Intelligent selection of demolition techniques

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INTELLIGENT SELECTION OF
DEMOLITION TECHNIQUES

by

ARHAM ABDULLAH

A Doctoral thesis submitted in partial fulfilment of the requirements for the
award of Doctor of Philosophy of Loughborough University

November 2003

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ABSTRACT

There is a need to improve the current demolition techniques selection process that involves a multicriteria decision making problems because the decision performed by demolition engineers were based on their knowledge and experience without any systematic procedure that can be followed to support the decision process. There is also a need to capture the expert’s knowledge since significant proportion of senior, experienced demolition engineers are close to retirement, and unless their knowledge is captured in some form, it would be lost. Concerning to these needs, the research aim is to develop an intelligent decision support system that incorporated the demolition expert’s knowledge in selecting the most appropriate demolition techniques for a given structure.

Various research methodologies were adopted to achieve the aim. Literature on demolition industry was first reviewed. Knowledge acquisition approaches were used to capture the demolition expert knowledge, which included an industry survey through postal questionnaire, semi-structured interviews, and protocol analysis. The rapid prototyping methodology was used in developing the prototype system. The proposed intelligent decision support system is called ‘Demolition Techniques Selection System’ (DTSS). The prototype system consists of two stages. The first stage will assist the decision maker to select the most appropriate demolition techniques in term of technical aspects by using Analytic Hierarchy Process (AHP) model. The second stage allows the decision maker to assess the demolition techniques in terms of cost by using the Demolition Cost Estimation model. The prototype was evaluated during and after the development process to verify, validates, and improves it. The evaluation revealed that the prototype system demonstrated many benefits and applicable for use in the industry.

It is concluded that the prototype provides a clear, systematic and structured framework that improved the current demolition techniques selection process. It also serves as an information source that contains a considerable amount of information on demolition techniques. It can act as a teaching aid for young professionals coming into the demolition industry by giving them a basic information and understanding of demolition. Demolition contractors can use the system as a marketing aid to impress potential clients to win a project because of its ability to give rational and structured decisions with the capability of generating graphical reports and sensitivity analysis.
DEDICATION

Allah hu Akbar

The research is dedicated to

My late mother (Rupeah Abu) who taught me love and kindness

My father (Abdullah Abdul Hamid) who taught me to be a wise man

My wife (Ezura) who gave support and understanding

Our son (Amin Aiman) for his laughter
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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND
The demolition industry in the United Kingdom (UK) has experienced transformation during the past 25 years. Today, most of the demolition projects undertaken are complex in nature demanding greater skill, experience and precision than ever before. In addition, more legislation that is stringent and growing commercial and environmental pressure have made a major impact on the selection of demolition techniques. Furthermore, various types of new demolition techniques are available in the demolition industry, which make the selection more complex. At present, hydraulic excavators with specialist attachments are used for almost every conceivable demolition work from dismantling the roof to breaking up and removing the foundations, replacing the once dominant crawler cranes and demolition balls. However, their use on demolition projects is not straightforward in practice due to complicated site conditions and other constraints. Before selecting any type of demolition technique, the demolition engineer needs to consider a set of criteria and assess their relevance to the demolition work to be undertaken in order to arrive at the most appropriate demolition technique.

The majority of today's urban construction is carried out on existing brownfield sites. The British government proposed in its statement 'Planning for the Communities of the Future', that 60% of new homes in England should be built on previously developed land and through conversion of existing building (Planning Policies Division, 1998). This will result in more demolition work as old buildings make way for new ones. This fact makes the demolition of structures or building a highly complex task that requires several considerations from various parties involved in the demolition process. The demolition of any type of structure is unique due to the sheer number of parameters that govern the demolition process. A parameter, which might be of great importance on a particular demolition project, might not be so if, for instance, the same demolition project was considered with a different site confinement. The changing nature of demolition parameters from one demolition project to another makes the selection of demolition techniques difficult for the demolition engineers.
1.2 JUSTIFICATION FOR THE RESEARCH

Part of the knowledge about demolition is written in books, legislative documents, guidance notes, journal papers and code of practice. This knowledge is either too general or too specialised for practical purposes and the task of searching through many documents for information relating to a particular situation is time-consuming. The largest and most useful part of this knowledge resides in the minds of expert demolition engineers and is difficult to access, and is lost when the engineer retires or dies. Furthermore, the current selection process is typically performed in an unstructured intuitive manner with considerable reliance on the experience, skill, knowledge, or judgement of the demolition engineer or other individual responsible for that demolition project. Therefore, to achieve a more successful solution to the current unstructured and unscientific approach to demolition techniques selection, it is essential to capture that knowledge and develop a more formalized and structured approach to this process. This is vital for the future survival of the demolition industry as a significant proportion of senior and experienced engineers are close to retirement and unless their knowledge is captured in some form, it would be lost. In addition, the knowledge captured can be very useful as a training tool for young engineers coming into the industry.

The demolition engineers can no longer depend totally on their past experience to decide which techniques to be used for each project because the nature of the selection process (which involves multicriteria decision-making ability), has become more complex during the past few years. To cope with this situation, there is a need by the demolition engineers as decision makers to have a sound technical framework for decision-making. This is to ensure that they do not miss out the important factors that might affect the safety and efficiency of the demolition process. An effective decision making process is important to systematically evaluate available demolition techniques against a number of influential criteria. It is also important that demolition engineers are well aware of the various demolition techniques available in the demolition industry, including their advantages and disadvantages. In order to satisfy these needs, it is therefore essential to carry out this research.
1.3 RESEARCH AIM AND OBJECTIVES
The main aim of the research was to develop a decision support system to aid demolition engineers in selecting the most appropriate demolition techniques for a given structure. The specific objectives of the project were:

- To understand the nature of the demolition industry and the characteristics of the demolition process;
- To explore the potential for using Artificial Intelligence (AI) techniques in improving the selection of demolition techniques;
- To investigate the range of demolition techniques available in the industry and the circumstances in which they are used;
- To investigate and define the criteria which affect the selection of demolition techniques; and
- To develop and evaluate a decision support system to assist demolition engineers in selecting the most appropriate demolition techniques in any given situation.

1.4 RESEARCH METHODOLOGY
Figure 1.1 illustrates the research methods used to achieve the specific objectives of the research. A brief description of the research methods used is given in this section. The detailed research methodology is presented in Chapter 2.

1. Literature Review: The extensive literature review focused on two major subjects: First, the overview of demolition industry to understand the nature of the demolition industry and the characteristics of the demolition process. Secondly, the reviews of decision-making to identify the potential application of Artificial Intelligent (AI) techniques as a decision support system. Literature reviews on these two subjects provided a theoretical background and form the basis for continuing further into the research. Review of the literature was achieved through several sources, which includes: publications from several professional bodies in
demolition; site visits and discussions with practitioners in the demolition industry; participation at workshop, seminars and conferences to interact with other researchers and professional in similar research areas; use of the Loughborough University Library to assess reports, thesis, journals and conference paper related to the subjects; and searches on the Internet.

