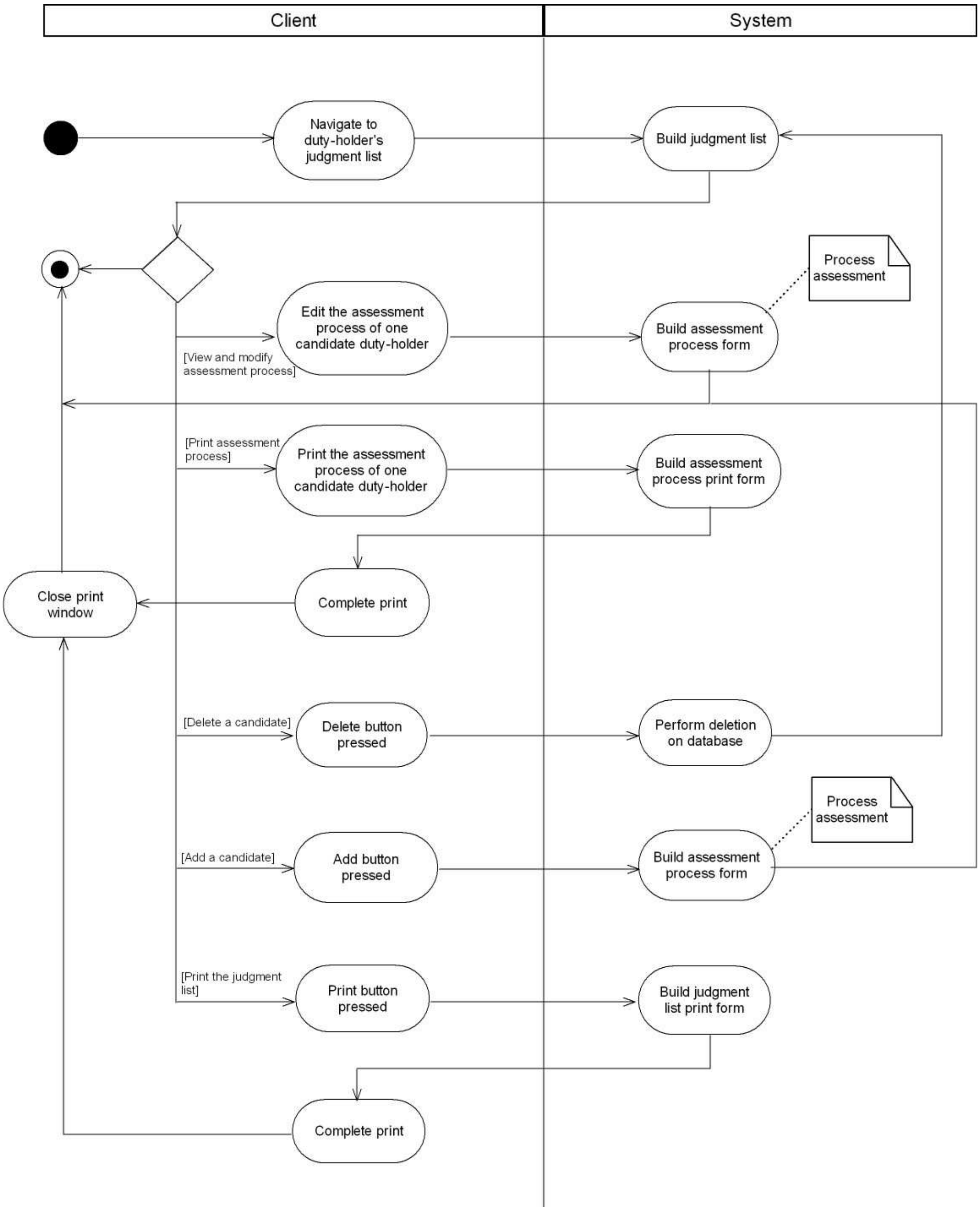


Figure 7.7 Activity Diagram of the Browse Judgment Results of Duty-holders in One Project Use Case

The Assessment Process is the main function of the KBS, enabling clients to apply three decision-support tools to assess the candidate duty-holder's H&S competence. As shown in Figure 7.8, the client can access to knowledge-support pages (textual knowledge base), the case enquiry page and the expert enquiry page while evaluating the candidate duty-holder's H&S competence against the 'Core Criteria'. The knowledge-support pages consist of the minimum satisfaction standards and measurement indicators of all 'Core Criteria'. After submitting the assessment form, the client can continue assessing another candidate duty-holder or see the judgment results automatically reporting by the KBS.

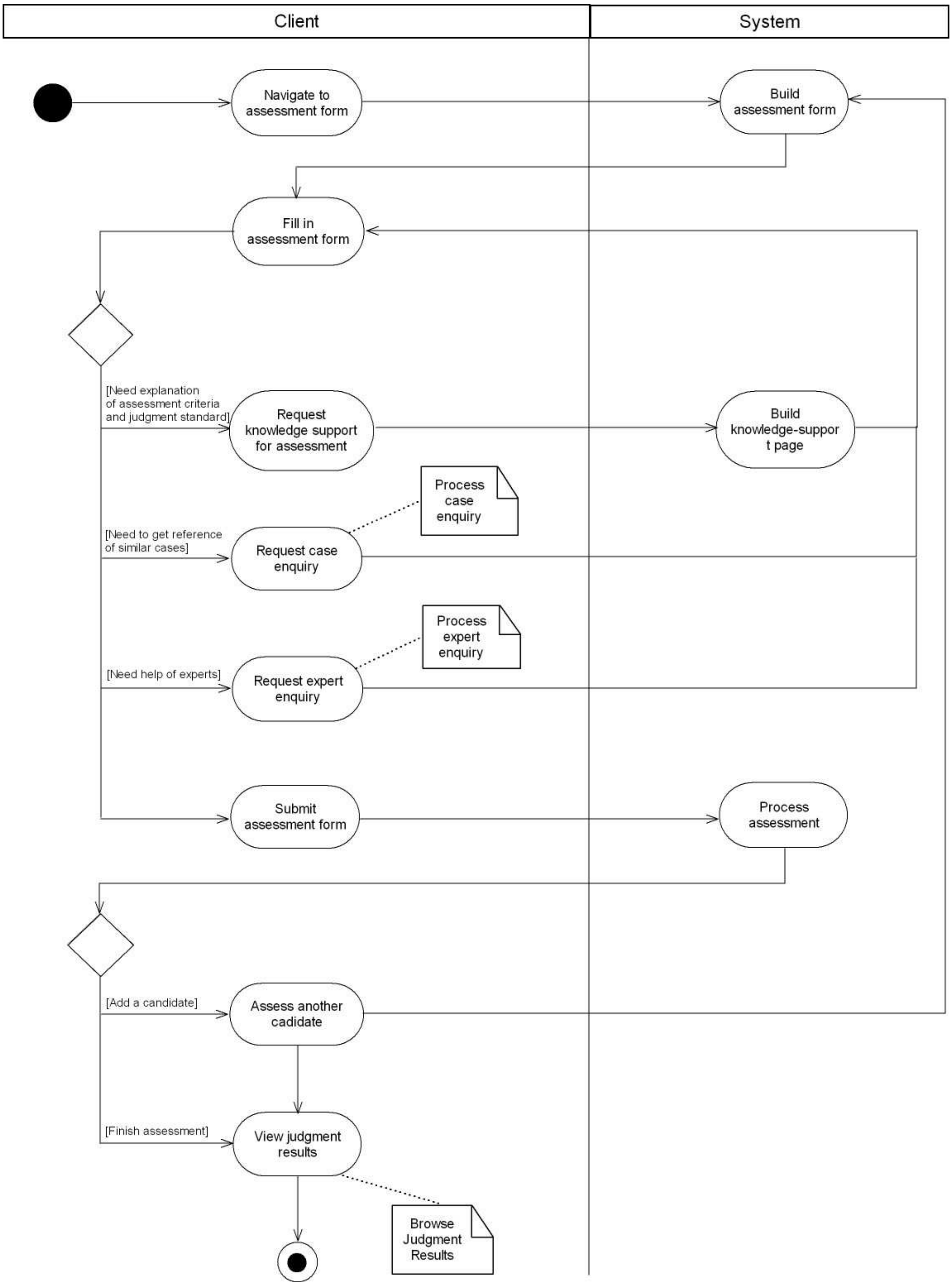


Figure 7.8 Activity Diagram of the Process Assessment Use Case

The KBS enables the client to search former cases as reference for current assessment. As illustrated in Figure 7.9, two steps are included in the case enquiry process. The first step enables the client to search projects conforming to the search criteria. Subsequently, the client can browse the assessment details of similar projects.

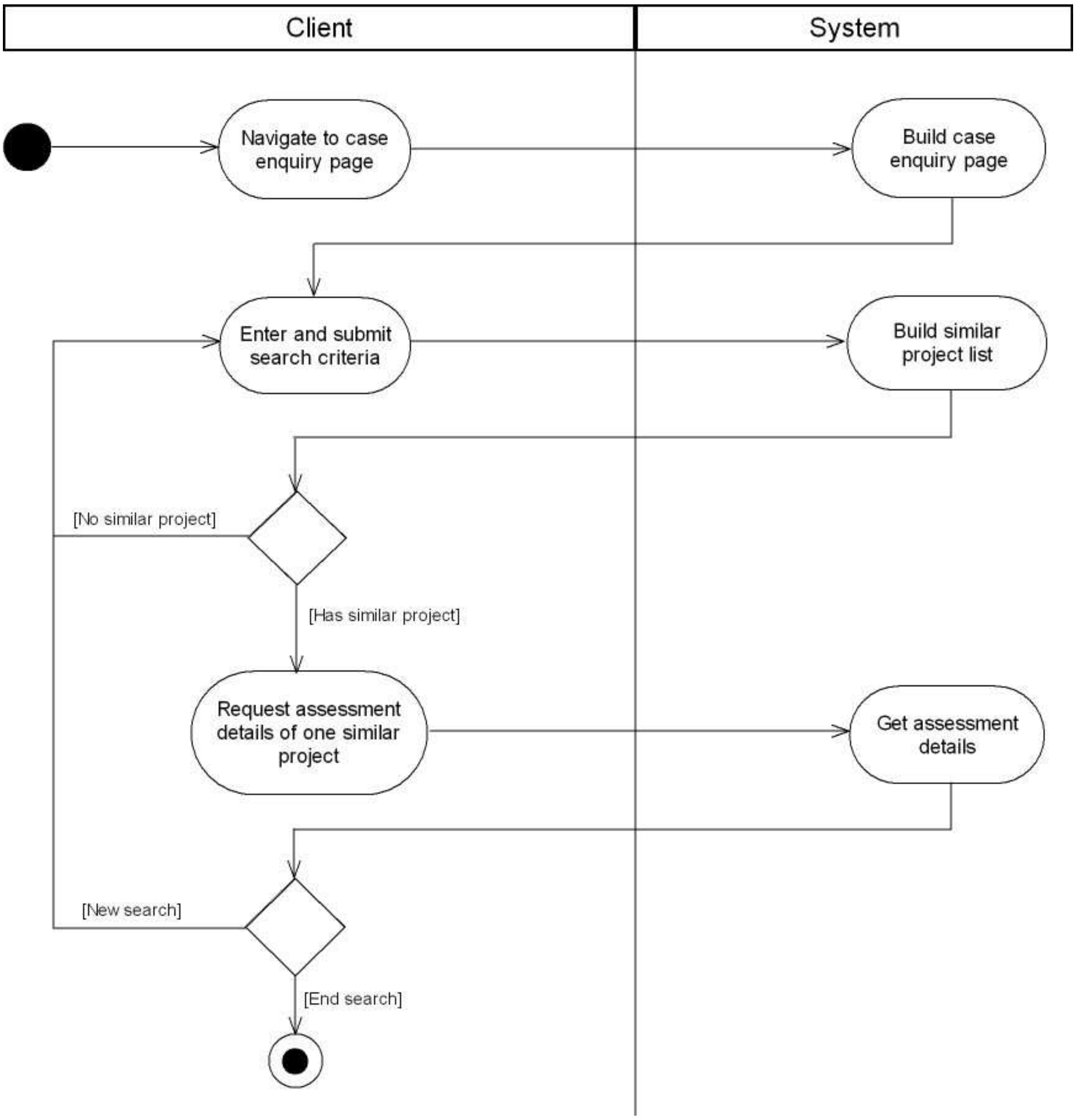


Figure 7.9 Activity Diagram of the Case Enquiry Use Case

As shown in Figure 7.10, the Expert Enquiry use case is simple and straightforward. The KBS sends the question to the expert interface after the client submits the question form.

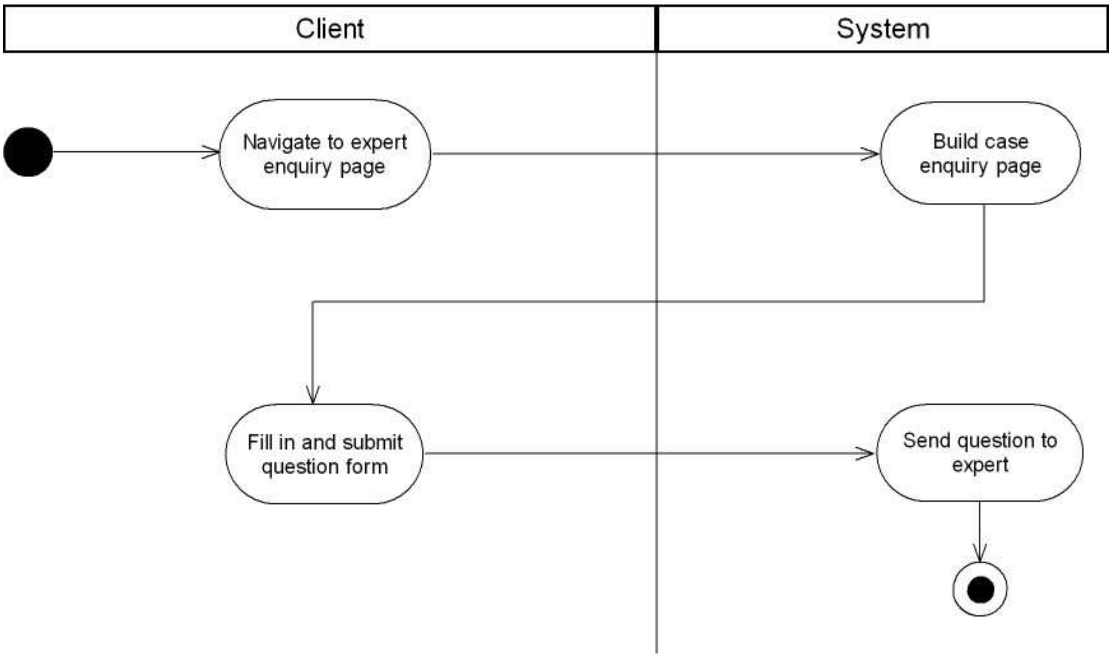


Figure 7.10 Activity Diagram of the Expert Enquiry Use Case

Figure 7.11 demonstrates the activities to process questions in the expert interface of the KBS. The expert can view all questions submitted by clients in the unsorted question list. After the expert answers a question, the KBS can forward the answer to the client. Simultaneously, the answered question appears in the sorted question list.

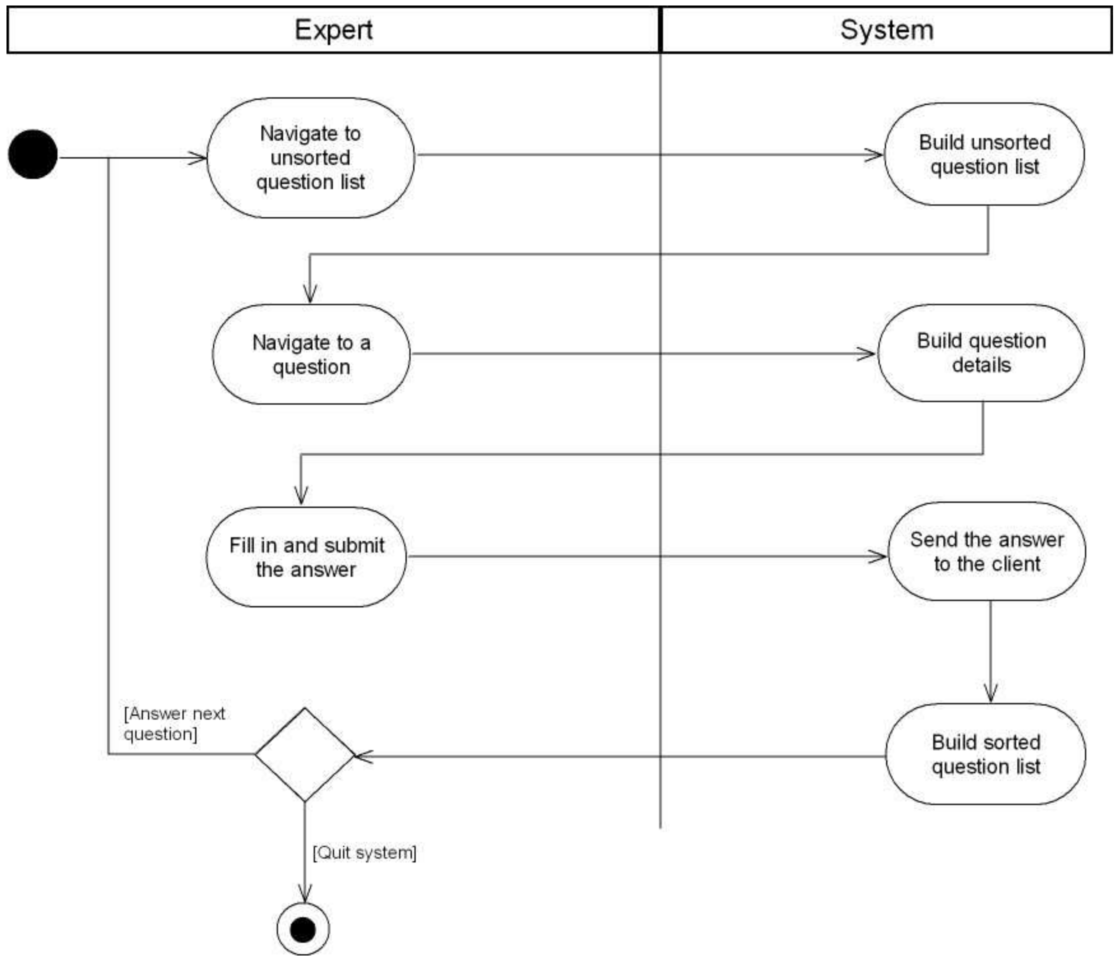


Figure 7.11 Activity Diagram of the Process Questions Use Case

The above use case and activity diagrams facilitate systematical analysis of the structure of the KBS by identifying the main functional requirements and specifying the interactions between actors and systems. The activities and workflows described in the activity diagrams provide a blueprint for the further system development.

7.6 Development of KBS

As introduced in 7.2, the key of deploying JSP Web applications is the selection of the Java servlet engine (container) that enables the Web server to run JSP programmes in response to user requests and return dynamic results to the user's browser. Apache Tomcat is a popular and effective Java servlet container and Web server providing both Java servlet and JSP technologies (Brittain and Darwin, 2003). The development of a JSP Web application can be realised on a standalone computer with JSE (Java Platform Standard Edition, which is a widely used platform for programming in the Java language) or JEE (Java Platform Enterprise Edition, which is a widely used platform for server programming in the Java language) and Tomcat server (Brittain and Darwin, 2003; Sun Microsystems, 2008a; The Appache Software Foundation, 2008). However, the standalone development machine was not permanently connected to the Internet, thus a commercial JSP Web server was employed to host the on-line KBS. The JSP Web server provides a real-time development environment facilitating efficient prototyping and debugging, and an online MySQL database system supporting the database management and database connection with JSP application via JDBC.

The KBS for construction H&S competence assessment was abbreviated as 'KBS-CHSCA' and developed under a domain name of 'www.constructionkbs.co.uk'. According to the functionalities illustrated by the activity diagrams for the KBS, a breakdown of the KBS architecture is developed and demonstrated in Figure 7.12. The breakdown diagram was modeled using the Web Application Extension (WAE) to UML, which can accurately express the entirety of the system in a model and maintain its traceability and integrity (Conallen, 2003).

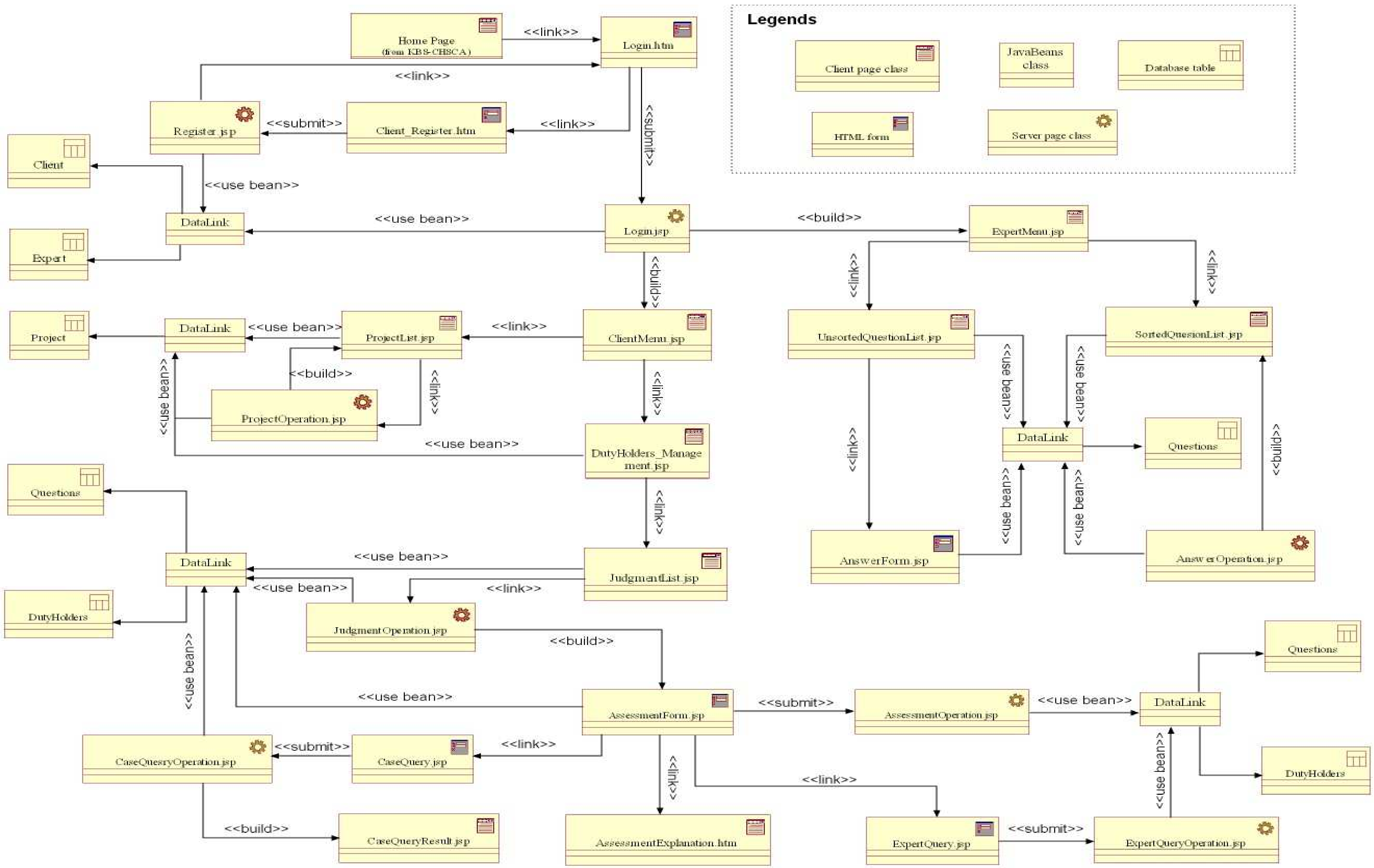


Figure 7.12 Structure of KBS-CHSCA

In the design of the KBS, most of the logic and functional operations are developed in the server pages executed by the server that interacts with server-side resources, such as a database. However, other pages including client pages and HTML forms also contain JSP elements in order to effectively interact with the database and execute logic operations. Further, in order to improve the security of information stored in the database and simplify code maintenance and development, a JavaBean class is developed, which compiles all database connection information including the username and password of a database and syntax into a Java class. A JavaBean is a Java class that can be developed and assembled easily to create sophisticated applications based on JavaBean specifications (Sun Microsystems, 2008b). The Web pages can utilise the JavaBeans with a useBean action element to execute relevant data exchange with the database.

The home page of the KBS shown in Figure 7.13, presents a brief introduction of the system. The start button prompts the user to the system login page.

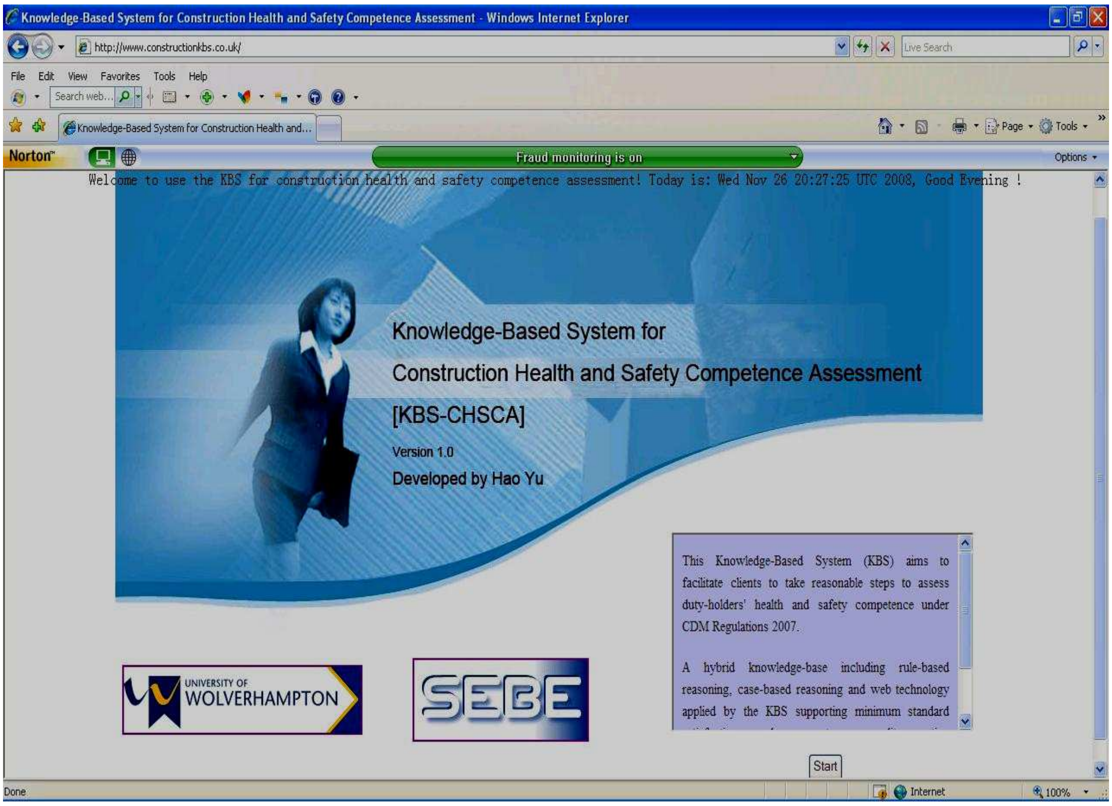


Figure 7.13 A snapshot of home page

In the login page (refer to Figure 7.14), a drop-down list offers the user the alternatives of user type. After inputting user name and password, the user is directed to the main interface of the system dependent on the selected user type. For the new client, the register button directs the user to the registration page in which the user is required to input personal information including company name, user name, password and E-mail address.

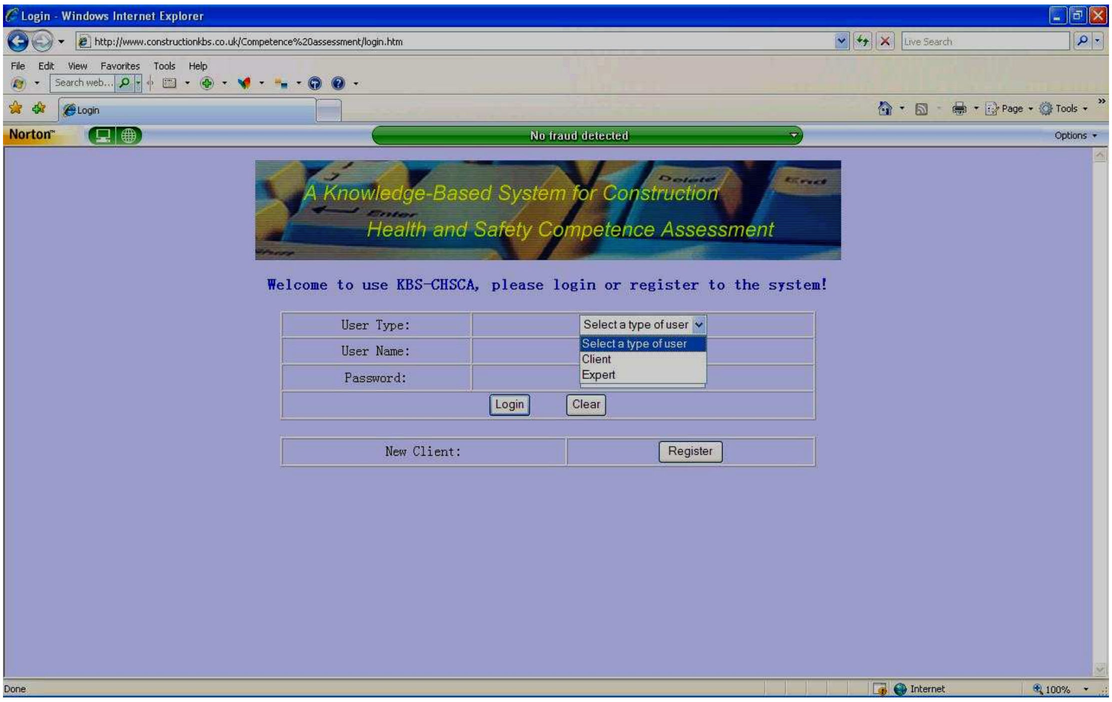


Figure 7.14 A snapshot of the login page

The main interface of the KBS is designed as a link-driven Web page (refer to Figure 7.15). The control panel on the left-hand side of the Web page enables the user to select the management task shown in the main window. In order to design a user friendly interface, the borderlines between different windows in the interface can be easily changed by moving the cursor so that the main window can be extend to the full screen if the user wants to have a full view of the management task.

As shown in Figure 7.15, the project management option in the control panel enables the client to view and manage an existing project. The general information of the project including project name, project type, procurement type, and notification status is listed. The client can edit, delete and add a project by click the corresponding buttons.

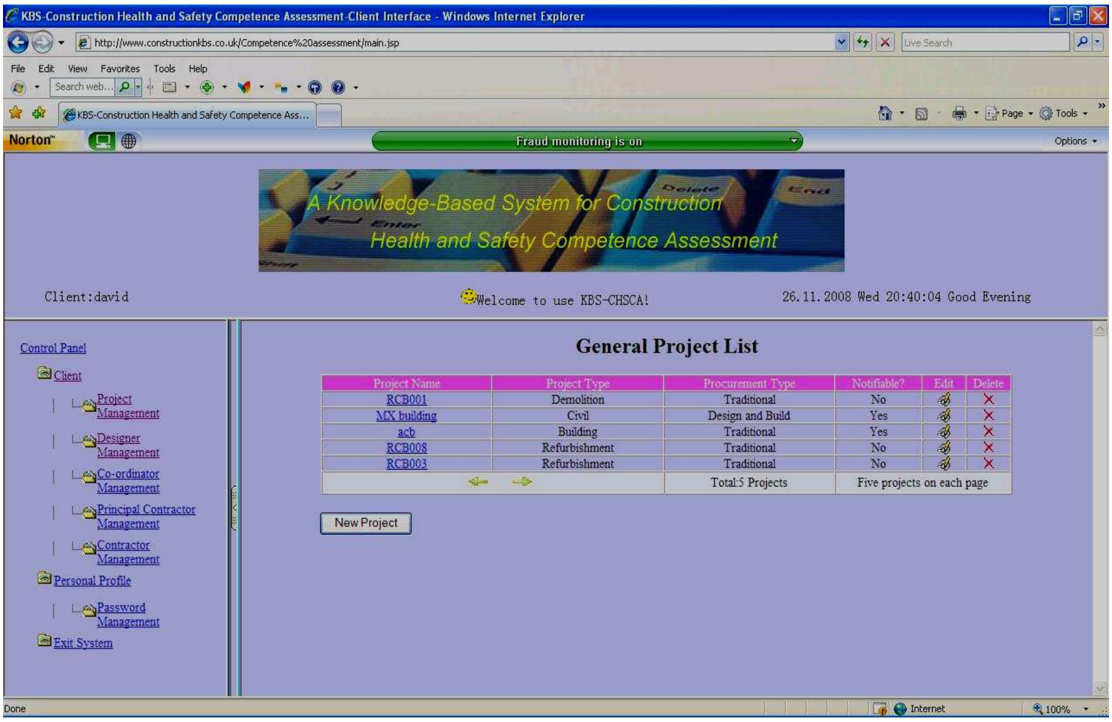


Figure 7.15 A snapshot of project management page

In addition, the system can notify the client of what kind of duty-holders should be appointed in the project in terms of the notification status of the project, after the client adds a project. For a notifiable project, the client should appoint a CDM co-ordinator, designer, principal contractor and contractor to plan, design, manage and monitor the construction work. However, for a non-notifiable project, the client just needs to appoint designer and contractor to undertake the work. Figure 7.16 presents a snapshot of the explanation of selecting the type of duty-holders for a notifiable project.