2. **Knowledge Acquisition:** The process involved capturing and transforming appropriate knowledge from demolition experts into some manageable form in order to develop a decision support system in selecting demolition techniques. The knowledge that needs to be captured from the experts reflects the third and fourth objectives of the research (refer figure 1.1). This research used large-scale survey approach or questionnaire survey to capture preliminary knowledge of the subject matter, while in depth survey approach or interviews and protocol analysis were used to validate and to gain a better understanding on the knowledge captured from the previous approach.

3. **Prototype Development:** The development of the proposed decision support system was based on the results captured from the knowledge acquisition process. Rapid prototyping methodology was used in the prototype development. The process involved demonstrated the prototype system to an expert in early stage to identify errors and propose possible improvement to the system.

4. **Evaluation:** The completed prototype was evaluated before and after the development process to assess its functionality and usability. The evaluators were drawn from demolition experts and researchers. An actual demolition project was used as a case study in the evaluation process. At the end of each evaluation process, the evaluators were requested to complete a questionnaire that assessed the prototype from various perspectives.
1.5 THESIS LAYOUT

This thesis is divided into 8 chapters and a brief summary of each chapter’s contents is presented below:

Chapter 1, **Introduction**, introduces the research project undertaken and describes its background briefly. It then justifies the need for the research and explains its aim, objectives and methodology.

Chapter 2, **Research Methodology**, comprises of two sections. First, it reviews the basic concepts and principles relating to research methodology. Secondly, it describes the research methodology adopted for the research and justifies this.
Chapter 3, *The Overview of Demolition Industry*, gives the overall view of demolition industry including definition and evolvement in demolition industry. It also discusses the characteristics of the demolition process and identifies the criteria for the selection of demolition techniques. It then, followed by the discussion on the type of structural demolition and demolition techniques available in the industry. The chapter also reviewed the demolition cost estimation process in practice.

Chapter 4: *Review of Decision Making*, begins with reviewing the basic concept of decision-making including its definitions and phases. It then described the Multicriteria Decision Making (MCDM) in term of its methods and justify why Analytic Hierarchy Process (AHP) was selected for the research. In addition, the background and theoretical aspects of the AHP were presented. Finally, the chapter reviewed the basic concept of Decision Support System (DSS) and justify why Expert Choice (EC) software was selected as DSS tool used in the research.

Chapter 5: *Knowledge Acquisition for Model Development*, presents the results obtained from the questionnaire survey, semi-structured interviews and protocol analysis. The findings were used in the development of the proposed prototype system.

Chapter 6, *Development and Operation of the Prototype System*, presents the functional architecture of the prototype system. It then describes in detail the development process of the prototype system. It also, demonstrates the operation of the prototype system, with the key features of the system highlighted.

Chapter 7, *Evaluation of the Prototype System*, describes the system evaluation process. This is followed by an analysis of the evaluation results based on questionnaires completed by the evaluators. The benefits and limitations of the system are also discussed.

Chapter 8, *Conclusions and Recommendations*, presents the summary and conclusions of this thesis. It highlights the extent to which the aims and the objectives of the research have been achieved. It then discusses and concludes the key findings of the research. It ends with recommendations for future work.
CHAPTER 2: RESEARCH METHODOLOGY

2.1 INTRODUCTION
This chapter consists of two parts. The first part of the chapter reviews the basic concepts and principles relating to research methodology. The second part describes and justifies the methodology adopted in order to realise the aims and objectives of this research.

2.2 RESEARCH METHODOLOGY
The Oxford Compact English Dictionary defines research as "the systematic investigation into and study of materials and sources, in order to establish facts and reach new conclusions" (OCED, 1996). According to Greenfield (2001), research can also be defined as "an art aided by skills of inquiry, experimental design, data collection, measurement and analysis, by interpretation and by presentation". Research methodology is a process, a set of tools for doing research and obtaining information, or even an art for doing the work of science (Adams and Schvaneveldt, 1985). According to Mingers (2001) research methodology can be define as "structured set of guidelines or activities to assist in generating valid and reliable research results". In general, there are three types of research methodology: quantitative, qualitative, or a combination of both that is called triangulation or hybrid method (Fielding and Schreier, 2001). The choice of research method influences the way in which the researcher collects data. Before discussing the adopted research methodology, the following sections, reviews the characteristics of these research methods including their advantages and limitations.

2.2.1 Quantitative Research
Quantitative research is an inquiry into an identified problem, which is based on testing a theory composed of variables, measured with numbers and analysed using statistical techniques (Neuman, 2000). It is the most commonly used as part of conclusive research, but it also sometimes used when conducting exploratory research. Quantitative research tend to measure "how much" and "how often" (Creswell, 1994). It uses a variety of research methods to provide objective description and/or causal explanations about social phenomena or processes. The most common quantitative research methods include:
Experimental research and Survey research (Fellows and Liu, 1997). Descriptions on each of the quantitative research method are discussed in the following sections.

2.2.1.1 Experimental Research
It is a research situation in which one or more variables are deliberately manipulated or varied by the researcher (Chadwick et al., 1984). The researcher then conducts an experiment to determine the relationship between variables and if a relationship is causal. Experimental research is usually thought to be generalisable. There are two approaches to experimental research: laboratory experiments and field experiments. Field experiments are an extension of laboratory experiments, but are not conducted in a conventional laboratory. They are conducted in real social, industrial, economic and political arena (Fellows and Liu, 1997).

The major strength of the experimental research is the ability of the researcher to control over the variables, increasing the possibility of more precisely determining individual effects of each variable. In addition, determining interaction between variables is more possible. The major weakness of the experimental research is often the sample may not be representative of a population. For example, subjects could be limited to one location, limited in number, studied under constrained conditions and for limited time. When a human population is involved, experimental research becomes concerned if behaviour can be predicted or studied with validity. Human response can be difficult to measure. Human behaviour is dependent on individual responses. Rationalizing behaviour through experimentation does not account for the process of thought, making outcomes of that process inaccurate (Adams and Schvaneveldt, 1985).

2.2.1.2 Survey Research
There is an important distinction between surveys and survey research. A survey is a way of “Gathering information about the characteristics, actions, or opinions of a large group of people, referred to as a population” (Fowler, 1993). Many data collection and measurement processes are called surveys to name some of the most common such as marketing surveys, opinion surveys and political polls. Survey research is the surveys that are conducted to advance scientific knowledge. Survey research is a quantitative method, requiring standardized information from and/or about the subjects being studied. The subjects studied might be individuals, groups, organizations, or communities. They also
might be projects, applications, or systems. According to Pinsonneault and Kraemer (1993), surveys conducted for research purposes have three distinct characteristics as follows:

- To produce quantitative descriptions of some aspects of the study population. Survey analysis may be primarily concerned either with relationships between variables, or with projecting findings descriptively to a predefined population;

- The main way of collecting information is by asking people structured and predefined questions. Their answers, which might refer to them-selves or some other unit of analysis, represent the data to be analyzed; and

- Information is generally collected about only a fraction of the study population (a sample) but it is collected in such a way as to be able to generalize the findings to the population. Usually, the sample is large enough to allow extensive statistical analyses.