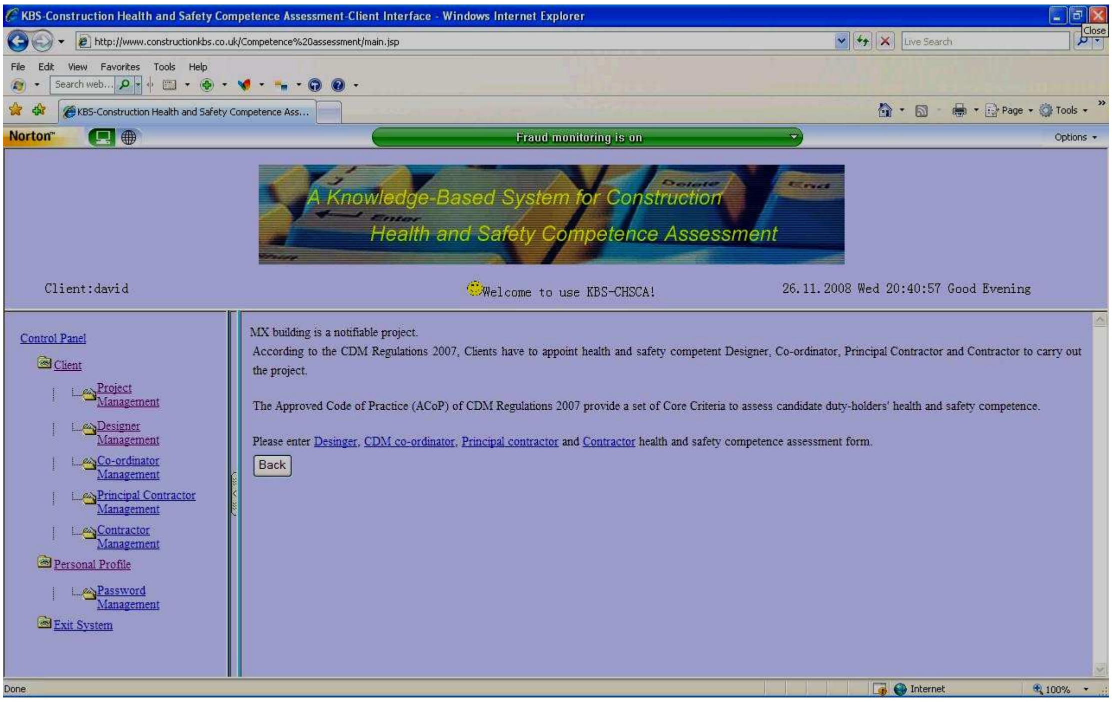


Figure 7.16 A snapshot of the explanation of selecting the type of duty-holders for a notifiable project.

7.6.1 Assessment process

The assessment process is the key part of the KBS, in which two decision-support mechanisms including the minimum satisfaction checking and the qualitative evaluation in the KBS decision-support model (refer to Chapter 5) are implemented. In addition, the textual knowledge base, case enquiry and expert enquiry facilitates can be used in the assessment process to help the client make reasonable decisions. As presented in Figure 7.17, the KBS applies different HTML Form Input techniques enabling the client to complete the minimum satisfaction checking and qualitative evaluation of each assessment criterion. The evidence provided by the candidate duty-holders for each assessment criterion and comments in the assessment process can be recorded by the KBS as evidence of reasonable decision-making.

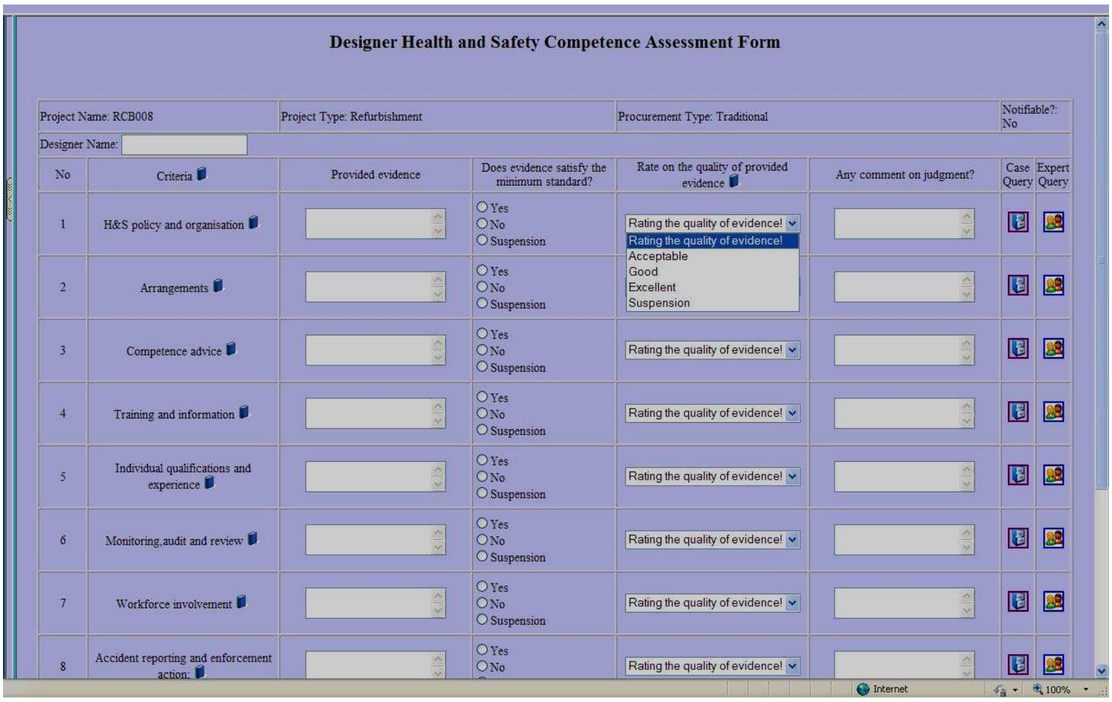


Figure 7.17 A snapshot of the assessment form

Simultaneously, the hyperlinks shown as ‘book’ images in the assessment form direct the client to the pages providing knowledge support with regards to assessment criteria including minimum satisfaction standards and qualitative rating standards. Figure 7.18 presents a snapshot of the knowledge support page.

Figure 7.18 A snapshot of the knowledge support page

7.6.2 Case Enquiry and Expert Enquiry Facilities

In the assessment form, the client can also use the case query and client query hyperlinks to search former similar assessment cases and put forward assessment questions to experts. As presented in Figure 7.19, the case enquiry facility of the KBS selects the project type, procurement type, notification status and assessment criterion title as the index features to retrieve the relative former assessment cases as reference for the current assessment. In order to improve the efficiency of case retrieval, two retrieval processes were developed. The first retrieval process uses the project-related indexing features including project type, procurement type and notification status to conduct a fast search in the database. The projects containing the same indexing features are listed with the number of candidate duty-holders in the assessment. If the client wants to view the assessment process regarding the assessment criterion in one project, the KBS then uses the selected assessment criterion title as the indexing feature to retrieve the relative assessment evidence and results of those candidate duty-holders for that assessment criterion.

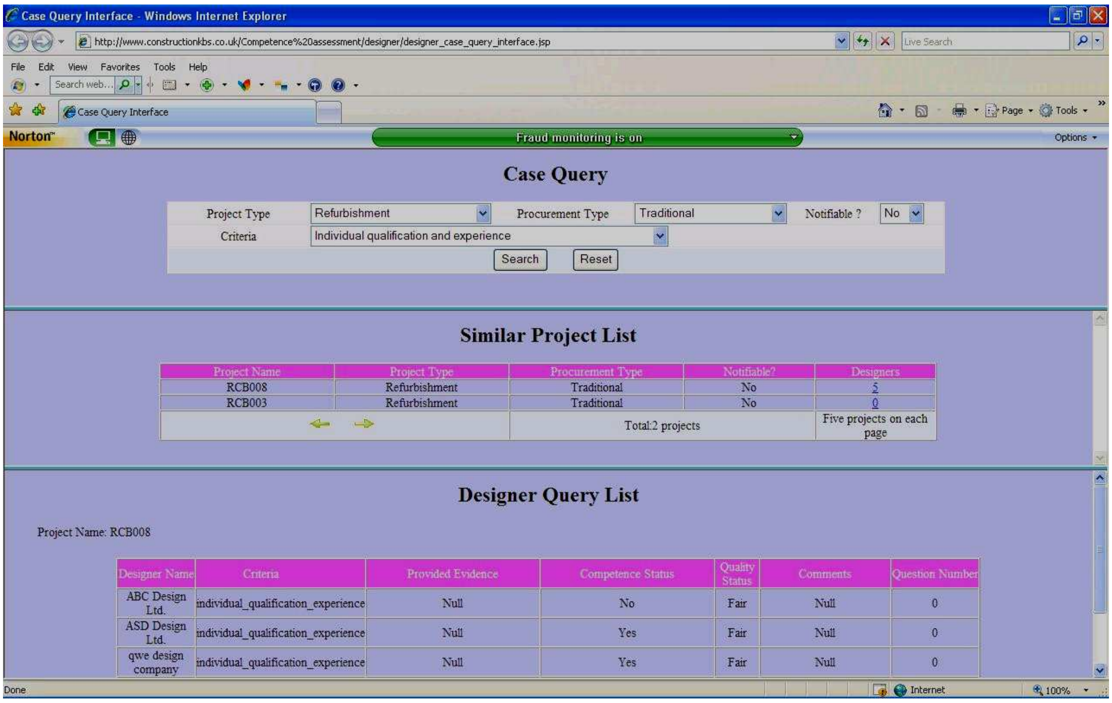


Figure 7.19 A snapshot of case enquiry page

Since KBS-CHSCA is envisaged to be managed by some umbrella organisations, it should enable in-house experts from those organisations to provide timely knowledge support to their members. In the assessment form, the KBS provides the client with a question form which can be forwarded to the expert interface after completion. Figure 7.20 presents a snapshot of expert enquiry page.

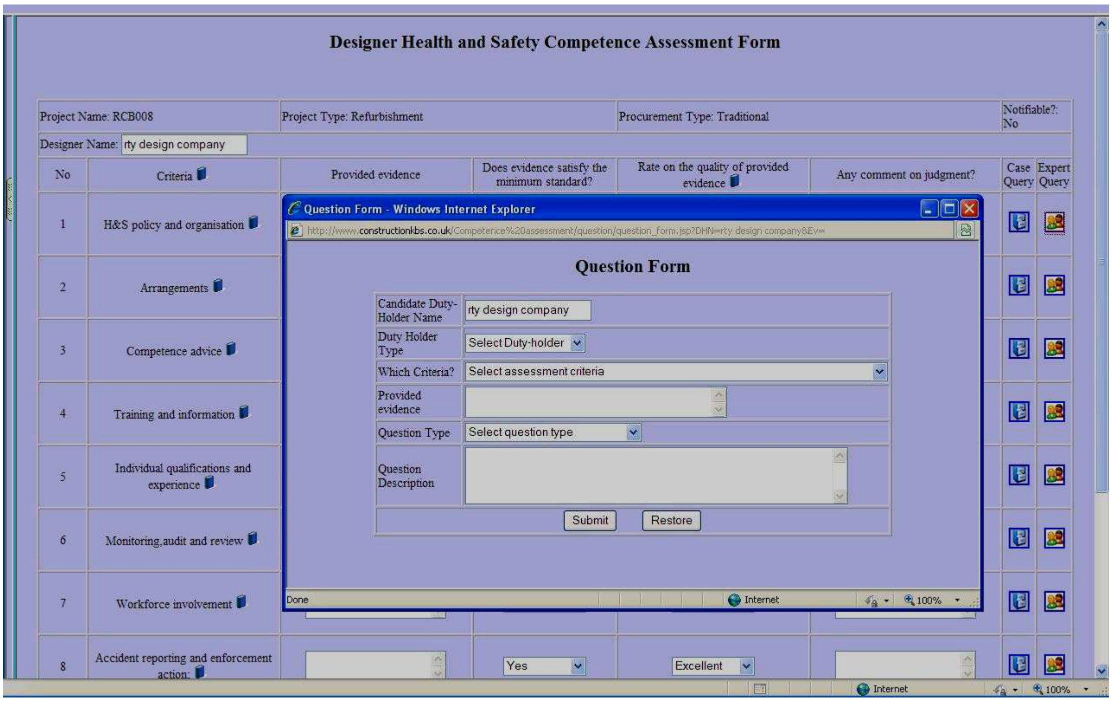


Figure 7.20 A snapshot of expert enquiry facility

In order to enable the effective and efficient communication and knowledge exchange between the expert and client, the KBS-CHSCA also provides the expert with an interface to view and answer the questions from the client. As presented in Figure 7.21, the layout of the expert interface is similar to the client interface. The answers provided by the experts are immediately fed back to the client who can use that as an important reference in the assessment process.

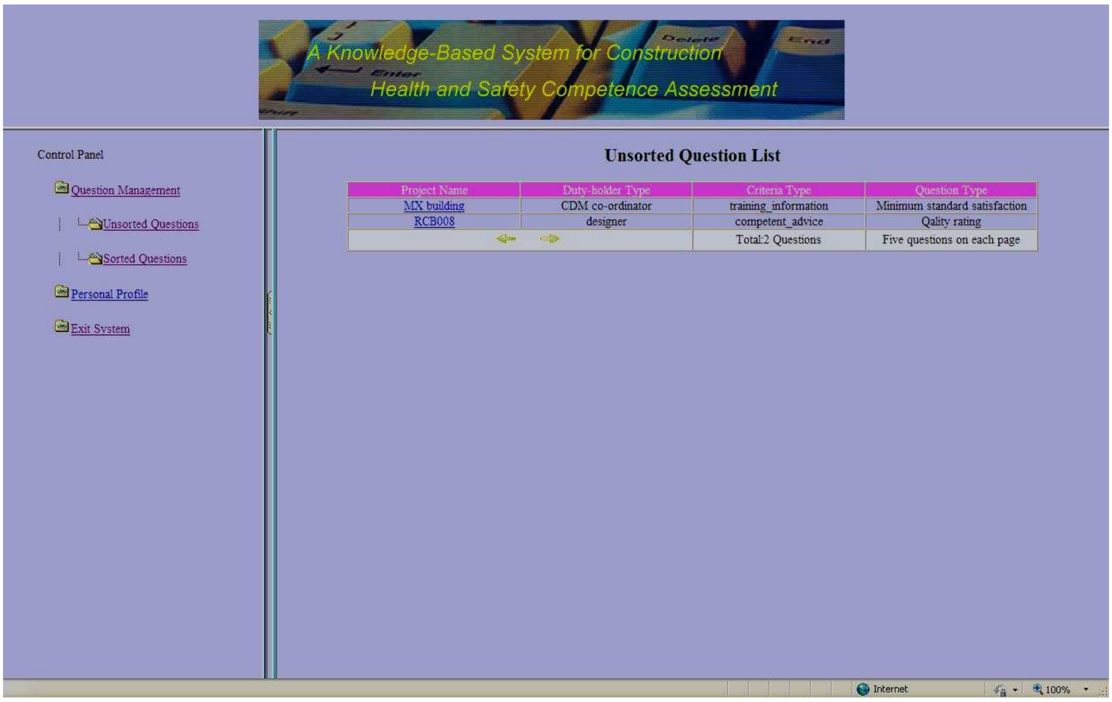
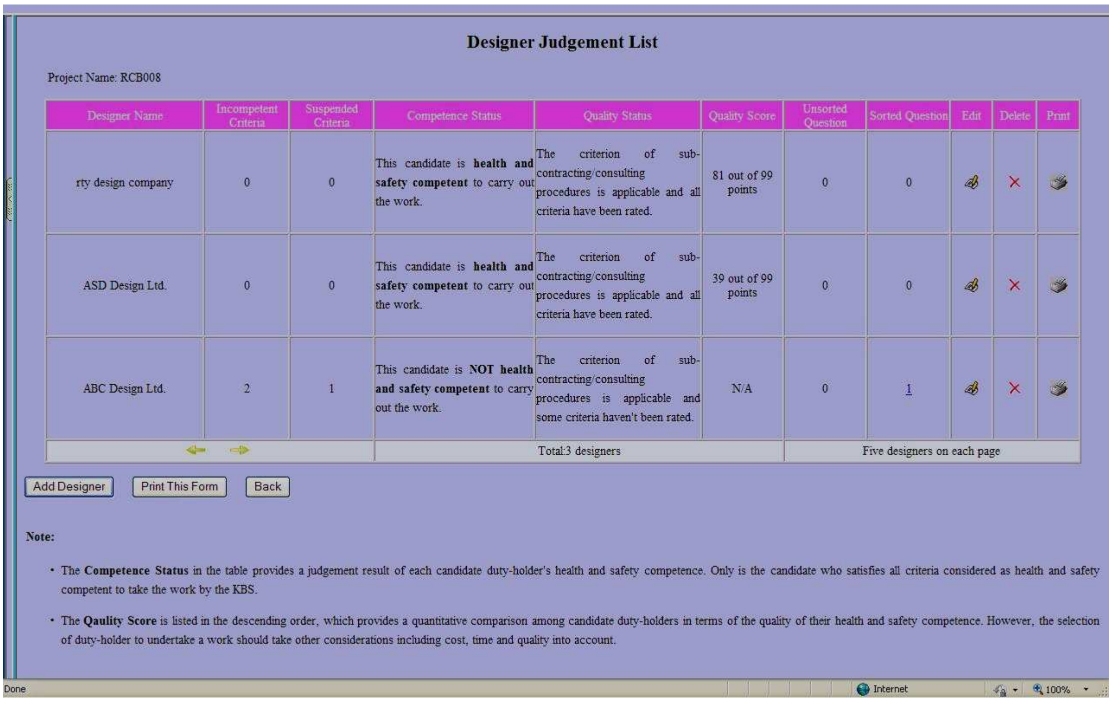


Figure 7.21 A snapshot of the expert interface

7.6.3 Assessment Result

The KBS can automatically and promptly provide the client with the assessment result after the client finishes assessing one type of duty-holder. In the result list, the system can tell the client the competence status of each candidate by providing the number of incompetent criteria. In addition, the candidate duty-holders are listed in descending order of their qualitative assessment scores which are the sums of their qualitative ratings of assessment criteria. The qualitative assessment score reveals the level of H&S management and performance for each of the candidate duty-holders and provides the client with a reasonable step to select the most suitable duty-holder. The score will not appear if a candidate is not health and safety competent or suspended in the minimum satisfaction checking. Further, the result list can display other assessment statuses including whether there is any criterion that has not been evaluated in the minimum satisfaction checking or qualitative assessment, the number of questions that have been forwarded to the experts and the number of questions that have been answered. Those assessment statuses provide a comprehensive summary of the assessment process to the client, which can be used as concrete evidence of reasonable decision-making to satisfy the requirement of CDM Regulations 2007.

In the result list, the client can be directed to the page containing the answers of questions forwarded to the experts. In addition, the KBS also enable the client to add and delete candidates, modify the assessment form and print the assessment form and result list. Figure 7.22 presents a snapshot of the judgment result list.



Designer Judgement List

Project Name: RCB008

Designer Name	Incompetent Criteria	Suspended Criteria	Competence Status	Quality Status	Quality Score	Unsorted Question	Sorted Question	Edit	Delete	Print
rty design company	0	0	This candidate is **health and safety competent** to carry out the work.	The criterion of sub-contracting/consulting procedures is applicable and all criteria have been rated.	81 out of 99 points	0	0			
ASD Design Ltd.	0	0	This candidate is **health and safety competent** to carry out the work.	The criterion of sub-contracting/consulting procedures is applicable and all criteria have been rated.	39 out of 99 points	0	0			
ABC Design Ltd.	2	1	This candidate is **NOT health and safety competent** to carry out the work.	The criterion of sub-contracting/consulting procedures is applicable and some criteria haven't been rated.	N/A	0	1			
			Total:3 designers			Five designers on each page				

Add Designer | Print This Form | Back

Note:

- The **Competence Status** in the table provides a judgement result of each candidate duty-holder's health and safety competence. Only is the candidate who satisfies all criteria considered as health and safety competent to take the work by the KBS.
- The **Qaulity Score** is listed in the descending order, which provides a quantitative comparison among candidate duty-holders in terms of the quality of their health and safety competence. However, the selection of duty-holder to undertake a work should take other considerations including cost, time and quality into account.

Done | Internet | 100%

Figure 7.22 A snapshot of a judgment result list

KBS-CHSCA can be accessed on http://www.constructionkbs.co.uk. Internet Explorer is recommended as the browser of the website. Users can register as a new client or login the system by using

- 'david' as username and
- '123456' as the password

to enter the client interface. Users can also use

- 'expert' as username and
- '123456' as the password

to enter the expert interface.

7.7 Summary

The process of developing an online KBS for construction H&S competence assessment under CDM Regulations 2007 has been presented in detail. The KBS decision-support model for construction H&S competence assessment has been realised on the database driven Web system, enabling the client to take reasonable steps in the selection of H&S competent duty-holders before the commencement of a project.

The KBS, named as KBS-CHSCA, was developed using Java Server Pages (JSP) technologies and a MySQL system. JSP is a popular and powerful Web application technology, providing significant advantages over other methods, including platform independence, efficient processing, solid performance, reliable security and highly scalable. In addition, the JSP technology is suitable for the further commercial development of the KBS-CHSCA. MySQL is an open source DBMS enabling the stable interaction with JSP through a JDBC-driver named as Connector/J. In order to deploy KBS-CHSCA in the Internet environment, a JSP server with a Web MySQL system was hired for the system development.

Prior to implementing KBS-CHSCA, Unified Model Language (UML) was applied to model the functional requirements of the KBS via Use Case Model and specify the details of interactions between the user and the KBS via Activity Diagrams. In addition, an Entity-Relationship (E-R) diagram was developed to illustrate the structure of the database in the KBS. Further, the Web Application Extension (WAE) to UML was used to demonstrate the breakdown structure of KBS-CHSCA.

In KBS-CHSCA, two link-driven interfaces were developed to facilitate the effective and efficient information communication and knowledge exchange between the client and the expert. The application of HTML and JSP technologies enables the client to easily conduct the assessment process, access case and expert enquiry facilities and view the judgment results. However, the usability and validity of KBS-CHSCA should be evaluated by the relevant practitioners from the industry. The method of conducting system evaluation and the evaluation result are discussed in details in the following Chapter.

Chapter 8 Evaluation of The KBS

8.1 Introduction

The previous chapter described the process of developing a KBS for construction H&S competence assessment (KBS-CHSCA). The KBS was designed to enable the client to take reasonable steps in the decision-making process of duty-holders' H&S competence assessment. Based on the proposed decision-support model, the KBS applied Java Server Pages (JSP) and MySQL to realise decision-support functions in a Web-based environment. The textual knowledge base, case enquiry facility and expert enquiry facility facilitated the client to select the H&S competent duty-holders in compliance with the CDM Regulations 2007. In order to evaluate the usefulness of the KBS, this chapter presents the evaluation strategy and process adopted to test the validity, reliability and usability of the KBS.

Section 8.2 describes the strategy of implementing the evaluation process, discussing the verification criteria and process of evaluating the internal properties of the KBS and illustrating the validation framework of evaluating the usability and user satisfaction of the KBS. Based on the validation framework, a questionnaire was designed to enable the experts/practitioners in the industry to evaluate the KBS.

Section 8.3 introduces the process of the evaluation questionnaire survey and analyses the survey results, highlighting the opinions of the construction professionals and including potential further improvements.

8.2 System Evaluation Strategy

After a computer based system is developed, it is necessary to test the effectiveness of the system. Evaluation is an assessment process of determining the overall value of a software system (Borenstein, 1998; Heesom, 2004).The focus of evaluation is to ensure system reliability and user satisfaction. In the context of Decision-Support System and KBS, system evaluation comprises Verification and Validation (V&V) to assess system's quality (Boeham, 1984; Meseguer and Preece, 1996; Borenstein, 1998; Tsai et al., 1999). Verification is classified as a 'white-box' process that focuses on the intrinsic properties of the system, testing the completeness and accuracy of the system in compliance with the user specifications while validation is classified as a 'black-box' process that focuses on the system performance in the realistic environment, testing the adequacy and usability of the system in compliance with user satisfaction (Awad, 1996; Ng and Smith, 1998).

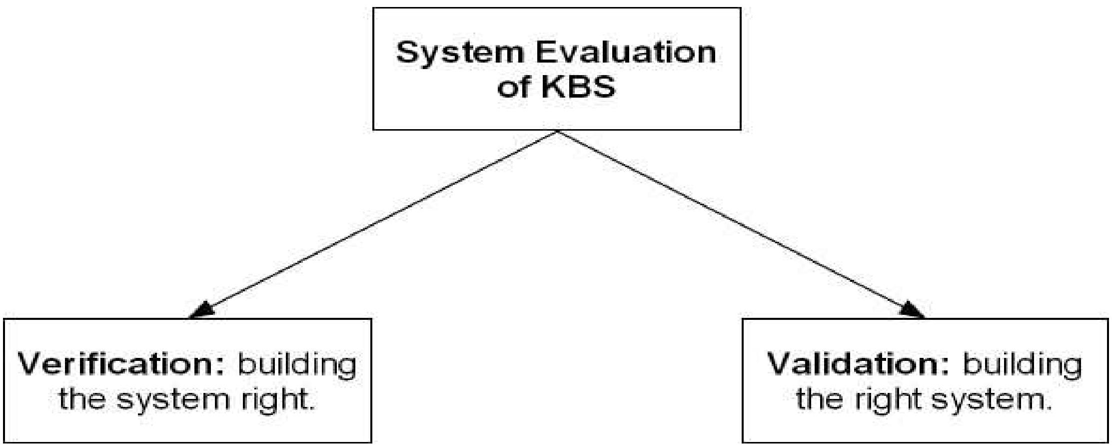


Figure 8.1 System evaluation of KBS (Adapted from Boehm, 1984)

Although evaluation is considered as a significant process in the life cycle of software system development, the implementation of AI systems evaluation is carried out on an ad hoc and informal basis (O'Keefe *et al.*, 1987; Ng and Smith, 1998). Therefore, the evaluation of KBS-CHSCA including system verification and validation focuses on determining whether the KBS is appropriate for modeling the reasonable decision-making process in construction H&S competence assessment domain.

8.2.1 Verification Process

Due to the intrinsic nature of verification, the verification process focuses on the syntactic or mechanical aspects of the KBS, catching and resolving common error in rule redundancy or syntax. Awad (1996) classified the verification criteria into three groups:

- **Verification of structural anomalies: circulate rules and redundancy**

1. Circulate rules: A circulate rule can result in the contradiction in meaning or logic. Since all production rules in the KBS-CHSCA were developed by JSP, any syntax or logic error can be detected by the JSP Container in the development process. Additionally, the attention had been given in the system development and internal testing to make sure the logic consistency among the linked production rules.

2. Redundancy: The redundancy rules refer to the duplication of knowledge in the rule-based system. Since the knowledge base of KBS-CHSCA didn't apply production rules, the redundancy checking was not implemented in the verification process.

- **Verification of content: completeness, consistency and correctness**

1. Completeness: The verification of completeness focuses on evaluating whether the developed system can deal with all possible situations within the knowledge domain. In order to ensure the completeness of the decision-making support function in KBS-CHSCA, the textual knowledge base contained the assessment standards, evidence examples, qualitative measurement indicators and specifications of relative regulations, providing a comprehensive knowledge support. The case and expert enquiry facilities also provided suitable and reasonable supports for the decision-making.

2. Consistency: The verification of consistency focuses on checking whether the system can produce unanimous answers to all input data with no contradiction and without errors and anomalies. In developing KBS-CHSCA, the internal test was carried out by feeding different data into the system to check the consistency of the results. The generation of duty-holders' judgment result was the focus of the consistency testing in order to ensure the consistency between the judgment results and input data in the assessment process.

3. Correctness: The verification of correctness focuses on measuring the accuracy of the system performance by comparing the number of correct answers against known answers. The correctness testing of KBS-CHSCA was carried out by comparing the judgment results produced by the system and the manually computed results after different combinations of data were input into the assessment process.

- **Verification of knowledge base and system functionality: confidence and reliability.**

1. Confidence: The verification of confidence focuses on checking the level of trust of system integrity and reliability. The robustness of the knowledge base and the technical reliability of the system are two main considerations in the confidence checking (Mounty, 2004). In the development of KBS-CHSCA, the textual knowledge-base was derived from the ACoP of CDM Regulations 2007, which was the official guidance from HSE. The technical reliability of development programmes, JSP and MySQL had been verified by a number of users through literatures (Mcgrath, 2002; Turner, 2002; Matthews et al., 2002; Sutrisna, 2004).

2. Reliability: The verification of reliability focuses on testing how well the system can perform its functions consistently, accurately and integrally. In the development of KBS-CHSCA, different combinations of data were input into the assessment process to compare the judgment results provided by the system and by the manual computation. Thus, the reliability of the KBS-CHSCA was ensured by iterating such a comparison process.

8.2.2 Validation Process

Following the verification of the internal properties of KBS-CHSCA, validation was carried out to evaluate the usability and user satisfaction of the KBS. The usability is derived from the older idea of user friendliness that is popularly used to describe whether or not a system is easy for the user to operate (Faulkner, 2000). The focus of user friendliness is on the system interface whilst the focus of usability is on the system performance for the task, i.e. effectiveness and efficiency. The user satisfaction attempts to test the user's reaction on the behaviour of the system against the user's specifications. Since the validation is a user-centered process, the measurement is usually qualitative and subjective (Awad, 1996). Interview (Poon, 2001; Satrisna, 2004), case study (Sutrisna, 2004) and questionnaire (Ng and Smith, 1998; Heesom, 2004) are popularly applied as the validation techniques. In order to encourage the participation of domain expert into the validation and reduce the subjectiveness of the assessment, a questionnaire was designed for this validation (refer to Appendix 4).

8.2.2.1 A validation framework

In the context of a KBS project, it is important to present guidelines and a strategy that specifies the validation methods and their criteria (Keefe and Preece, 1996). In order to effectively conduct the questionnaire evaluation, a validation framework was applied to setup the validation objective, criteria and measurement category, facilitating the questionnaire design. The validation framework was derived from goal-question-metric (GQM) paradigm for software system evaluation (Boloix and Robillard, 1995).

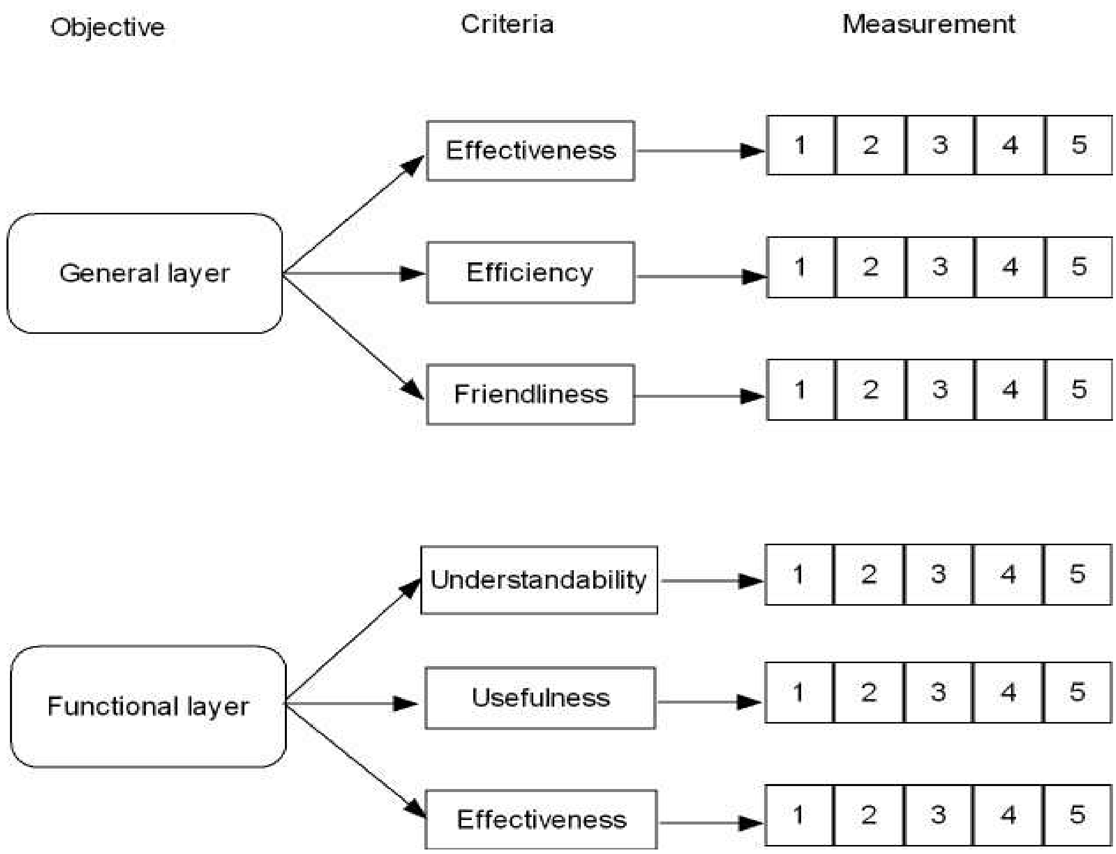


Figure 8.2 Validation Framework (Adapted from Boloix and Robillard, 1995)

As illustrated in Figure 8.2, the main objective of validating the KBS-CHSCA was to evaluate the system performance on the general layer and functional layer. The validation on the general layer focused on testing the effectiveness and efficiency of the KBS supporting the decision-making, and the friendliness of the KBS interface. On the functional layer, four major functions of KBS-CHSCA, including the explanation facility of the textual knowledge base in the assessment process, the case enquiry facility, the expert enquiry facility and the judgment report facility were evaluated against the user's satisfaction. The understandability of the explanation facility, the usefulness of case and expert enquiry facility and the effectiveness of the judgment report facility were respectively used as the evaluation criteria.

Due to the subjectiveness of the validation process, the Likert scale was used as the measurement indicator for each evaluation criteria as it can effectively provide the ability to demonstrate an average opinion of the evaluators (Bailey, 1987; Heesom, 2004). Usually, an odd number of response points is used in the Likert scaling (Fellows and Liu, 2003). In order to establish a threshold that effectively provides the subjective assessment, five categories were employed in the Likert scale to measure the user's satisfaction level of each validation criteria (Sutrisna, 2004). In the Likert scale of 1 to 5, 1 is assigned for very low satisfaction; 2 is for low; 3 is for moderate; 4 is for high and 5 is for very high. The threshold was set to be 3 (60%). Each validation criteria should be scored over 3, which means that only minor modification might be conducted based on the respondents' suggestions. Otherwise (below 3), a serious modification or re-design of the particular modular would be required against the criteria.

8.2.2.2 Evaluation Questionnaire Design

According to the validation framework, a system evaluation questionnaire (refer to Appendix 4) was designed to validate the usability and user's satisfaction of

KBS-CHSCA. A presentation was provided at the beginning of the questionnaire, outlining the background of the study, describing the aim of the questionnaire survey and introducing the method of accessing the website of KBS-CHSCA.