There are two main type of data collection method in survey research, which includes: questionnaires and interviews surveys. The choice of data collection method is significant because it affects the quality and cost of the data collected. For example, questionnaires are very good for collecting factual data, but they are less effective when sensitive data and complex data are needed. In general, quality and cost are highest with interviews whereas quality and cost are lower with questionnaires.

2.2.2 Qualitative Research
Holloway (1997) defined qualitative research as “A form of social inquiry that focuses on the way people interpret and make sense of their experience and the world in which they live”. Qualitative research, designed to observe social interaction and understand the individual perspective, provides insight into what people’s experiences are. Similar to quantitative research, qualitative research also includes a wide variety of methods and techniques and most authors do not agree on one classification system. According to Creswell (1994), to simply illustrate the diversity of the qualitative research methods, they may include action, case study and ethnography research.
2.2.2.1 Action Research

Action research is a combination of both action and research. Action research is a flexible spiral process, which allows action (change, improvement) and research (understanding, knowledge) to be achieved at the same time (Denzin and Lincoln, 2000). People affected by the change are usually involved in the action research. This allows the understanding to be widely shared and the change to be pursued with commitment.

Action research is used in real situations, rather than in experimental studies, since its primary focus is on solving real problems. It can, however, be used by social scientists for preliminary or pilot research, especially when the situation is too uncertain to frame a precise research question. Mostly, though, in accordance with its principles, it is chosen when circumstances require, flexibility, the involvement of the people in the research, or change must take place quickly or holistically. According to (O'Brien, 1998), it is often the case that those who apply this approach are:

- Practitioners who wish to improve understanding of their practice;
- Social change activists trying to mount an action campaign; and
- Academics who have been invited into an organization by decision-makers aware of a problem requiring action research, but lacking the requisite methodological knowledge to deal with it.

The advantages in using action research include: It provides an experience for researchers who want to work closely with the practitioner community; It can be used in many research modes, both to generate new theory and to reinforce or contradict existing theory; and It can be combined with other research methods for diversifying a research program (Patton, 1990). Despite it advantages, the limitations of action research method include: lack of control over individual variables that resulted in difficulties when attempting to distinguish between cause and effect; and its applications are usually restricted to a single organization and therefore arose the problem in the generalizations of individual studies.
2.2.2.2 Case Studies

Although there are numerous definitions, Yin (1994) defines the scope of a case study as follows:

"A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident"

Case study refers to the collection and presentation of detailed information about an individual, a group of people, an institution, or a whole community. The case study can be exploratory, explanatory and descriptive (Yin, 1994). In exploratory case studies, fieldwork and data collection may be undertaken before definition of the research questions and hypotheses. This type of study has been considered as an introduction to some social research. Explanatory cases are suitable for doing causal studies to explain causal links in real life interventions. Descriptive cases require that the investigator begin with a descriptive theory, to describe an intervention and the real-life context in which it occurred (Benbasat et al., 1987).

Case studies can be either single or multiple-case. Single cases are used to confirm or challenge a theory, or to represent a unique or extreme case (Yin, 1994). The single case study is appropriate where the objective is to develop a new theory rather then to test or prove an existing theory. When there is more than one single case, the study has to use multiple-case studies. Each individual case study consists of a "whole" study, in which facts are gathered from various sources and conclusions drawn on those facts.

The strength of case study research lies particularly when researchers want to get a detailed contextual view of an individual's life or of particular phenomena. In some situations, case studies provide a necessary starting point where no other information exists upon which to base other forms of research methodology. Case studies are also useful when researchers cannot, for practical or ethical reasons, do experimental studies (Gillham, 2000). The weakness of case studies is that they are restricted to a single individual or organisation or just a few and therefore may not be representative of the general group or population and it is difficult to generalise from case study research.
2.2.2.3 Ethnographic Research

Ethnography research relies heavily on up-close, personal experience and possible participation, not just observation, by researchers trained in the art of ethnography (Denzin and Lincoln, 2000). These ethnographers often work in multidisciplinary teams. The ethnographic focal point may include intensive language and culture learning, intensive study of a single field or domain, and a blend of historical, observational and interview methods. It differs from other qualitative research methods by its emphasis on culture. A cultural group can be any group of individuals who share a common social experience, location, or other social characteristics of interest. Typical ethnographic research employs three kinds of data collection: interviews, observation and documents (Spradley, 1979). This in turn, produces three kinds of data: quotations, descriptions and excerpts of documents, resulting in one product called 'narrative description'. The narrative description often includes charts, diagrams and additional artefacts that help to tell "the story" (Hammersley, 1990).

A key strength of ethnographic research is that it provides the researcher with a much more comprehensive 'in-depth' or 'intensive' research method possible than do other forms of research. One of the main disadvantages of ethnographic research is that it takes a lot longer than most other kinds of research. Not only does it take a long time to do the fieldwork, but it also takes a long time to analyze the material and write it up (Myers, 1999).

2.2.3 Triangulation Research

Triangulation can be seen as a concept for research method integration between quantitative research methods and qualitative research methods. Creswell (2003) describes triangulation as a mixed method approach, which involves both quantitative and qualitative data in a single study or multiple studies in a sustained program of inquiry. Triangulation may involve the convergence of different sources of information, different investigators, or different methods of data collection. The convergence can provide the advantages of each individual method and at the same time eliminate the disadvantages of each (Kelle, 2001). Table 2.1 shows a summary of the comparison between quantitative and qualitative research methods adopted from (Amaratunga et al., 2002).
Table 2.1: Comparison of Quantitative and Qualitative Research

<table>
<thead>
<tr>
<th></th>
<th>QUANTITATIVE RESEARCH</th>
<th>QUALITATIVE RESEARCH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of reasoning</strong></td>
<td>• Objective</td>
<td>• Subjective</td>
</tr>
<tr>
<td></td>
<td>• Inquiry from the outside</td>
<td>• Inquiry from the inside</td>
</tr>
<tr>
<td><strong>Type of questions</strong></td>
<td>• Pre specified</td>
<td>• Open ended</td>
</tr>
<tr>
<td></td>
<td>• Outcome oriented</td>
<td>• Process oriented</td>
</tr>
<tr>
<td><strong>Sampling</strong></td>
<td>• Large</td>
<td>• Small</td>
</tr>
<tr>
<td><strong>Data Collection</strong></td>
<td>• Structured questionnaires</td>
<td>• Structured, semi-structured or unstructured interviews</td>
</tr>
<tr>
<td><strong>Data Analysis</strong></td>
<td>• Numerical estimation</td>
<td>• Narrative description</td>
</tr>
<tr>
<td></td>
<td>• Statistical inference</td>
<td>• Constant comparison</td>
</tr>
<tr>
<td><strong>Outcome/Findings</strong></td>
<td>• Conclusive</td>
<td>• Not conclusive</td>
</tr>
<tr>
<td></td>
<td>• Generalised</td>
<td>• Cannot be generalised</td>
</tr>
<tr>
<td><strong>Strengths</strong></td>
<td>• Provide wide coverage of the range of situations</td>
<td>• Data gathering methods seen more as natural than artificial</td>
</tr>
<tr>
<td></td>
<td>• Fast and economical</td>
<td>• Ability to look at change process over time</td>
</tr>
<tr>
<td></td>
<td>• Where statistics are aggregated from large samples, they may be considerable relevance to policy decisions</td>
<td>• Ability to understand people's meaning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Ability to adjust to new issues and ideas as they emerge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Contribute to theory generation</td>
</tr>
<tr>
<td><strong>Weakness</strong></td>
<td>• Tend to be rather inflexible and artificial</td>
<td>• Data collection can be tedious and require more resources</td>
</tr>
<tr>
<td></td>
<td>• Not very effective in understanding process</td>
<td>• Analysis and interpretation of data may be more difficult</td>
</tr>
<tr>
<td></td>
<td>• Not very helpful in generating theories</td>
<td>• Harder to control the pace, progress and end-points of research process</td>
</tr>
</tbody>
</table>

(Source: Amaratunga et al., 2002)

There has been an increasing number of studies that advocate the benefits of combining qualitative and quantitative research methods (Erzberger and Prein, 1997; Kaplan and Duchon, 1988; Kelle, 2001). As Kaplan and Duchon (1988) point out, combining these methods increases the robustness of results because findings can be strengthened through cross validation. Moreover, combining these methods may lead to a better understanding of the phenomena under investigation, when additional information may be revealed that would otherwise remain undiscovered via a single methodological approach. For example, using a quantitative method such as a questionnaire can provide a broad idea on the subject studied and combining it with qualitative methods such as interviews or/and case studies provide a better understanding of the same study. There are four possible research design that combined both research approaches (Huberman and Miles, 2002):
1. The first design involves both quantitative and qualitative data being collected at the same time.

2. The second design uses a multi-wave survey, where both quantitative and qualitative data is being collected in parallel with continuous fieldwork. The first survey wave may raise specific issues to which the researcher should pay specific attention. The later fieldwork results may then modify the way in which the second survey wave is conducted.

3. The third design alternates the two methods, one after another. The first stage employs exploratory qualitative data collection that leads to the adoption of a quantitative data instrument such as questionnaire. The questionnaire results can be studied in more detail in further round of qualitative research.

4. The fourth design also uses an alternating style but in slightly different way. First, the survey is conducted to point the researcher to a specific phenomenon. Using qualitative research, the researcher develops a strong close-up conceptual understanding of the relationship between things and how they work and the quantitative experiment is designed to test the resulting hypotheses.

2.2.4 Choice of Research Approach

From previous discussion it is apparent that both quantitative and qualitative research methods involve differing strength and weakness. McGrath (1982) in his study of research choices make it clear that there are no ideal solutions, only a series of compromise. According to Neuman (2000), deciding on which type of research approach to choose depends on the purpose of the study, type and availability of information which is required. Galliers (1992) provides a list of research approaches that can be chosen based on the quantitative or qualitative research. Table 2.2 summarises this list according to the general philosophical base underpinning the different research approaches. It is important to note that most research approaches listed in the table can be used, at least to some extent, as either quantitative or qualitative research.
Table 2.2: Quantitative and Qualitative Research Approach

<table>
<thead>
<tr>
<th>RESEARCH APPROACHES</th>
<th>QUANTITATIVE RESEARCH</th>
<th>QUALITATIVE RESEARCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory Experiments</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Field Experiments</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Large Scale Survey</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>In Depth Survey</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Action Research</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Case Studies</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Ethnographic</td>
<td></td>
<td>√</td>
</tr>
</tbody>
</table>

(Source: Amaratunga et al., 2002)

2.3 THE METHODOLOGY ADOPTED FOR THE RESEARCH

The aim of the research is to develop a systematic approach, which act as a decision-making aid for demolition engineers in selecting the most appropriate demolition techniques. In order to develop the systematic approach this research adopted both quantitative and qualitative research depends on the objective need to be achieved. Brief descriptions of the methods used to achieve the aim and objectives of this research were presented in Chapter 1, Section 1.4. The following sections described each of the methods adopted in detailed.

2.3.1 Literature Review

A crucial element of all research is the review of relevant literature (Cooper, 1984). Literature reviews are used to inform researchers of the background to research projects and to provide context and ideas for the studies. According to Greenfield (2001), there are good reasons for spending time and effort on a review of the literature before embarking on a research project. These reasons include:

- To identify gaps in the literature;
- To avoid reinventing the wheel (at the very least this will save time and it can stop the research from making the same mistakes as others);
- To carry on from where others have already reached (reviewing the field allows the research to build on the platform of existing knowledge and ideas);
- To identify other people working in the same fields;
- To identify information and ideas that may be relevant to the research; and
- To identify methods that could be relevant to the research.
Several steps were taken to carry out the reviews of the literatures, which include: defining the topic; identifying source of information; keeping records; and reading and note taking.

2.3.1.1 Defining the Topic
This research selected two main topics to be reviewed based on the first and second objective of the research, which include:

- The demolition industry and the characteristics of the demolition process; and
- The potential for using Artificial Intelligent (AI) techniques in improving the selection of demolition techniques;

Literature reviewed on these two topics provided a theoretical background for the research. Other topic that related to the research such as research methodology was also reviewed.

2.3.1.2 Identifying Sources of Information
Having identified the literature to be reviewed, ways have to be found of obtaining copies of it all. In this research, most of the books and journal articles have been obtained, through libraries. The task of searching the published literature is made easier through the existence of computer databases, computerised catalogues and searches on the Internet. Specialise publications on demolition have been obtained from the Institute of Demolition Engineers United Kingdom (IDE), National Federation of Demolition Contractors United Kingdom (NFDC), European Demolition Association (EDA), Institute of Explosive Engineers (IEE) and National Association of Demolition Contractors United States (NADC).

Because a review is concerned with 'the literature', it is easy to assume that the only interest is in written information. However, people can be very important sources in a number of ways. One of the most effective ways to get the literature of an unfamiliar field is to ask for a list of key readings from an acknowledged expert. Such a person should be able to provide guidance to the 'specialised' material, the latest findings, journals that publish particularly the relevant material, and perhaps to unpublished material and other useful contacts.
2.3.1.3 Keeping Records
An important adjunct to the whole process of identifying and locating the material for a review is the necessity for keeping full and accurate bibliographic details, including information on the location of materials to help in finding something again quickly if necessary. Index cards are the classic format for storing bibliographic records (Greenfield, 2001). However, there is an increasing variety of computer-based record systems now available, ranging from simple databases which mimic the index card system in electronic form, to more powerful applications incorporating the ability to cross-reference, and to attach fields for notes to the bibliographic details. For the similar purpose, the research used 'EndNote' software for managing all the literatures that have been reviewed.