Following the introduction, four sections were included in the questionnaire. The first section of the questionnaire aimed to obtain the basic information of the evaluator, including name of organisation, size of organisation (number of employees), the job title and the length of time in current work role area. This information could define the characteristics of evaluators and analyse the potential beneficiary of the KBS in the industry. Additionally, the section also requested the information on whether the evaluator had known or worked on the H&S competence assessment. In the subjective validation, the evaluator's background knowledge with regards to the problem domain significantly influences the validity and reliability of the validation result. The response from an evaluator with the domain knowledge would be more useful than the response from an evaluator without the domain knowledge.

The second section of the evaluation questionnaire sought to test the overall performance of KBS-CHSCA. In order to achieve the validation objective of the general layer, the evaluator was requested to measure the effectiveness and efficiency of the KBS decision-support capability after he/she used the prototype version. The evaluator's satisfaction of the KBS usability was also measured to assist in the validation of system friendliness. In addition, the information of whether the evaluator had used or seen any similar system was requested, allowing the evaluator to make a comparison between KBS-CHSCA and the similar system if he used or saw before. This information was important to evaluate the originality of KBS-CHSCA and identify the difference between KBS-CHSCA and other existing systems. Further, the evaluator's impression on the commercial prospects of KBS-CHSCA was requested to test whether the KBS has the potentiality to become a practical-solution for the industry.

After evaluating the general performance of KBS-CHSCA, the evaluator was requested to assess four important decision-support functions of the KBS in the third section of the questionnaire. The following information was requested to facilitate the system evaluation:

- the understandability of the explanations provided by the knowledge base: The textual knowledge base is the key part of KBS-CHSCA, including the explanations of the minimum satisfaction standards, the qualitative measurement indicators, and examples or evidence for the user's assessment. Since the user's comprehensibility of those explanations significantly influenced the result of decision-making, it was important to request the user to evaluate the extent of understanding of the explanations contained in the textual knowledge base.
- the usefulness of case and expert enquiry facilities: The case and expert enquiry facilities are two important decision-support tools of KBS-CHSCA. The information of the user's impression of the usefulness of the two decision-support

tools played an important role in the system validation.

- the effectiveness of the final judgment report: The final judgment report is a summary of the assessment process containing all decision-making statuses and records. Since the final judgment report was an important function of KBS-CHSCA, providing the evidence of reasonable decision-making, it was thereby, necessary to request the user to evaluate its effectiveness.

The final part of the questionnaire aimed to collect information on the user's additional thoughts, opinions, suggestion, criticism and recommendations to help future improvements of KBS-CHSCA.

In order to encourage the user to express any comment in the evaluation process, most questions in the questionnaire had open-ended options.

8.3 Analysis of Evaluation Result

The nature of KBS-CHSCA places the client at the center of decision-making in H&S competence assessment. According to the CDM Regulations 2007, the client includes local authorities, school governors, insurance companies and project originators on Private Finance Initiative (PFI) projects (HSC, 2007). In practice, those organisations usually employ H&S consultants to deal with the H&S issues. Therefore, a purposive sampling method, in which the pre-defined groups were selected as the survey target because of the unique positions of the sample elements, was employed in the system evaluation survey (Schutt, 2006; Silverman, 2004). The main sample targets of the evaluation questionnaire survey included the H&S consultants and others with knowledge and experience in H&S management. The questionnaire was conducted through a commercial on-line questionnaire platform (www.free-online-surveys.co.uk) and sent to 106 members of Association of Project Safety, 68 members of Safety Groups UK, 15 members of Major Contractor Group and 8 local authority's property service departments in West Midlands. In addition, an evaluation invitation with the questionnaire link was announced in a Yahoo group of construction researchers (Co-operative Network of Construction Researcher) to collect feedbacks from academic practitioners who were working in the relevant research field.

Within one month survey period, 20 effective responses were received by the on-line system. Appendix 5 presents the evaluation results of the questionnaire survey. Followings are the summary of the system evaluation result.

8.3.1 Background of Respondents

As illustrated by Figure 8.3, the majority of respondents are working in the industry and have H&S knowledge and 9 respondents are experts in construction H&S management in term of their job titles.

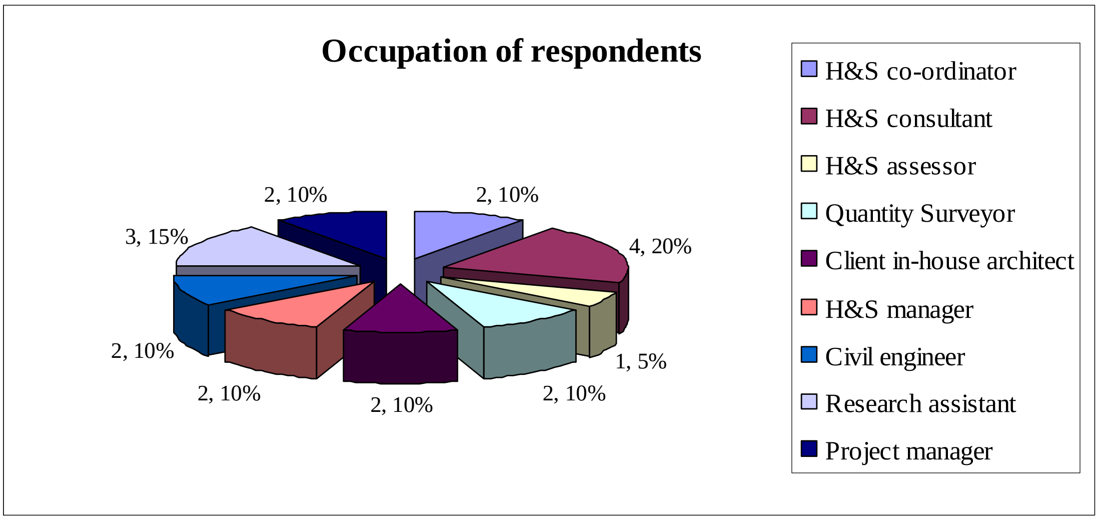


Figure 8.3 The occupations of respondents

Seen from Figure 8.4, 70% of respondents have been working in the industry over 5 years. In addition, 18 (90%) respondents have known or worked on H&S competence assessment.

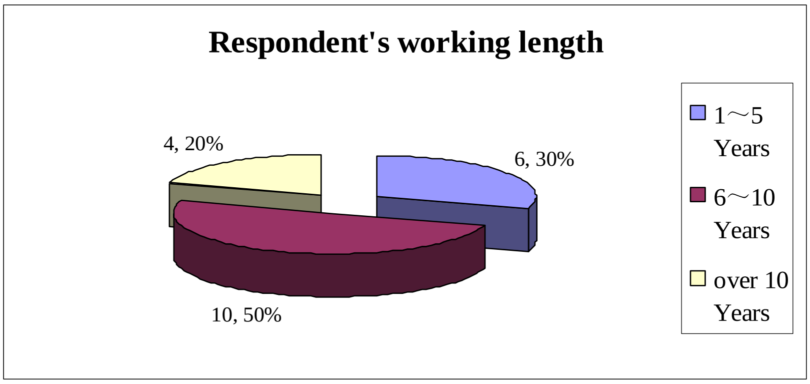


Figure 8.4 The respondent's working length

Regarding the background of respondents, most of respondents are experienced practitioners/experts in construction H&S management and have the background knowledge of H&S competence assessment. Therefore, the respondents can be seen as the domain experts whose knowledge and intuition are effective for the comparison of the system's performance against that of human experts.

8.3.2 General Validation

As mentioned in 8.2.2.2, the general validation focused on evaluating the efficiency and effectiveness of the decision-making process of the KBS and its usability. Results on the first general validation question revealed that only had 3 (15%) respondents used or seen any other system for construction H&S competence assessment. 2 respondents left comments on the difference of their system with KBS-CHSCA. The support for self-assessment and reduction of paper work were considered as the main difference between KBS-CHSCA and other H&S competence assessment system.

Table 8.1 summarises the evaluators' satisfaction with the three general validation criteria. As shown in Table 8.1, 19 out of 20 respondents expressed above moderate satisfaction with the effectiveness of KBS-CHSCA. Among them, 11 respondents thought the effectiveness of KBS-CHSCA was high. For the efficiency of KBS-CHSCA, the respondents' satisfaction was between moderate and high. 10 respondents were highly satisfied with the efficiency of the KBS decision-making process. Compared to the KBS effectiveness and efficiency, the satisfactory rate of the KBS usability was a little bit of lower. 11 respondents were moderately satisfied by the usability and interaction unit of KBS-CHSCA; and 8 respondents expressed highly satisfaction with it.

Table 8.1 The general validation result of KBS-CHSCA

Validation Item \ Rate	1	2	3	4	5
The effectiveness of KBS-CHSCA in supporting the decision-making for H&S competence assessment	-	1	8	10	1
Average score			3.55		
The efficiency (time and efforts spending on decision-making) of using KBS-CHSCA compared with the current method	-	-	10	9	1
Average score			3.55		
the usability and interaction unit of KBS-CHSCA	-	1	11	7	1
Average score			3.4		

Note: Score 1: very low; Score 2: low; Score 3: moderate; Score 4: high; Score 5: very high.

As the average scores for the three general functions of KBS-CHSCA were above 3, the performance of the KBS decision-making process and its usability were considerably satisfied by the evaluators. Over 50% of evaluators were highly satisfied by the decision-making process and 40% of them expressed high satisfaction with the system usability. The validation results of the KBS general function were encouraging as they demonstrated that the current prototype of KBS-CHSCA can effectively and efficiently support the experienced practitioners to make decisions of selecting H&S competent duty-holders; and the interface of KBS-CHSCA was comparatively easy to learn and use. In addition, 80% of evaluators considered KBS-CHSCA to be a potential practical-solution for the industry.

8.3.3 Functional Validation

The third part of the questionnaire survey focused on investigating the evaluator's satisfaction with the KBS explanation facility, case enquiry facility, expert enquiry facility and the final judgment report. As shown in Table 8.2, 8 respondents expressed moderate satisfaction with the explanation facility of KBS-CHSCA while 11 were highly satisfied by it. Two evaluators suggested increasing the examples or cases in the explanation facility to improve the understandability of the minimum satisfaction standards and the measurement indicators. Regarding the case inquiry facility, 14 respondents were moderately satisfied with its usefulness while 6 considered it to be highly useful. The result on the usefulness of the expert inquiry facility presented that 10 respondents were moderately satisfied by the expert facility and 9 respondents expressed high satisfaction with it. One respondent opined that the expert facility would be useless without the real support from some professional organisations. For the judgment list facility of KBS-CHSCA, 8 respondents expressed moderate satisfaction with it while 12 respondents considered it as a highly useful facility. One respondent regarded it as a good summary of decision-making result. Another respondent praised the usefulness of it for audit and record-keeping.

Table 8.2 The functional validation result of KBS-CHSCA

Validation Item \ Rate	1	2	3	4	5
The understandability of the explanation facility (textual rules) for the minimum satisfaction standards and measurement indicator system	-	1	8	9	2
Average score			3.6		
The usefulness of the case inquiry facility for decision-making	-	-	14	5	1
Average score			3.35		
The usefulness of the expert inquiry facility for decision-making	-	1	10	7	2
Average score			3.5		
The effectiveness of the duty-holder judgment list as evidence of reasonable decision-making	-	-	8	11	1
Average score			3.65		

Note: Score 1: very low; Score 2: low; Score 3: moderate; Score 4: high; Score 5: very high.

Table 8.2 revealed that the four facilities scored higher than 3, and thus demonstrated their effectiveness in KBS-CHSCA. The lowest score was for the case inquiry facility because of the lack of practical cases for the decision-making. Similarly, the lack of real support from professional organisations impaired the effectiveness of the expert inquiry facility. The explanation facility could be more effective with the increasing of cases and examples in the textual knowledge base. The judgment result list was borne out to be a useful facility to summarise the decision-making process and keep relative records.

Following the functional validation, some respondents left their general opinions on KBS-CHSCA. Four respondents thought the KBS was a useful tool for H&S competence assessment and would have commercial prospects. One respondent considered that KBS-CHSCA bridged the gap between the CDM documental requirements on H&S competence assessment and the practical implementation. However, one respondent suggested further improvement on the usability of the KBS, such as the adjustment of control button position.

8.5 Summary

Verification and Validation (V&V) are two associated techniques used to evaluate the KBS. In order to evaluate the performance of KBS-CHSCA, verification and validation were respectively applied to testify the correctness of the KBS and assess its effectiveness, efficiency and usability. The verification was conducted through internal examination of the KBS structural anomalies, content, knowledge base and system functionality. The validation process of KBS-CHSCA was conducted using a questionnaire survey to encourage more practitioners to participate and reduce the subjectiveness of the validation result. Based on a goal-question-metric (GQM) paradigm, a validation framework was developed including two validation layers and six criteria. According to the validation framework, a validation questionnaire was designed and sent to pre-defined practitioner's groups.

The results of validation questionnaire survey demonstrated that KBS-CHSCA was an appropriate system to support decision-making for construction H&S competence assessment. The majority of respondents expressed moderate or high satisfaction with the general performance and four decision-support facilities of the KBS. Some advice was also put forward for the improvement of the KBS usability and the increase of cases and examples in the text knowledge base. In addition, some respondents suggested that expert inquiry facility would be useless without the participation of professional groups.

In general, the respondents' acceptance confirmed that KBS-CHSCA is a useful decision-support system to improve the performance of selecting H&S competent duty-holders under CDM Regulations 2007.

Chapter 9 Conclusions and Recommendations

9.1 Introduction

The improvement of construction H&S is a systematic progress involving the different duty-holders and multiple disciplines. The Construction (Design and Management) (CDM) Regulations specified procedures to improve the planning and management of construction H&S by assigning duties and responsibilities to all duty-holders in the management of risk. According to the CDM Regulations 2007, the H&S competence assessment is an important pro-active H&S duty for the client to ensure that all duty-holders have adequate knowledge and experience with regards to H&S management and performance before they are appointed or engaged into the project. In order to help the client fulfill the duty of competence assessment, this research was conducted, principally to develop a Knowledge-Based System (KBS) assisting the client to take reasonable steps to assess duty-holders' H&S competence.

The first chapter established the research aims and objectives, providing a guidance and structure of the research process. Following a literature review of H&S performance and the legal system of construction H&S in UK, the details of construction H&S competence assessment including the basic concepts, legislation development and the 'Core Criteria' for H&S competence assessment was introduced. Furthermore, case studies of existing formal schemes for H&S competence assessment were undertaken to identify the knowledge representative characteristics and reveal practical drawbacks in the decision-making process of H&S competence assessment. Additionally, a feasibility study was conducted to demonstrate the structural and functional appropriateness to apply KBS for H&S competence assessment by reviewing A.I. technologies, the working principles of KBS and three examples of using KBS for construction H&S management. Based on the findings of the literature review and the case studies, a KBS decision-support model was developed to highlight the suitable A.I. and I.T. technologies for reasonable decision-making of H&S competence assessment, whilst also providing requirements of developing an online KBS. According to the decision-support model, a textual knowledge base including the minimum satisfaction standards and qualitative measurement indicators was developed to construct the key part of the KBS. Using the textual knowledge base, a KBS was developed to realise the decision-support mechanisms required in the decision-support model. The KBS was then evaluated through verification and validation processes.

In order to summarise the research findings, this chapter discusses the achievement of research objectives in details. Following the outline of research contribution, the limitations of the research are discussed, leading to the recommendations for future research in the area of construction H&S competence assessment.

9.2 Review of Research Aim and Objectives

The main aim of this research is to develop a KBS to facilitate clients to take reasonable steps in assessing duty-holders' H&S competence assessment under the CDM Regulations 2007. In achieving the research aim, the research objectives have been accomplished through different phases of the research. In order to provide a comprehensive conclusion to this research, it is important to briefly describe the process of achieving the research objectives

9.2.1 Review of the Research Scope in Construction H&S Management

The first research objective focused on extensively reviewing the literature in the scope of UK's construction H&S performance, the framework of H&S legal system and H&S culture model in order to develop generic knowledge of construction H&S management, highlighting the importance of ensuring a positive H&S culture for the good H&S performance. In order to accomplish this research objective, the following literature was reviewed:

- Construction H&S performance in UK: This part of the review provided an outline of the current situation of H&S performance in the UK's construction industry. The review of statistics in occupational injury and ill-health revealed that the UK construction H&S performance had improved in recent decades but still had considerable drawbacks which needed to be overcome by the industry.

- H&S legislation: This part of the review provided a general introduction of the legislation affecting the H&S performance in UK. The H&S legal system was described to demonstrate the structure, hierarchy and functions of H&S legislation influencing the construction industry.
- H&S culture: This part of the review provided an outline of the concepts and theory of H&S culture, introducing the model of measuring safety culture and exploring the importance and means of developing a positive H&S culture. The review of H&S culture indicated that the competence assessment required by CDM Regulations 2007 could play an important role of ensuring a positive H&S culture and improving the H&S performance in the construction industry.

9.2.2 Analysis of the Knowledge Representative Nature Embedding in the Decision-making Process of H&S Competence Assessment

Following the first objective, this research objective focused on reviewing the literature related to the H&S competence assessment in order to reveal the knowledge representative nature in its decision-making process. The concept of construction H&S competence and relative legislations were extensively reviewed to highlight the importance of implementing H&S competence assessment. Further, the 'Core Criteria' for H&S competence assessment designated by the ACoP of CDM Regulations 2007 were introduced and analysed to reveal that the 'Core Criteria' could effectively measure duty-holders' H&S culture, management system of H&S

and former H&S performance to ensure the selection of competent duty-holders for the current project. In addition, the latent shortcomings of implementing the 'Core Criteria' were identified for further discussion.