2.3.1.4 Reading and Note Taking
All the written materials have been read fully and reflectively, on the lookout for patterns, argument, new ideas, methodology, and areas of further enquiry. The information gathered was systematically transferred into notes by classifying it under various heading. In reviews covering a large amount of quantitative information, clearly presented tables of the data was noted, whereas reviews of qualitative material were noted in text.

2.3.2 Knowledge Acquisition
Turban and Aronson (1998) defined Knowledge Acquisition (KA) as "the process of extracting, structuring and organizing knowledge from one or more sources". It is also referred as the process of getting and transforming appropriate information from sources of expertise into some manageable form (McGraw and Harbison-Briggs, 1989). In the process of KA, the knowledge engineer carries out the activity of extracting the knowledge from an expert, checking it with the expert, and then representing the knowledge in the knowledge base. This activity is known as the "elicitation of knowledge" (Turban and Aronson, 1998). The aim of knowledge acquisition is to develop methods and tools that make the tough task of capturing and validating an expert's knowledge as efficient and effective as possible. Experts tend to be important and busy people, hence, it is vital that the methods used minimise the time each expert spends off the job taking part in knowledge acquisition sessions.

In this research, the KA process involved capturing and transforming appropriate knowledge from demolition experts into some manageable form in order to develop a
decision support system in selecting demolition techniques. The human expert in this research is the demolition engineer who makes the decision on what demolition technique to be used for a specified demolition project. The knowledge that needs to be captured from the experts reflects the third and fourth objectives of the research which include:

- The range of demolition techniques available in the industry and the circumstances in which they are used; and
- The criteria, which affect the selection of demolition techniques.

Many methods have been developed to help elicit knowledge from the experts. Research done by Welbank (1983) provide a comprehensive review on the appropriateness of KA methods when referred to the type of knowledge. Table 2.3 illustrates the findings from his reviews. When referred to the specific strength of the KA method, this research adopted large-scale survey approach or questionnaire survey (quantitative) to capture preliminary knowledge of the subject matter, while in depth survey approach or interviews and protocol analysis (qualitative) were used to validate and to gain a better understanding on the knowledge captured from the previous method. The research also used laddering method to represents the knowledge captured from the KA process. The detailed characteristics of these methods are discussed in the following sections.

<table>
<thead>
<tr>
<th>Method</th>
<th>Facts</th>
<th>Conceptual structure</th>
<th>Causal Knowledge</th>
<th>Procedures or Process</th>
<th>Expert’s strategy</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Questionnaire Survey</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Interview</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Case Studies</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protocol Analysis</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Card Sorting</td>
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<tr>
<td>Laddering</td>
<td></td>
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<td></td>
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<tr>
<td>Repertory grid</td>
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<td></td>
<td></td>
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</tr>
</tbody>
</table>

(Source: Welbank, 1983) X denotes the applicability of methods.
2.3.2.1 Questionnaire Survey

This research used questionnaire survey as the method for capturing the expert knowledge to establish a general industry wide perspective on demolition. A questionnaire can be defined as "a list or grouping of written questions which a respondent answers" (Adams and Schvaneveldt, 1985). It also known as a "manual expert driven system" or "Expert's Self-report" (Turban and Aronson, 1998). The questionnaire survey is a self-reported data collection method. It can be collected using mail survey through postal services or Internet survey through web and email. According to Schonlau et al. (2002), the Internet survey may be preferable to mail survey in the following cases:

- The survey is being conducted in an organization that has a list of e-mail addresses for the target population. The benefits in terms of cost and timeliness are greatest when the target population can be contacted initially by e-mail.

- The sample size is moderately large. Generally, web surveys have a larger initial start-up cost than mail surveys, but they have a lower marginal cost per survey respondent. Therefore, the web is not a cost-efficient medium for surveys with a small number of respondents. Quantifying "small" is difficult and estimates vary considerably with the assumptions being made.

Since most of the targeted population for the research do not have email addresses, and the population is considerably low (100 respondents), therefore a mail survey through postal services was considered more appropriate compared to the Internet survey.

Sampling is a process whereby one makes estimates or generalizations about a population based on information contained in a portion (a sample) of the entire population (Adams and Schvaneveldt, 1985). Sampling is concerned with drawing individuals or entities in a population in such a way as to permit generalization about the phenomena of interest from the sample to the population (Pinsonneault and Kraemer, 1993). The most critical element of the sampling procedures is the choice of the sample frame, which constitutes a representative subset of the population from which the sample is drawn. The sample frame must adequately represent the unit of analysis. The results from a good sample can be generalized to the entire client population from which the sample was drawn. The results from a poor sample only refer to the clients who participated.
Sampling methods are classified as either *probability* or *non-probability* (Sapsford, 1999). In probability samples, each member of the population has a known non-zero probability of being selected. Probability methods include random sampling, systematic sampling, and stratified sampling. On the other hand, if it is not possible to specify the probability of each member of the population, the sampling falls under the non-probability sampling. In non-probability sampling, members are selected from the population in some non-random manner. These include convenience sampling, judgment sampling, quota sampling and snowball sampling. Chapter 5 describes in more detail the sampling method used for the research.

The questionnaire needs to be designed to ensure the largest possible return, which enables meaningful analysis. The design of the questionnaire was referred to the procedures recommended by Creswell (2003), Fellows and Liu (1997) and Fowler (1993). The recommendations include the following:

- The questions must be clear, not ambiguous, and easy to answer;
- The questions should be in short sentences and brief;
- The language used for writing the questions should be simple;
- The questionnaire should be designed attractively and should be uncluttered;
- The questionnaire must be designed so that the analysis of results is easy; and
- Biased terms should be avoided in order to get a real view from the respondents.

There are two types of questions that can be used in the questionnaire survey: Closed questions and Open-ended questions. Closed questions limit respondents' answers to the survey. The respondents are allowed to choose from either a pre-existing set of answers, such as yes/no, true/false, or multiple choice with an option for "other" to be filled in, or ranking scale response options. Open-ended questions do not give respondents answers to choose from, but rather are phrased so that the respondents are encouraged to explain their answers and reactions to the question with a sentence, a paragraph, or even a page or more, depending on the survey. Fowler (1993) suggested that when a self-administered questionnaire is used, it is better to have a closed questions. In some questions, a space was provided as an option for respondents to give additional information.
A pilot survey is a process in questionnaire design to pre-test the questionnaire before it is used in a full-scale survey. The purpose of pre-testing the questionnaire is to determine:

- Whether the questions have any mistakes that need correcting;
- Whether the questions have been placed in the best order;
- Whether the questions are understood by all classes of respondent;
- Whether additional or specifying questions are needed or whether some questions should be eliminated; and
- Whether the instructions to interviewers are adequate.

Usually a small number of respondents from the targeted population are selected for the pre-test. After the questionnaire has been subjected to a thorough pilot test, all that remains to be done is the mechanical process of setting up the questionnaire in its final form. This will involve grouping and sequencing questions into an appropriate order, numbering questions, and inserting interviewer instructions. Chapter 5 describes in more detail the pilot survey conducted.

The descriptive statistics method was used to analyse the data collected from the questionnaire survey. Descriptive statistics used two basic approaches: numerical and graphical to summarize a collection of data in a clear and understandable way. The numerical approach computed statistics such as the mean and standard deviation, while the graphical approach created bar chart or pie chart. Graphical methods are better suited than numerical methods for identifying patterns in the data. Numerical approaches are more precise and objective. Since the numerical and graphical approaches compliment each other, it is wise to use both. Microsoft excel was used to ease the data analysis process. The results from questionnaire survey were presented in Chapter 5.

Questionnaire survey has several advantages when compared to interview and is described as follows (Suskie, 1992):

- It is more cost effective typically for studies involving large sample sizes and large geographic areas. It become even more cost effective as the number of research questions increases;
• There is uniform question presentation and no middleman, which can reduce bias. The researchers own opinions will not influence the respondent to answer questions in a certain manner. There are no verbal or visual clues to influence the respondent;

• Data entry and tabulation can be easily analyzed with many computer software packages;

• Most people have had some experience or familiarity completing questionnaires and they generally do not make people apprehensive; and

• It was less intrusive than interviews surveys. When a respondent receives a questionnaire in the mail, he is free to complete the questionnaire on his own timetable.

The limitations of questionnaire surveys include:

• The possibility to get low response rates from the survey. Response rates vary widely from one questionnaire to another. However, well-designed studies consistently produce high response rates.

• It allows little flexibility to the respondents with respect to response format. By allowing frequent space for comments, the researcher can partially overcome this disadvantage. Comments are among the most helpful of all the information on the questionnaire, and they usually provide insightful information that would have otherwise been lost.

• It is natural to assume that the respondent is the same person the researcher sent the questionnaire to but this may not actually be the case. Many times questionnaires are handed to other employees for completion.

• Questionnaires are simply not suited for some people. For example, a written survey to a group of poorly educated people might not work because of reading
skill problems. More frequently, people are turned off by written questionnaires because of misuse.

- The lack of personal contact will have different effects depending on the type of information being requested. A questionnaire requesting factual information will probably not be affected by the lack of personal contact. A questionnaire probing sensitive issues or attitudes may be severely affected.

2.3.2.2 Interviews

Interviews represent an effective method for collecting in-depth information about a topic or issue through direct verbal interaction between the interviewer and the respondent. It is the most popular type of knowledge acquisition method and requires the knowledge engineer and expert to talk to each other about the actual problem that the expert system should solve. It involves collecting information via instruments such as tape recorders, video camera, questionnaires etc. It is also important that the knowledge engineer has good communication skills and the expert should be able to express his knowledge to the engineer (McGraw and Harbison-Briggs, 1989). The interviewer can explain and clarify questions, and probe by asking additional questions, to enhance the likelihood of obtaining useful responses from the respondent. Interviews are particularly useful for getting information behind a respondent's experiences. It may also be useful as follow-up to certain respondents to questionnaires, e.g., to further investigate their responses.

Interviews can be conducted face-to-face or by telephone. Like face-to-face interviews, they allow for some personal contact between the interviewer and the respondent. Telephone interviews are typically used before a face-to-face interview often as a way of undertaking initial screening of respondents. There are three basic types of interviews: structured, semi-structured and unstructured (Fowler, 1993).

Structured interviews are, for the most part, orally administered questionnaires. It is known as a "systematic goal-oriented process" as it uses a systematic approach and therefore being a well-organized approach (Wright and Ayton, 1987). Semi-structured interviews make use of open-ended questions but seek specific information. It combines a highly structured agenda with the flexibility to ask subsequent questions. This is often the
preferred style of interview as it helps to focus the expert on the key questions and helps avoid them giving unnecessary information. Unstructured Interviews are informal and usually used as a starting point by obtaining a quick way of understanding the structure of the problem domain. It needs simple planning and is a brief way of understanding the structure of the problem domain and is usually followed by a more structured approach for understanding the attributes of the problem. It has the advantage of being a fast method to obtain the requirements but it has the limitation of being to vague (Wright and Ayton, 1987). Table 2.4 shows the comparison of these three types of interviewing techniques in term of it processes, advantages and disadvantages.

Table 2.4: Comparison of Interview Techniques

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structured Interview</strong></td>
<td>• Questions are set in advance</td>
<td>• Inflexible</td>
</tr>
<tr>
<td></td>
<td>• Each interview is conducted in exactly the same way</td>
<td>• Participants may be forced into giving responses which do not reflect their true feelings about an issue</td>
</tr>
<tr>
<td></td>
<td>• The questions and their order are the same for all respondents</td>
<td>• Gathers a limited amount of information: lack the richness obtained by more open-ended interviews</td>
</tr>
<tr>
<td></td>
<td>• The range of possible responses is determined by the researcher</td>
<td></td>
</tr>
<tr>
<td><strong>Semi-structured Interview</strong></td>
<td>• Very much like a questionnaire</td>
<td>• Requires interviewing skill</td>
</tr>
<tr>
<td></td>
<td>• Open-ended questions</td>
<td>• Need to meet sufficient people in order to make general comparisons</td>
</tr>
<tr>
<td></td>
<td>• Permissible to stray from the subject area and ask supplementary questions</td>
<td>• Time consuming and resource intensive</td>
</tr>
<tr>
<td></td>
<td>• Two-way communication. They can be used both to give and receive information</td>
<td>• Preparation must be carefully planned so as not to make the questions prescriptive or leading</td>
</tr>
<tr>
<td></td>
<td>• Less intrusive to those being interviewed as the semi-structured interview encourages two-way communication</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Confirms what is already known but also provides the opportunity for learning</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Gives the freedom to explore general views or opinions in more detail</td>
<td></td>
</tr>
<tr>
<td><strong>Unstructured Interview</strong></td>
<td>• Exploratory approach</td>
<td>• Requires interviewing skill</td>
</tr>
<tr>
<td></td>
<td>• No prepared list of questions</td>
<td>• Lack of standardization</td>
</tr>
<tr>
<td></td>
<td>• Open-ended questions</td>
<td>• The answers are difficult to analyse</td>
</tr>
<tr>
<td></td>
<td>• Allows flexibility</td>
<td>• Depends on the ability of respondents to express themselves</td>
</tr>
<tr>
<td></td>
<td>• Respondents can answer in their own words</td>
<td>• Time consuming</td>
</tr>
<tr>
<td></td>
<td>• The nature of the response in not limited</td>
<td>• Largest potential for interviewer bias</td>
</tr>
<tr>
<td></td>
<td>• The result of this more open-ended approach is a richness of data</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• More complex and sensitive questions possible</td>
<td></td>
</tr>
</tbody>
</table>
A semi-structured interview combines a highly structured agenda with the flexibility to ask subsequent questions. The questions for a semi-structured interview are ideally constructed some time before the interview and are sent to the expert so he/she can start to prepare responses. For an interview lasting 1 hour, around 10-15 questions might be asked. This allows time in between the set questions for the knowledge engineer to ask supplementary questions to clarify points and ask for more detail where necessary. This is often the preferred style of interview as it helps to focus the expert on the key questions and helps avoid them giving unnecessary information.