Apart from the literature review, a case study was conducted to investigate the current practice of H&S competence assessment. 19 existing formal H&S competence assessment schemes were reviewed and categorised into two groups, i.e. the self-assessment guidance and the expert-assessment programme. The case study identified the drawbacks of current practice in H&S competence assessment and the knowledge representative characteristics embedded in the decision-making process of H&S competence assessment.

9.2.2 Exploration of the Application of KBS for Decision-making Support for Construction H&S Competence Assessment

This research objective aimed to explore the feasibility of developing a KBS to support decision-making for construction H&S competence assessment. An extensive review was carried out to discuss the relationship between the decision-making process and KBS and describe the working theory of KBS. Subsequently, A.I. technologies for different reasoning processes applied in the KBS were outlined by highlighting both advantages and disadvantages. The current application of KBS in construction was also reviewed to identify the barriers of developing the KBS for construction activities.

Following the introduction and discussion of A.I. technologies and KBS, three examples of applying KBS in construction H&S management were reviewed to investigate the structural and functional appropriateness of KBS for H&S competence assessment. As a result of the investigation, the KBS was considered a suitable tool to facilitate the qualitative and subjective decision-making process of H&S competence assessment. Furthermore, the constraint of bias and inconsistency in the subjective assessment and limitation of structured rules should be overcome in the KBS development.

9.2.4 Development of A Decision-Support Model for H&S Competence Assessment by Applying Appropriate I.T. and A.I. Technologies

This research objective was to use appropriate I.T. and A.I. technologies to develop a decision-support model for H&S competence assessment. According to the characteristics of regulation-compliance checking problem, a decision-making framework was developed to illustrate a distributed process of information and knowledge exchange among regulations, clients and candidate duty-holders. The decision-making framework specified the requirements for the decision-support model.

Further, a KBS decision-support model was developed to help the client take reasonable steps in H&S competence assessment. According to the knowledge representative characteristics in the decision-making process and the decision-making framework, three decision-support mechanisms were proposed involving the rule-based inference process, case-based inference process and Web technologies to develop the decision-support model based on the 'Core Criteria' of H&S competence assessment under CDM Regulations 2007.

9.2.5 Design and Development of a Textual Knowledge Base to Appropriately Represent Knowledge in The Decision-making Process of H&S Competence Assessment

This research objective focused on developing a textual knowledge base for the subjective and qualitative decision-making process in H&S competence assessment. According to the decision-support model, the key part of the KBS for construction H&S competence assessment was to develop a practical mechanism to support the client in evaluating the candidate duty-holders' H&S competence in terms of the 'Core Criteria'. Since it is unreasonable and impractical to develop production rules for regulation-compliance checking, a textual knowledge base including the minimum satisfaction standards and qualitative measurement indicators derived from the Appendix 4 and 5 of the ACoP for CDM Regulations 2007 was developed to fulfill the requirement of reasonable decision-making against the CDM Regulations 2007.

The textual knowledge base explained the 'Core Criteria' in detail, specifying the judgment standards, and suggested judgment examples and evidence to provide a guidance for the subjective and qualitative decision-making in H&S competence assessment.

9.2.6 Prototyping of Online KBS to Support Decision-making for H&S Competence Assessment under CDM Regulations 2007

This research objective aimed to incorporate the textual knowledge base and the three decision-support mechanisms in an online KBS to facilitate the client to make reasonable decisions in the selection of H&S competent duty-holders.

Following the introduction of a database driven Web system and analysis of existing Web technologies, Java Sever Pages (JSP) technology and MySQL were selected as the appropriate technologies for the Web applications of the KBS. The Unified Model Language (UML) and Entity-Relationship (ER) diagram were used to analyse the functional requirements of the KBS, describe the interactions between the KBS and the end-users, and illustrate the structure of the database.

Based on the use case model and the activity diagrams, an online KBS for construction H&S competence assessment (KBS-CHSCA) was developed on the website www.constructionkbs.co.uk by renting a commercial JSP server. The KBS applied two user interfaces enabling the information and knowledge exchange between clients and in-house experts from an umbrella organisation. The client can assess different duty-holders' H&S competence by using the textual knowledge base, case enquiry facility and expert enquiry facility. The judgment result can be automatically generated by the KBS to provide an evidence of reasonable decision-making. In addition, the decision-making process can be stored in the database as reference for future projects.

9.2.7 Evaluation of the KBS for Construction Health and Safety Competence Assessment

The last research objective was to evaluate the overall value of the developed KBS by verifying the completeness and accuracy of the system and validating the users' satisfaction and usability of the system.

The verification was implemented using six internal system examination criteria in the process of coding and debugging the KBS. Following the verification, a validation framework was designed to guide the evaluation of usability and user satisfaction of the KBS. Two evaluation layers containing six testing criteria were established to enable the experts/practitioners to assess the KBS using a 5-category Likert scale.

Based on the validation framework, an evaluation questionnaire was developed consisting of four sections to collect the evaluation data regarding the evaluator's basic information, the general performance of the KBS, and the functional performance of the KBS. The evaluation questionnaire was developed by a commercial on-line questionnaire system (www.free-online-surveys.co.uk) and disseminated to experts/practitioners in the industry.

9.3 Innovation in Research

Throughout the completion of the research objectives, four main innovations have been made in research and should be highlighted as contribution to current knowledge in the field of construction H&S management and I.T. application.

- An empirical research of the existing formal schemes for H&S competence assessment: The development of a KBS requires the appropriate representation of the domain knowledge. The investigation of the decision-making process applied by the existing formal schemes for H&S competence assessment provided an empirical means of analysing the knowledge representative characteristics for H&S competence assessment. As a result of the case study of 19 existing formal schemes for H&S competence assessment, knowledge representative characteristics were identified (refer to Chapter 3). Additionally, the drawbacks of implementing H&S competence assessment were recognised as the main problems that should be resolved in the development of the KBS.

- Development of a decision-making framework and decision-support model for H&S competence assessment: According to the case study findings, a decision-making framework demonstrated the knowledge and information flow in the decision-making process of H&S competence assessment, highlighting the essence of making reasonable H&S competence assessment under the CDM Regulations 2007. Based on the decision-making framework, a decision-support model was developed to help the effective and efficient decision-making using appropriate artificial intelligence (A.I.) and information technology (I.T.) solutions (refer to Chapter 5).

- Interpretation of 'Core Criteria' under CDM Regulations 2007: The duty-holders' H&S competence assessment is a new responsibility for the client imposed by CDM Regulations 2007. Although the ACoP of the CDM Regulations 2007 introduces the 'Core Critiera', the latent shortcomings of the 'Core Criteria' and the drawbacks of implementing the H&S competence assessment (refer to Chapter 3) significantly influence the effectiveness and practicality of applying the 'Core Critiera'. In order to assist the client to easily use the 'Core Criteria' in practice, this research generated a textual knowledge base (refer to Chapter 6) interpreting the 'Core Criteria' with the minimum satisfaction standards and the qualitative measurement indicators. The textual knowledge base was contained in the KBS to ensure the client to take reasonable steps in the selection of H&S competent duty-holders under CDM Regulations 2007.

- A comprehensive research of applying KBS for construction H&S competence assessment: Looking back at the nature of this particular research, the research focused on applying I.T. to deal with a problem in relation to construction H&S management. The application of KBS for construction H&S competence assessment provides a solution for the subjective and qualitative assessment of regulations-compliance checking problem. In addition, this research enriched the example of automating the decision-making process in the construction field.

9.4 Recommendations for Future Research

This research has provided a prototype online KBS to improve the decision-making process of construction H&S competence assessment under CDM Regulations 2007. However, in the process of conducting the research, several issues have been identified, which could potentially enhance the reliability, intelligence and applicability of the KBS in practice.

- Issue of subjectivity: The CDM Regulations 2007 have only become effective for about two years. It is, therefore relatively difficult to collect the data regarding the practice of H&S competence assessment from the industry. The development of the textual knowledge base including the minimum standards and qualitative measurement indicators was based on interpretation of the 'Core Criteria' in the ACoP of the CDM Regulations 2007. Although the evaluation questionnaire contained the assessment of the textual knowledge base, it is not enough to conduct an objective evaluation of the effectiveness of the developed textual knowledge base mainly due to the time and resource constraints.

- Issue of intelligence: KBS-CHSCA is an online KBS supporting the decision-making process of H&S competence assessment. However, the decision-making process is still semi-automatic, requiring the involvement of human beings. This issue results from the lack of heuristics regarding the practice of H&S competence assessment as the CDM Regulations 2007 and the H&S competence assessment are still new to the industry. In addition, it is difficult to access the domain experts from the industry due to the time, resource and security reasons.
- Issue of applicability: Since KBS-CHSCA requires the knowledge support of human experts from some umbrella organisations, the KBS is suitable to be run by an umbrella organisation and used by the members of the organisation.

Based on the identified issues of the research, the possible areas for future research can focus on:

- Improving the knowledge acquisition technique: Further investigation can be conducted to acquire the useful heuristics or rule of thumb from experts doing the H&S competence assessment in the industry. The focus group discussion or interview with relevant experts from some umbrella organisations, such as HSE, ICE, APS, can facilitate to acquire practical knowledge and decrease the subjectivity of the textual knowledge base.

- Enriching the textual knowledge base: With the use of CDM Regulations in the industry, further exploration can be conducted to collect useful best practice regarding the implementation of 'Core Criteria' for H&S competence assessment. The best practice can enrich the textual knowledge base and improve the effectiveness of subjective and qualitative assessment process.
- Promoting the intelligence of the KBS: Further improvement can be undertaken to promote the intelligence of decision-making process in the KBS. The further acquisition of the heuristics regarding the assessment process can help to identify some usually applied rules of thumb which can further be developed into reasoning production rules to promote the intelligence of the decision-making process in KBS-CHSCA.
- Developing a candidate duty-holder's interface: The current KBS-CHSCA requires clients to collect data from candidate-duty-holders, increasing the work load of clients in the decision-making process. It would be efficient to develop a duty-holder's interface to support H&S competence data collection and self-assessment. As duty-holders are familiar with their H&S process, the interface can enhance the efficiency of data collection and help duty-holder's continuous improvement of H&S management under CDM Regulations 2007.
- Applying semantic Web technology: The semantic Web technology can be used to improve the ability of the KBS in searching the most similar cases and expert comments for the current project.
- Enhancing the usability of the KBS: The further modification can be

implemented to improve the usability of KBS-CHSCA by collecting and analysing feedback from more industry practitioners. Further investigation can also focus on developing the training function of the KBS to improve the awareness of industry practitioners and graduates in relation to H&S competence.

- Connecting with other duty-holders' selection criteria: Apart from the H&S competence, the selection of duty-holders should take other considerations into account, such as the cost, quality and time. Further research can investigate the feasibility of integrating KBS-CHSCA with other selection criteria to develop a collective decision-support system for duty-holder selection.

9.5 Summary

This chapter has made a general conclusion of the research by reviewing the achievements of the research objectives. The discussion was then extended to describe the innovation of the research, acknowledge the limitations of the research and present recommendations for future research.

In a nutshell, this research has developed a KBS to help the client take reasonable steps to assess duty-holders' H&S competence assessment under CDM Regulations 2007. The textual knowledge base contained in the KBS effectively translates the 'Core Criteria' into a practical means of supporting the reasonable decision-making process. Furthermore, the case and expert enquiry facilities applied by the KBS effectively enhance the decision-making process and improve the information and knowledge acquisition and exchange.

Although the KBS still requires the human involvement in the decision-making process, it enhances the quality and efficiency of decision-support for regulation-compliance checking problem. In addition, use of the KBS is an active learning of H&S knowledge, which can effectively improve H&S management in duty-holder’s organisation and encourage a positive H&S culture in construction industry. With the further improvement, the KBS would become more intelligent and practical in the decision-making for construction H&S competence assessment.

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Appendices

Appendix 1: An Outline of Health and Safety Regulations Influencing Construction Activities (Adapted from Hughes and Ferrett, 2005)

No.	Regulations	Relevant Activities
1.	*The Work at Height Regulations 2005*	roof working, scaffold and ladder using, etc.
2.	*Confined Spaces Regulations 1997*	working in any chamber, tank, vat, silo, pit, trench, pipe, sewer, flue, well or similar enclosed space
3.	*Provision and Use of Work Equipment Regulations (PUWER) 1998*	any work involving work equipment (machinery, appliance, apparatus, tool or installation)
4.	*The Manual Handling Operations (HMO) Regulations 1992*	any transporting or supporting (lifting, putting down, pushing, pulling, carrying or moving) of loads
5.	*Lifting Operations and Lifting Equipment Regulations (LOLER) 1998*	any work involving equipment for lifting or lowering loads, the lifting working equipments include cranes, folk lift trucks, lifts, hoists, mobile elevating work platforms, vehicle inspection platform hoists and lifting accessories such as chains, slings, eyebolts etc.
6.	*Electricity at Work Regulations 1989*	any work involving electrical system

		or equipment
7.	*Fire Precautions (Special Premises) Regulations 1976*	Setting up temporary accommodation units such as offices, workshops or storage facilities
8.	*Fire Precautions (Workplace) Regulations 1997*	Dealing with general fire precautions including: means of detection and giving warning in case of fire, the provision of means of escape, means of fighting fire, and the training of staff in fire safety.
9.	*Control of Substances Hazardous to Health Regulations (COSHH) 2002*	any work involving hazardous substances (solvents, paints, adhesives, cleaners and dust) in workplaces of all types
10.	*Dangerous Substances and Explosive Atmospheres Regulations (DSEAR) 2002*	dealing with hazardous substances like petrol, LPG, paints, cleaners, solvents, flammable gases and explosive mixture in air (dusts)
11.	*Chemical (Hazard Information and Packaging for Supply) Regulations 2002*	Receiving chemicals from suppliers
12.	*Control of Asbestos at Work Regulations 2002*	any work could be exposure to asbestos
13.	*Asbestos (Licensing) Regulations 1998*	Applying for license of working with asbestos insulation, asbestos coating or asbestos insulation board
14.	*Ionising Radiation Regulations 1999*	any activities involving use of ionising radiation equipment (e.g.

		X-ray weld crack detector)
15.	*Personal Protective Equipment at Work Regulations 1992*	any work requiring the use of PPE
16.	*Construction (Head Protection) Regulations 1989*	building operations and works of engineering construction
17.	*The Control of Noise at Work Regulations 2005*	any work affected by noise
18.	*The Reporting of injuries, Diseases and Dangerous Occurrences Regulations 1995*	reporting process when specific accidents occurring on construction sites
19.	*Health and Safety (Safety Signs and Signals) Regulations 1996*	correctly using safety signs and signals at any work place
20.	*Health and Safety (Display Screen Equipment) Regulations 1992*	use of display screen equipment
21.	*Health and Safety (First Aid) Regulations 1981*	providing first aid facilities

Appendix 2: Core criteria for demonstration of comp etence (Appendix 4 of ACoP for CDM Regulations 2007)

	Criteria	Standard to be achieved	Examples of the evidence that you could use to demonstrate you meet the required standard
Stage 1 assessment			
1	Health and safety policy and organization for health and safety	You are expected to have and implement an appropriate policy, regularly reviewed, and signed off by the Managing Director or equivalent. The policy must be relevant to the nature and scale of your work and set out the responsibilities for health and safety management at all levels within the organization.	A signed, current copy of the company policy (indicating when it was last reviewed and by whose authority it is published). Guidance on writing company policies for health and safety can be found in HSE free leaflet INDG259.
2	Arrangements	These should set out the arrangements for health and safety management within the organization and should be relevant to the nature and scale of your work. They should set out how the company will discharge their duties under CDM2007. There should be a clear indication of	A clear explanation of the arrangements which the company has made for putting its policy into effect and for discharging its duties under CDM02007. Guidance on making arrangements for the management of health and safety can be found in

		how these arrangements are communicated to the workforce.	HSE free leaflet INDG259.
3	Competent advice – corporate and construction – related	Your organization, and your employees, must have ready access to competent health and safety advice, preferably from within your own organization. The advisor must be able to provide general health and safety advice, and also (from the same source or elsewhere) advice relating to construction health and safety issues.	Name and competency details of the source of advice, for example a safety group, trade federation, or consultant who provides health and safety information and advice. An example from the last 12 months of advice given and action taken.
4	Training and information	Your should have in place, and implement, training arrangements to ensure your employees have the skills and understanding necessary to discharge their duties as contractors, designers or CDM co-ordinators. You should have in place a programme or life-long learning which will keep your employees updated on new developments and changes to legislation or good health and safety practice. This applies throughout the	Headline training records. Evidence of a health and safety training culture including records, certificates of attendance and adequate health and safety induction training for site-based workforce. Evidence of an active CPD programme. Sample ‘toolbox talks’.

		organization – from Board or equivalent, to trainees.	
5	Individual qualifications and experience	Employees are expected to have the appropriate qualifications and experience for the assigned tasks, unless they are under controlled and competent supervision.	Details of qualification and/or experience of specific corporate post holders for example Board members, health and safety advisor etc. Other key roles should be named or identified and details of relevant qualifications and experience provided. For contractors: details of number/percentage of people engaged in the project who have passed a construction health and safety assessment, for example the CITB Construction Skills touch screen test or similar schemes, such as the CCNSG equivalent. For site managers, details of any specific training such as the Construction Skills CITB 'Site Management Safety Training Scheme' certificate or equivalent. For professionals, details of qualifications and/or professional institution membership.