In this research, the large-scale surveys through postal questionnaires were followed by in-depth surveys through interviews to obtain deeper understanding of the problem found from the analysis of the questionnaire survey. Semi-structured interviews have been chosen as it allows the interviewer more freedom to explore expert's views or opinions while maintaining a level of comparability between interviewees.

Prior to interviewing, the researcher defined the information required based on the objectives of the interview. The information was incorporated into the overall research framework. Next, detailed questions were prepared and reviewed with a number of researchers to ensure all issues are covered and no language mistake made. Then, the interview was confirmed (time and place) in writing, and interviewees were supplied with the summary of the questions and a general outline of the issues to be reviewed. The critical role and assurance of confidentiality of the respondent was emphasized to secure cooperation. After a few weeks, follow up phone calls were made to the selected interviewees to fix the date and time for the interview.

Each interview was conducted on one to one basis at the interviewee office and last about one hour. During the interview, the interviewer gave a brief statement to describe the objectives of the interview and granting permission from the interviewee to record the interview, so that the interviewer could concentrate on the discussion and to ensure that information is accurately reported. Even though the tape recorder is running taking brief notes is useful. It provides the interviewer with something to do while the respondent formulates an answer and slows the pace of the interview to ensure everything is covered. In addition, taking notes indicates to respondents that their words are important.
The interviewer provides a summary of interview notes to the interviewee for approval after the interview session ends. Then, the interview was transcribed in detail after each interview to ensure ‘freshness’ and understanding of the information captured. Chapter 5 describes the findings from each interview.

Other techniques such as card sorting and laddering techniques were also used during the interview session to elicit specific knowledge from the interviewees. Card sorting techniques are used to capture the way experts compare and order concepts, and can lead to the revelation of knowledge about classes, properties and priorities (Turban and Aronson, 1998). In laddering techniques, the interviewee and interviewer both refer to a ladder or hierarchy presented on paper or a computer screen, and add, delete, rename or re-classify nodes as appropriate (Diaper, 1989). The interviewer can make use of a set of generic questions to prompt the expert to elaborate the hierarchy. Both of these techniques will be further discussed in the next section.

2.3.2.3 Card Sorting
In this technique, the expert is given a number of cards each labelled with a concept (object name). The expert has the task of repeatedly sorting the cards into piles such that the cards in each pile have something in common (Diaper, 1989). This creates hierarchical structures, which can be used to develop rules and the position of each concept with respect to others.

In this research, card-sorting technique was used during the semi-structured interviews. The expert was asked to group a randomly distributed set of cards, each labelled with the name of demolition techniques (identified from the questionnaire survey and literature) into three types of structural demolition. After they build up the hierarchy, the expert was asked to define each of the demolition techniques based on their understanding. The results are shown in Chapter 5.

2.3.2.4 Laddering
Laddering method involve the creation, reviewing and modification of ladders or hierarchies (Diaper, 1989). In this method the expert and knowledge engineer both refer to a ladder presented on paper or a computer screen, and add, delete, rename or re-classify nodes as appropriate. The knowledge engineer can make use of a set of generic questions
to prompt the expert to elaborate the ladder. Various forms of ladder can be used as follows:

**Concept Ladder**
A concept ladder shows concepts and instances and the classes and sub-classes to which they belong. All relationships in the ladder are the ‘is a’ relationship, e.g. car is a vehicle. A concept ladder is more commonly known as taxonomy and is vital to representing knowledge in almost all domains.

**Composition Ladder**
A composition ladder shows the way a knowledge object is composed of its constituent parts. All relationships in the ladder are the ‘has part’ or ‘part-of’ relationship, e.g. wheel is part of car. A composition ladder is a useful way of understanding complex entities such as machines, organisations and documents.

**Decision Ladder**
A decision ladder shows the alternative courses of action for a particular decision. It also shows the pros and cons for each course of action, and possibly the assumptions for each pro and con. A decision ladder is a useful way of representing detailed process knowledge.

**Attribute Ladder**
An attribute ladder shows attributes and values. All the adjectival values relevant to an attribute are shown as sub-nodes, but numerical values are not usually shown. For example, the attribute *colour* would have as sub-nodes those colours appropriate in the domain as values, e.g. *red*, *blue* and *green*. An attribute ladder is a useful way of representing knowledge of all the properties that can be associated with concepts in a domain.

**Process Ladder**
This ladder shows processes (tasks, activities) and the sub-processes (sub-tasks, sub-activities) of which they are composed. All relationships are the *part of* relationship, e.g. boil the kettle *is part of* make the tea. A process ladder is a useful way of representing process knowledge.
The laddering method was used in this research to create a hierarchy that represent the decision problem in selecting demolition techniques. The process involves creating, reviewing and modification of the decision hierarchy with the experts during the development of the proposed prototype. Chapter 6 described in details the laddering method used in the research.

2.3.2.5 Protocol Analysis

Tracking methods were used to track the reasoning process of an expert. It allows the knowledge engineer to see what information the expert is using and how he/she is using it. Tracking methods can be a formal one or an informal one, the main formal approach is Protocol Analysis and an informal approach is Observations (Turban and Aronson, 1998).

Protocol Analysis is similar to interviewing but more formal and logical. The expert is asked to carry out a task but he/she has to think out aloud while working through the problem/task. The difference between this and interviews is that there is mainly a one-way communication in protocol analysis as the knowledge engineer gives a scenario and plans the process. In addition, the difference of protocol analysis over interviews is that in interviews the expert tells a knowledge engineer, what he thinks should be done in practice rather than how it is done in practice. The expert will then talk about what he/she is doing to solve the problem, while the knowledge engineer is listening and recording what is being said, thus enabling the knowledge engineer to obtain an accurate result.

Observational approach is another way of generating protocols. Simply observing and making notes as the expert performs their daily activities can be useful, although a time-consuming process. Videotaping their task performance can be useful. On the whole, though, observation approach was rarely used, as they are an inefficient means of capturing the required knowledge.