			For site workers, details of any relevant qualifications or training such as S/NVQ certificates. Evidence of a company-based training programme suitable for the work to be carried out. For design organizations – Details of number/percentage of people engaged in the project, who have passed a construction H&S assessment, for example the CITB Construction Skills touch screen test or affiliated schemes, such as the CCNSG equivalent. Details of any relevant qualifications and/or professional institution membership and any other specific qualifications such as ICE construction H&S register, NEBOSH Construction Certificate, APS Design Register. For CDM co-ordinators – Details of number/percentage of people engaged in the project who have passed a construction health

			and safety assessment, for example the CITB Construction Skills touch screen test or affiliated schemes, such as the CCNSG equivalent. Evidence of health and safety knowledge such as NEBOSH Construction Certificate. Details of professional institution membership and any other specific qualifications such as member of the CDM co-ordinators' register administered by the APS or ICS that is formerly the IPS, or the ICE construction health and safety register etc. Evidence of a clear commitment to training and the Continuing Professional Development of staff.
6	Monitoring, audit and review	Your should have a system for monitoring your procedures, for auditing them at periodic intervals, and for reviewing them on an ongoing basis	Could be through formal audit or discussions/reports to senior managers. Evidence of recent monitoring and management response. Copies of site inspection reports.

7	Workforce involvement	You should have, and implement, an established means of consulting with your workforce on health and safety matters.	Evidence showing how consultation is carried out. Records of health and safety committees. Names of appointed safety representatives (trade union or other). For those employing less than five, be able to describe how you consult with your employees to achieve the consultation required.
8	Accident reporting and enforcement action; follow-up investigation	You should have records of all RIDDOR (the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1999) reportable events for at least the last three years. Your should also have in place a system for reviewing all incidents, and recording the action taken as a result. You should record any enforcement action taken against your company over the last five years, and the action which you have taken to remedy matters subject to enforcement action.	Evidence showing the way in which you record and investigate accidents and incidents. Records of any enforcement action taken over the last five years, and what action was taken to put matters right (information on enforcement taken by HSE over the last five years is available on the HSE website). For larger companies, simple statistics showing incidence rates of major injuries, over three-day injuries, reportable cases of ill health and dangerous occurrences for the last three years. Records should include any incidents that

			occurred whilst the company traded under a different name, and any incidents that occur to direct employees or labour-only sub-contractors.
9	Sub-contractor/consulting procedures (if applicable)	You should have arrangements in place for appointing competent sub-contractors/consultants. You should be able to demonstrate how ensure that sub-contractors will also have arrangements for appointing competent sub-contractors or consultants. You should have arrangements for monitoring sub-contractor performance.	Evidence showing how you ensure sub-contractors are competent. Examples of sub-contractor assessments you have carried out. Evidence showing how you require similar standards of competence assessment from sub-contractors. Evidence showing how you monitor sub-contractor performance.
10	Hazard elimination and risk control (designers only)	You should have, and implement, arrangements for meeting your duties under regulation 11 of CDM 2007	Evidence showing how you: ensure co-operation and co-ordination of design work within the design team and with other designers/contractors; ensure that hazards are eliminated and any remaining risks controlled; ensure that any structure which will be used as

			workplace will meet relevant requirements of the Workplace (Health, Safety and Welfare) Regulations 1992. Examples showing how risk was reduced through design. A short summary of how changes to designs will be managed. (Note: the emphasis here should be on practical measures which reduce particular risks arising from the design, not on lengthy procedural documentation highlighting generic risks.)
11	Risk assessment leading to a safe method of work (contractors only)	You should have procedures in place for carrying out risk assessments and for developing and implementing safe systems of work/method statements. The identification of heath issues is expected to feature prominently in this system. This will depend upon the nature of the work, but must reflect the importance of this risk area.	Evidence showing how the company will identify significant H&S risks and how they will be controlled. Sample risk assessment/safe systems of work/method statements; If you employ less than 5 persons and do not have written arrangements, you should be able to describe how you achieve the above.

12	Cooperating with others and coordinating your work with that of other contractors	You should be able to illustrate how cooperation and coordination of your work is achieved in practice, and how you involve the workforce in drawing up method statements/safe systems of work	Evidence could include for sample risk assessments, procedural arrangements, project team meeting notes. Evidence of how the company co-ordinates its work with other trades.
13	Welfare Provision (contractors)	You should be able to demonstrate how you will ensure that appropriate welfare facilities will be in place before people start work on site;	Evidence could include for example health and safety policy commitment; contracts with welfare facility providers; details of type of welfare facilities provided on previous projects.
14	Co-ordinator's duties (coordinator)	Your should be able to demonstrate how you go about encouraging cooperation, coordination and communication between designers.	The evidence should be in the form of actual examples rather than by generic procedures.
Stage 2 assessment			
1	Work experience	You should give details of relevant experience in the field of work for which you are applying	A simple record of recent projects/contracts should be kept, with the phone numbers/addresses of contacts who can verify that work was carried out with due regard to health and safety. This should be sufficient to demonstrate your

			ability to deal with the key health and safety issues arising from the work you are applying for. Where there are significant shortfalls in your previous experience, or there are risks associated with the project which you have not managed before, an explanation of how these shortcomings will be overcome.

Appendix 3 Textual Knowledge Base (Copy from corresponding web pages on http://www.constructionkbs.co.uk)

Criterion 1: Health and Safety policy and organisation for health and safety

- HSE free leaflet INDG259 providing guidance on writing company policies for health and safety

- Minimum satisfaction standard for organisation more than five persons
- Minimum satisfaction standard for organisation less than five persons
- The qualitative measurement indicator for orgainsation more than five persons
- The qualitative measuremnet indicator for orgainsation less than five persons

Minimum satisfaction standard for organisation more than five persons

The organisation has to display a copy of written H&S policy dated and signed by the most senior person in the organisation. The H&S policy should include a policy statement (specifying H&S aims and objectives) and organisation of H&S (the duties and responsibilities of employees in different level).

Minimum satisfaction standard for organisation less than five persons

The organisation can demonstrate the H&S policy and relative organisation. (The demonstration could be carried out through interview or other communication forms.)

The qualitative measurement indicator for orgainsation more than five persons

- **Acceptable**: The health and safety policy contains statements of the organisation’s commitment to H&S and is reviewed regularly.
- **Good**: The health and safety policy contains the organisation’s statement to H&S, specifies the H&S principles in which the organisation believes and identifies the general responsibilities of employees.
- **Excellent**: The health and safety policy contains the organisation’s statement and principles to H&S, and clearly sets out the responsibilities for health and safety management at all levels within the organisation in relation to the nature and scale of the work.

The qualitative measurement indicator for orgainsation less than five persons

- **Acceptable**: The demonstration of health and safety policy can explain the organisation’s commitment to H&S.
- **Good**: The demonstration of health and safety policy can explain the organisation’s commitment to H&S, H&S principles in which the organisation believes and general H&S responsibilities of employees.

- **Excellent**: The demonstration of health and safety policy can explain the organisation's commitment to H&S and clearly identifies the H&S responsibilities of all employees in relation to the nature and scale of the project.

Criterion 2: Arrangements

- HSE free leaflet INDG259 providing guidance on making arrangements for the management of health and safety

Get Adobe Reader

- Minimum satisfaction standard for organisation more than five persons
- Minimum satisfaction standard for organisation less than five persons
- The qualitative measurement indicator for orgainsation more than five persons
- The qualitative measurement indicator for orgainsation less than five persons

Minimum satisfaction standard for organisation more than five persons

A written document should be provided by the organisation to illustrate details of means used to arrange H&S management, rules of discharging its duties under CDM 2007 and the way of communicating these arrangements to the workforce.

Minimum satisfaction standard for organisation less than five persons

The organisation can demonstrate arrangements to realise its health and safety policy, discharge their duties under CDM 2007. (The demonstration could be carried out by oral presentation.)

The qualitative measurement indicator for orgainsation more than five persons

- **Acceptable**: The general arrangements which the organisation has made for putting its H&S policy into effect, discharging its duties under CDM 2007 and communicating to the workforce are in place.
- **Good**: The arrangements which the organisation has made for putting its H&S policy into effect, discharging its duties under CDM 2007 and communicating to the workforce are clearly specified.
- **Excellent**: The arrangements which the organisation has made for putting its H&S policy into effect, discharging its duties under CDM 2007 and communicating to the workforce are clearly specified. Besides the general arrangements, there are specific H&S rules, procedures and the provision of facilities to fit the nature and scale of current project.

The qualitative measurement indicator for orgainsation less than five persons

- **Acceptable**: The general arrangements which the organisation has made for putting its policy into effect, discharging its duties under CDM 2007 and communicating to the workforce can be demonstrated.
- **Good**: The arrangements which the organisation has made for putting its policy into effect, discharging its duties under CDM 2007 and communicating to the workforce can be demonstrated in a clear and understandable manner.
- **Excellent**: The arrangements which the organisation has made for putting its policy into effect, discharging its duties under CDM 2007 and communicating to the workforce can be demonstrated in a clear and understandable manner. There are also details and specific arrangements to fit the nature and scale of current project.

Criterion 3: Competent advice – corporate and construction-related

- Minimum satisfaction standard
- The qualitative measurement indicator

Minimum satisfaction standard

The organisation should provide name and competency details of the source of advice, for example a safety group, trade federation, or consultant who provides health and safety information and advice. The advisor must be able to provide general H&S advice, and also advice relating to construction H&S issues.

The qualitative measurement indicator

- **Acceptable**: The organisation and employees have ready access to competent H&S advice from outside the organisation.
- **Good**: The organisation and employees have ready access to competent H&S advice from within the organisation.
- **Excellent**: The organisation and employees have ready access to competent H&S advice from within the organisation. Evidence showing that advice was given and action was taken in last 12 months.

Criterion 4: Training information

- Minimum satisfaction standard
- The qualitative measurement indicator

Minimum satisfaction standard

The organisation should have training arrangements to provide employees with knowledge and skills to perform their job safely and understand the necessary to discharge their duties. One or some of following examples can be seen as evidence to satisfy this element:

- Headline training records

- Evidence of a H&S training culture including records, certificates of attendance and adequate H&S induction training for site-based workforce.
- Sample'toolbox talks'
- Other equivalent and substantial evidence.

The organisation also should have a programme for refresher training. An active Continuing Professional Development (CPD) programme can be seen as an evidence for this element.

The qualitative measurement indicator

- **Acceptable**: A general training programme is sent out for all levels of employees from Board to trainees.
- **Good**: A detail training programme including induction training, job-specific training and supervisory and management training is adequately sent out for all levels of employees from Board to trainees.
- **Excellent**: A detail training programme including induction training, job-specific training and supervisory and management training is adequately sent out for all levels of employees from Board to trainees. There is solid evidence or record showing the effectiveness of the training programme, such as the improvement of H&S performance on site.

Criterion 5 Individual qualification and experience

- Minimum satisfaction standard
- The qualitative measurement indicator

Minimum satisfaction standard

Employees of the organisation who will engage in the project should have the appropriate qualifications and experience for the assigned tasks, unless they are under controlled and competent supervision. One or some of following examples can be seen as evidence to meet the minimum standard:

For contractors

- Details of number/percentage of people engaged in the project who have passed a construction health an safety assessment, for example the CITB (Construction Industry Training Board) Construction Skills touch screen test or similar schemes, such as the CCNSG (Client Contractor National Safety Group) equivalent.
- For site managers, details of any specific training such as the Construction Skills CITB 'Site Management Safety Training Scheme' certificate or equivalent.
- For professionals, details of qualifications and/or professional institution membership.
- For site workers, details of any relevant qualifications or training such as S/NVQ (National and Scottish Vocational Qualifications) certificates.

- Evidence of a company-based training programme suitable for the work to be carried out
- Other equivalent and substantial evidence.

For designers

- Details of number/percentage of people engaged in the project who have passed a construction health an safety assessment, for example the CITB (Construction Industry Training Board) Construction Skills touch screen test or affiliated schemes, such as the CCNSG (Client Contractor National Safety Group) equivalent.
- Details of any relevant qualifications and/or professional institution membership and any other specific qualifications such as ICE (Institute of Civil Engineer) construction H&S register, NEBOSH (National Examination Board in Occupational Safety and Health) Construction Certificate, APS (Association for Project Safety) Design Register.
- Other equivalent and substantial evidence.

For CDM co-ordinators

- Details of number/percentage of people engaged in the project, who have passed a construction H&S assessment, for example the CITB (Construction Industry Training Board) Construction Skills touch screen test or affiliated schemes, such as the CCNSG (Client Contractor National Safety Group) equivalent.
- Evidence of H&S knowledge such as NEBOSH Construction Certificate.

- Details of professional institution membership and any other specific qualifications such as member of the CDM co-ordinators' register administered by the APS or ICS that is formerly the IPS (Institute of Planning Supervisors), or the ICE construction health and safety register etc.
- Evidence of a clear commitment to training and the Continuing Professional Development of staff.
- Other equivalent and substantial evidence.

For a large or more complex project, or one with high or unusual risks, a CDM co-ordinator should satisfy the following requirements

- Task knowledge appropriate for the tasks to be undertaken. May be technical or managerial. The examples of attainment include:
  - Professionally Qualified to Chartered level (Chartered membership of a recognised construction related institution)
  - Membership of a relevant construction institution, for example CIBSE; ICE; IEE; IMechE; IstructE; RIBA; CIAT
- H&S knowledge sufficient to perform the task safely, by identifying hazard and evaluating the risk in order to protect self and others, and to appreciate general background. Validated CPD in this field (For current professionals this needs to include at least 3 days of appropriate training within the last 2 years, including a general 'health and safety' course with a construction bias and/or a specialist 'co-ordinator' course.), and typical additional qualification eg:
  - NEBOSH Construction Certificate
  - Member of H&S Register administered by the ICE (Open to any member of a construction related institution)

    - Fellowship of Association for Project Safety
    - Membership of Institution of Planning Supervisors

- Experience and ability sufficient to perform the task, (including where appropriate an appreciation of constructability), to recognise personal limitations, task related faults and errors and to identify appropriate actions. For example, Evidence of significant work on similar projects with comparable hazards, complexity and procurement route.

The qualitative measurement indicator

- **Acceptable**: Specific corporate post holders (for example Board members and health and safety advisor) and other key roles have the appropriate qualification and experience. Some of other employees have the appropriate qualification and experience and others are controlled or supervised by those competent employees.
- **Good**: Specific corporate post holders (for example Board members and health and safety advisor) and other key roles have the appropriate qualification and experience. Most of other employees have the appropriate qualification and experience and others are controlled or supervised by those competent employees.
- **Excellent**: All employees have the appropriate qualification and experience.

Criterion 6: Monitoring, audit and review

- Minimum satisfaction standard
- The qualitative measurement indicator

Minimum satisfaction standard

TThe organisation should have a system that can monitor the procedures of H&S performance, audit them at periodic intervals and review them on an ongoing basis. One or some of following examples can be seen as evidence to meet the minimum standard:

- Evidence of formal audit or discussions/reports to senior managers.
- Evidence of recent monitoring and management response.
- Copies of site inspection reports.
- Other equivalent and substantial evidence.

The qualitative measurement indicator

- **Acceptable**: Documented evidence (at least one type of the above evidence for minimum satisfaction checking) shows that general monitoring, audit and review system has been in place.
- **Good**: Documented evidence (at least two type of the above evidence for minimum satisfaction checking) shows that structured monitoring, audit and review system has been established.
- **Excellent**: Documented evidence (at least two type of the above evidence for minimum satisfaction checking) shows that structured monitoring, audit and review system has been established. Furthermore, evidence shows that the

system can identify limitations or drawbacks in the performance of H&S management and develop corrective methods to improve the effectiveness of H&S management.

Criterion 7: Workforce involvement

- Minimum satisfaction standard
- The qualitative measurement indicator

Minimum satisfaction standard

The organisation* should have, and implement, an established means of consulting with its workforce on H&S matters. One or some of following examples can be seen as evidence to meet the minimum standard:

- Evidence showing how consultation is carried out.
- Records of health and safety committees
- Names of appointed safety representatives (trade union or other).
- Other equivalent and substantial evidence.

***** For those employing less than five persons, they should be able to describe how they consult with their employees to achieve the consultation required.

The qualitative measurement indicator

- **Acceptable**: There is a general workforce involvement system i.e. Safety committee or safety representatives.

- **Good**: There is a structured workforce involvement system, i.e. evidence showing that the system is working in the organisation and is helpful to improve H&S performance and management.
- **Excellent**: There are routine procedures of ensuring that the workforce is involved in the H&S management, i.e. evidence showing the monitoring and review of H&S publicity and communication throughout the organisation.

Criterion 8: Accident reporting and enforcement action; following-up investigation

- Minimum satisfaction standard
- The qualitative measurement indicator

Minimum satisfaction standard

- The organisation should provide records of all RIDDOR (the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1999) reportable events for at least the last three years.
- A system should be established to review all incidents and recording the action taken as a result.
- The organisation should record any enforcement action taken against the organisation over the last five years, and the action which the organisation has taken to remedy matters subjective to enforcement action.

One or some of following examples can be seen as evidence to meet the minimum standard:

- Evidence showing the way in which the organisation record and investigate accidents and incidents.
- Records of last two accidents/incidents and action taken to prevent recurrence.
- Records of any enforcement action taken over the last five years, and what action was taken to put matters right (please check HSE Enforcement Action Home and HSE Public Register of Convictions to retrieve information on enforcement taken by HSE over the last five years).
- For larger companies, simple statistics showing incidence rates of major injuries, over three-day injuries, reportable cases of ill health and dangerous occurrences for the last three years. Records should include any incidents that occurred whilst the company traded under a different name, and any incidents that occur to direct employees or labour-only sub-contractors.
- Other equivalent and substantial evidence.

The qualitative measurement indicator

- **Acceptable**: All RIDDOR reportable events in the recent three years are in the place. The records including last two accidents/incidents and follow-up actions, and any enforcement actions if occurred in last five years are available.
- **Good**: Besides the evidence listed at acceptable level, other documented evidence is provided to show that the accident investigation system has been established and can work effectively.
- **Excellent**: Besides the evidence listed at acceptable level, other documented evidence showing that the accident investigation system can work effectively and the corrective or preventative recommendations resulted from the

investigation can be implemented and have positive impact on the organisation's H&S performance.

Criteria 9: Sub-contracting/consulting procedures (if applicable)

- Minimum satisfaction standard
- The qualitative measurement indicator

Minimum satisfaction standard

The organisation should have arrangements in place for appointing and monitoring competent sub-contractors to ensure that they can work safely and without risk to health. One or some of following examples can be seen as evidence to meet the minimum standard:

- Evidence showing how the lead organisation ensure sub-contractors are competent.
- Examples of sub-contractor assessments the lead organisation have carried out.
- Evidence showing how the lead organisation require similar standards of competence sub-contractors.
- Evidence showing how the lead organisation monitor sub-contractor performance.
- Other equivalent and substantial evidence.

The rating standard on the quality of evidence

- **Acceptable**: Some forms of pre-qualification H&S assessment such as questionnaire responses, meeting minutes or audit records, have been applied to select competent sub-contractors/consultants and monitor their work and further appointment.
- **Good**: A general selection and monitoring system for different layer's sub-contractors/consultants has been in the place with practical evidence (at least three samples) showing that sub-contractors/consultants can be appropriately selected and effectively monitored.
- **Excellent**: A general selecting and monitoring system for different layer's sub-contractors/consultants has been in the place with substantial evidence (a record of projects in recent three years) showing that sub-contractors/consultants can be appropriately selected and effectively monitored.

Criterion 10: Hazard elimination and risk control (designers only)

- Minimum satisfaction standard
- The qualitative measurement indicator

Minimum satisfaction standard

The organisation should have appropriate arrangements to meet designer's duties under regulation 11 of CDM2007. One or some of following examples can be seen as evidence to meet the minimum standard:

- Evidence showing how you:
  - ensure co-operation of design work within the design team and with other designers/contractors;
  - ensure that hazards are eliminated and any remaining risks controlled;
  - ensure that any structure which will be used as a workplace will meet relevant requirements of the Workplace (Health, Safety and Welfare) Regulations 1992.
- Examples showing how risk was reduced through design.
- A short summary of how changes to designs will be managed.
- Other equivalent and substantial evidence.

(Note: the emphasis here should be on practical measures which reduce particular risks arising from the design, not on lengthy procedural documentation highlighting generic risks.)

The qualitative measurement indicator

- **Acceptable**: Evidence is provided to show the detail arrangements to meet designer's duties, i.e. hazard assessment and risk control forms or report.
- **Good**: A documented hazard assessment processes and practical samples are provided to show the arrangements to meet designer's duties.
- **Excellent**: A detailed record of projects in recent three years is provided to show the structured method and arrangements to meet designer's duties.

Criterion 11: Risk assessment leading to a safe method of work (contractors only)

- Minimum satisfaction standard
- The qualitative measurement indicator

Minimum satisfaction standard

The organisation should have procedures in place for carrying out risk assessments and for developing and implementing safe systems of work (the identification of health issues is expected to feature prominently in the system) / method statements. One or some of following examples can be seen as evidence to meet the minimum standard:

- Evidence showing how the organisation will identify significant H&S risks and how they will be controlled.
- Sample risk assessments / safe systems of work / method statements.

- If the organisation employ less than 5 persons and do not have written arrangements, it should be able to describe how it can achieve the above.
- Other equivalent and substantial evidence.

The qualitative measurement indicator

- **Acceptable**: Evidence is provided to show the process of doing risk assessment in practice.
- **Good**: A documented procedure and practical samples (at least three) are provided to show the arrangements for the risk assessment and control.
- **Excellent**: A detailed record of projects in recent three years is provided to show the structured method and arrangements for the risk assessment and control.

Criterion 12: Cooperating with others and coordinating your work with that of other contractors (contractors)

- Minimum satisfaction standard
- The qualitative measurement indicator

Minimum satisfaction standard

The organisation should illustrate the means of cooperating and coordinating with other parties in practice and the procedures of involving workforce in drawing up method statements / safe systems of work. One or some of following examples can be seen as evidence to meet the minimum standard:

- Evidence could include for sample risk assessments, procedural arrangements, project team meeting notes.
- Evidence of how the organisation coordinates its work with other trades.
- Other equivalent and substantial evidence.

The qualitative measurement indicator

- **Acceptable**: Evidence is provided to show the process of cooperating and coordinating with other parties and workforce in projects.
- **Good**: A documented procedures and practical samples (at least three) are provided to show the arrangements of cooperation and coordination with other parties and workforce in projects.
- **Excellent**: A detailed record of projects in recent three years is provided to show the structured procedures and arrangements for cooperation and coordination with other parties and workforce.

Criterion 13: Welfare provision (contractors)

- Minimum satisfaction standard
- The qualitative measurement indicator

Minimum satisfaction standard

The organisation should be able to demonstrate how it will ensure that appropriate welfare facilities will be in place before people start work on site. One or some of following examples can be seen as evidence to meet the minimum standard:

- Evidence could include
    - Health and safety policy commitment;
    - Contracts with welfare facility providers;
    - Details of type of welfare facilities provided on previous projects.
- Other equivalent and substantial evidence.

The qualitative measurement indicator

- **Acceptable**: Evidence is provided to show that the organisation has the ability to arrange the workforce facilities, but lacks experience of dealing with the same size of workforce before as in the current project.
- **Good**: Evidence is provided to show that the organisation has the ability to arrange the workforce facilities and some experience (at least one project) of dealing with the same size of workforce before as in the current project.
- **Excellent**: Evidence is provided to show that the organisation has the ability to arrange the workforce facilities and sufficient experience (at least five projects) of dealing with the same size of workforce before as in the current project.

Criterion 14: CDM co-ordinator's duties:

- Minimum satisfaction standard
- The qualitative measurement indicator

Minimum satisfaction standard

The organisation should demonstrate how it will go about encouraging cooperation, coordination and communication between designers. Generic procedures and practical samples are two key elements of the minimum satisfaction standard.

The qualitative measurement indicator

- **Acceptable**: Generic procedures are in place with at least one practical sample showing the effectiveness of implementing the procedures.
- **Good**: Generic procedures are in place with at least three practical samples showing the effectiveness of implementing the procedures.
- **Excellent**: Generic procedures are in place with a record of projects in recent three years showing the effectiveness of implementing the procedures.

Work experience

- Minimum satisfaction standard
- The qualitative measurement indicator

Minimum satisfaction standard

The organisation should provide details of relevant experience in the field of work for which it is applying. One or some of following examples can be seen as evidence to meet the minimum standard:

- A simple record of recent projects / contracts should be kept with the phone numbers / addresses of contracts who can verify that work was carried out with due regard to health and safety.
- Evidence showing that the organisation should have sufficient ability to deal with key health and safety issues arising from the work it is applying for.
- Where there are significant shortfalls in the organisation's previous experience, or there are risks associated with the project which it has not managed before, an explanation of how these shortcomings will be overcome should be provided.
- Other equivalent and substantial evidence.

The rating standard on the quality of evidence

- **Acceptable**: The organisation shows previous experience in at least one similar project with good recommendations from former clients, or evidence of good H&S performance. If there is any shortcoming in that project, detail explanation of improvement methods should be provided.
- **Good**: The organisation shows previous experience in at least three similar projects before with good recommendations from former clients, or evidence of good H&S performance. If there is any shortcoming in those projects, detail explanation of improvement methods should be provided..
- **Excellent**: The organisation shows previous experience in at least five similar projects before with outstanding recommendations from former clients, or evidence of perfect H&S performance. If there is any shortcoming in those projects, detail explanation of improvement methods should be provided.

Appendix 4 System Evaluation Questionnaire

Dear Sir/Madam

I am a Ph.D. research student at the School of Engineering and the Built Environment, University of Wolverhampton.

My research topic is 'A Knowledge-Based System for Construction Health and Safety Competence Assessment'. The aim of this project is to develop a Knowledge-Based System (KBS) to facilitate clients to take reasonable steps of assessing duty-holders' health and safety competence under the CDM Regulations 2007.

The prototype KBS for Construction Health and Safety Competence Assessment, named as KBS-CHSCA, has been developed, which can be accessed on http://www.constructionkbs.co.uk (Please use Internet Explorer to access the website). Presently, I am evaluating the developed KBS-CHSCA. I would appreciate it if you could spend a little time reviewing the system and filling in the following evaluation questionnaire to help further improvements to be made.

You can register as a new client or log in by using:

- 'david' as username and
- '123456' as password

to enter the client interface. You also can use:

- 'expert' as username and
- '123456' as password

to enter the expert interface.

The work being undertaken will investigate if the KBS-CHSCA could become a useful platform to facilitate efficient and effective judgment for H&S competence assessment. Any advice or constructive criticism would be highly appreciated and valuable for the research. Please feel free to contact me if there are any questions. The information provided by respondents will be held securely in the office and only accessible to the direct research team of this study. The respondents and their companies will not be identified in any research publications.

Thank you for your attention and kind assistance.

Yours faithfully

Hao Yu Ph.D. Research Student

School of Engineering and the Built Environment

University of Wolverhampton, WV1 1SB, UK

E-mail: H.Yu@wlv.ac.uk

Section 1: Basic Information

1. Name of organisation:

2. Size of organisation (number of employee):

3. What is your job title?

4. Length of time in current work role area (including previous jobs in the same area):

5. Have you ever known or worked on H&S competence assessment

Yes ☐ No ☐

Section 2: General Validation

1. Have you ever used or seen any other system for construction health and safety competence assessment?

Yes ☐ No ☐

If your answer is yes, please comment on the difference between other system and KBS-CHSCA.

2. How effective do you think KBS-CHSCA in supporting your decision-making for H&S competence assessment? Please rate the effectiveness of KBS-CHSCA (1= not at all effective 5 = very effective)

1 ☐, 2 ☐, 3 ☐, 4 ☐, 5☐

Any other comment?

3. How would you categorise the efficiency (time and efforts spending on decision-making) of using KBS-CHSCA compared with your current method? Please rate the satisfaction for the efficiency of using KBS-CHSCA (1 = very dissatisfied to 5 = very satisfied)

1 ☐, 2 ☐, 3 ☐, 4 ☐, 5 ☐

Any other comment?

4. What do you think the usability and interaction unit of KBS-CHSCA? Please rate the satisfaction for the friendliness (ease of use) of KBS-CHSCA (1 = very dissatisfied to 5 = very satisfied)

1 ☐, 2 ☐, 3 ☐, 4 ☐, 5 ☐

Any other comment?

5. Would you consider KBS-CHSCA to be a potential practical-solution and may have commercial prospects?

Yes ☐ No ☐

Section 3: Functional validation

1. What is your impression of the explanation facility (textual rules) for the minimum satisfaction standards and measurement indicator system? Please rate on the extent of understanding of those explanations (1 = not at all understood 5 = understood completely)

1 ☐, 2 ☐, 3 ☐, 4 ☐, 5 ☐

Any other comment or suggestion for improvement?

2. What is your impression of the usefulness of the case query facility for decision-making? (1= not at all useful 5 = very useful)

1 ☐, 2 ☐, 3 ☐, 4 ☐, 5 ☐

Any other comment or suggestion for improvement?

3. What is your impression of the usefulness of the expert query facility for decision-making? (1= not at all useful 5 = very useful)

1 ☐, 2 ☐, 3 ☐, 4 ☐, 5 ☐

Any other comment or suggestion for improvement?

4. What is your impression of the effectiveness of duty-holder judgment lists as evidence of reasonable decision-making? (1= not at all effective 5 = very effective)

1 ☐, 2 ☐, 3 ☐, 4 ☐, 5 ☐

Any other comment or suggestion for improvement?

Section 4: General opinion

Please provide any additional thoughts, opinions, suggestion, criticism, recommendations to help future improvements of KBS-CHSCA.

Appendix 5 Results of Evaluation Questionnaire Survey

No	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9a	Q9a-other	Q10a	Q10a-other	Q11a	Q11a-other	Q12	Q13a	Q13a-other	Q14a	Q14a-other	Q15a	Q15a-other	Q16a	Q16a-other	Q17	Date Taken
1			3500 in Group, 800 in Region	Regional Intergrated Systems Manager	6 years with this company.	Yes	No		3		3		3		No	3		3		3		3			9/2/2008 2:31:00 AM
2			20	Quantity Surveyor	35 years	Yes	No		3	who decides what is competance	3		3		No	4		3		4		3		don't like it, prefer my own assessment	9/2/2008 1:45:00 PM
3			20	Architect	20 years	Yes	No		4		4		3		Yes	4		3		3		4		It could be a helpful tool for Health and Safety evaluation under CDM	9/3/2008 2:43:00 PM
4			100	H&S competence assessor	6	Yes	Yes	our system doesn't support self-assessment	3		4		3		Yes	3		3		3		4		I was recently involved in evaluation of several CDM-Cs using ACoP L144 Appendix criteria.Some significant gap areas came out of this, including lack of documented arrangements for CDM compliance & ACM/ management awareness.A valuable part of the exercise was to invite prospective CDM-C in for interview - particularly important w.r.t App 5 requirements. The system helps bridge the gap and has the potetial to become a useful decision-support tool in practice.	9/9/2008 1:23:00 PM
5			As of 30 June 2007, the University has 1,094 teaching staff, 206 academic equivalent administrative staff and 1,507 general grade and ancillary staff (funded by UGC's block grant)	Postdoctoral fellow	about 4 years	No	No	Nil	3	Nil	3	Nil	3	Nil	Yes	3	Nil	3	Nil	3	Nil	3	Nil	Sorry that I am not familiar with the above questions and I just tried to answer it by estimation. Therefore, please ignore my answers	9/10/2008 7:43:00 AM
6				Civil engineer	9	Yes	No		2		3		2		No	2		3		2		4			9/11/2008 7:45:00 AM
7			50	Quantity Surveyor	10years	Yes	No		5		5		5		Yes	4		4		5		5			9/13/2008 9:36:00 AM
8			12	Health and Safety consultant	12years	Yes	No		4		4		4		Yes	4	It would be better to suppot decision if the explainatio n include more cases and examples	4		3		4	a GOOD SUMMARY OF DECISION-MAKING RESULTS		9/15/2008 8:05:00 AM

Appendix 5 Results of Evaluation Questionnaire Survey

No	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9a	Q9a-other	Q10a	Q10a-other	Q11a	Q11a-other	Q12	Q13a	Q13a-other	Q14a	Q14a-other	Q15a	Q15a-other	Q16a	Q16a-other	Q17	Date Taken
9			270	H&S Manager	6years	Yes	Yes	Document-based system	4		4		4		Yes	4		4		4		4	a useful judgment summary for the record-keeping		9/15/2008 10:15:00 AM
10			45	Architect	8years	Yes	No		3		4		3		Yes	4		3		3		4			9/15/2008 12:03:00 PM
11			300	Principal Structural Engineer	10 Years	Yes	No		4		4		3		Yes	3		3		3		4		more improvements can be made to its user friendliness (the button position) but well done so far!	9/15/2008 15:08:00 PM
12			1000	Research Associate	7 years	Yes	No		4		3		4		Yes	5		5		4		4			9/16/2008 2:38:00 AM
13			300	H&S coordinator	5years	Yes	Yes		3		3		3		Yes	3		3		4		3			9/16/2008 7:10:00 PM
14			200	qs	4years	Yes	No		3		3		3		Yes	4		3		4	The expert support facility could be useless without the real support from some organisations	3			9/16/2008 7:14:00 PM
15			50	H&S consultant	10years	Yes	No		4		3		4		Yes	3	More examples would be better	4		4		4			9/18/2008 11:45:00 AM
16			160	H&S Manager	3years	Yes	No		4		4		4		Yes	4		3		3		4			9/18/2008 2:45:00 PM
17			10	Health and Safety Consultant	15 years	Yes	No		4		4		4		Yes	3		3		4		3			9/18/2008 3:18:00 PM
18			20	Health and Safety Consultant	5years	Yes	No		4		4		4		Yes	5		4		5		4		Very useful tool. I can see that it has the potential to be used commercially.	9/18/2008 3:25:00 PM
19			200	Project Manager	7years	Yes	No		4		3		3		Yes	4		3		3		3			9/19/2008 9:25:00 AM

Appendix 5 Results of Evaluation Questionnaire Survey

No	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9a	Q9a-other	Q10a	Q10a-other	Q11a	Q11a-other	Q12	Q13a	Q13a-other	Q14a	Q14a-other	Q15a	Q15a-other	Q16a	Q16a-other	Q17	Date Taken
20			3,000	Research Project officer	3 months	No	No		3		3		3		Yes	3		3		3		3			9/19/2008 11:22:00 AM