The protocol analysis approach was conducted in this research by asking the expert to think aloud while estimating the cost when an example of a demolition project was given to them. The researcher used a video camera to record what was being said after the expert allowed permission to use it. The protocol was analysed by highlighting all the concepts that are relevant to the demolition cost estimation process including the list that contains the cost involved for each type of demolition technique. The findings were then
reviewed and validated by the expert. A series of meetings were conducted for this purpose until all the experts agreed with the findings. Chapter 5 describes the findings from the protocol analysis approach.

2.3.3 Prototype Development

An important element of the methodology used which also the fifth objective of the research was the development of the prototype system (refer to Chapter 1, Figure 1.1). The prototype system development uses a methodology known as Rapid Prototyping. In rapid prototyping interactive prototypes are developed which can be quickly replaced or changed in line with design feedback (Smith, 1996). This feedback may be derived from the experts or users as they work with the prototype. The process of rapid prototyping is shown in Figure 2.1 (Turban and Aronson, 1998).

![Figure 2.1: Rapid Prototyping Process (Source: Turban and Aronson, 1998)](image)

The process starts with the design of the prototype system, which includes designing the system architecture, and identifying the implementation and operational framework. Then the knowledge was acquired through the knowledge acquisition process and represented in the prototype. Next, several tests have been carried out using historical and hypothetical cases for self-evaluation of the prototype system. Afterwards, the expert was asked to judge the results and evaluate the prototype where the knowledge representation methods and the software and hardware effectiveness were checked. The results or findings from the evaluation were analysed, and if the improvement is needed the prototype is redesigned. The prototype went through several iterations with appropriate refinements. The process continues until the prototype is ready for a formal
demonstration. Once the prototype was demonstrated, it is evaluated again and improved. This process continues until the final (complete) prototype is ready. Chapter 6 described the overall development of the prototype system.

2.3.4 Evaluation

According to Preece et al. (1994), evaluation is concerned with gathering data about the usability of a design or product by a specific group of users for a particular activity within a specified environment or work context. With respect to human computer interaction, evaluation can be distinguished into ‘formative’ and ‘summative’ depending upon the stage at which it occurs. Some authors emphasize that formative evaluation takes place during development and summative evaluation after development. The definition of these terms includes:

"Formative evaluation is typically conducted during the development or improvement of a program or product (or person, and so on) and it is conducted, often more than once, for the in-house staff of the program with the intent to improve. Summative evaluation of a program is conducted after completion of the program and for the benefit of some external audience or decision maker."

(Scriven, 1991)

"Formative evaluation is evaluation of the interaction design as it is being developed, early and continually throughout the interface development process. This is in comparison to summative evaluation, which is evaluation of the interaction design after it is complete, or nearly so."

(Hix and Hartson, 1993)

The prototype system developed was evaluated in two stages. The first stage involved the evaluation of the prototype system during the development process, which also known as 'formative evaluation'. Several demolition experts participated in the evaluation process to validate and verify the prototype. The prototype went through several iterations with appropriate refinements to improve it. The second stage involve the evaluation of the prototype system after the development process, which also known as 'summative evaluation'. Several demolition experts and researchers were invited to give their views
on the final prototype. The comments and recommendations are noted and some modification made to improve it. The prototype evaluation is described in detail in Chapter 7.

2.4 SUMMARY

In this chapter, the basic concepts and principles relating to research methodology were reviewed and the different types of research methodologies were described. The chapter has also described the methodology adopted in order to realise the aims and objectives of the research. The research methodology adopted several approaches and is presented through four main sections: literature review; knowledge acquisition; prototype development; and evaluation of the prototype system. The next chapter focuses on an overview of the demolition industry including a discussion of existing industry practice.
3.1 INTRODUCTION
This chapter gives an overview of the demolition industry including recent developments in the industry. It also discusses the characteristics of the demolition process and identifies the criteria for the selection of demolition techniques. Types of structural demolition and demolition techniques available in the industry are also discussed in this chapter. The chapter also reviews the process for estimating the cost of demolition projects.

3.2 DEFINITION
Various definitions of the term ‘demolition’ have been found in the literature. Some of the common definitions include:

"The controlled removal of selected part of the structure or key structural members to cause complete collapse of the whole or part of the building structures"
(BS 6187: 2000)

"The complete or partial dismantling of a building or structure, by pre-planned and controlled techniques or procedures"
(AS 2601: 2000)

"Dismantling, razing, destroying or wrecking any building or structure or any part thereof by pre-planned and controlled techniques"
(Building Department Hong Kong, 1998)

"Dismantling, wrecking, pulling down or knocking down of any building or structure or part thereof"
(Department of Labour New Zealand, 1994)

These definitions can be summarized as the removal, dismantling, destruction, razing, wrecking, pulling down or knocking down of any building or structure by pre-planned and controlled techniques to cause complete collapse of the whole or part of the building or structure.
3.3 DEVELOPMENTS IN THE DEMOLITION INDUSTRY

The demolition industry has experienced radical transformation during the past 25 years. High reach hydraulic excavators and specialist attachments have superseded crawler cranes and demolition balls; demolition site safety and procedures have been improved significantly; and demolition contractors have become highly specialised experts in the art of demolition. In addition to this transformation, the 'British Standard Code of Practice for Demolition', has been revised three times since its introduction in 1971. It started with CP94, which has been superseded by BS 6187: 1982 and currently by BS 6187: 2000.

The mechanisation of demolition work started in the late 1950s with the introduction of pneumatic hand hammer breakers and steel balls as far as concrete structures are concerned (Kasai, 1988a). The slabs of multi-storey buildings were first broken up by 'balling' and then hand hammer breakers crushed the beam-ends. Finally, the remaining large walls, often of several spans and storeys, were then felled in a single operation.

The trend during the 60's and 70's towards building in concrete and steel has made fresh demands on the skills and working techniques of demolition contractors. From 1967, chemical expansive demolition agents were developed in Japan and available as commercial products by 1978 (Kasai, 1988a). The removal of surface concrete by the rebar heating technique using alternating current was another Japanese development and after the initial experimental trials were complete in 1968, it was later used for the demolition of special structures (Brydon, 1991).

A most important development in demolition techniques was the introduction of concrete crushers in England in 1975 (Polman, 2000). During this period, manufacturers of construction plant and general contractors joined in developing hydraulic 'C-shaped' concrete crushers, diamond cutters and flame jetting techniques. Motivated by this and using the experience gained from the production of 'C-shaped' crushers, a number of highly efficient concrete crushers were developed and can be seen in use today.

In 1979, a study of the demolition of the Japan Power Demonstration Reactor (JPDR) by the Japan Atomic Energy Research Institute (JAERI), resulted in many useful developments for the demolition of reinforced concrete structures by explosives, core boring machines, large diamond cutters, abrasive water jetting and techniques for
stripping surface concrete by the use of microwaves (Kasai, 1988b). In 1981, diamond wire saw for cutting reinforced concrete was introduced to the industry and it was expected that this technique would be the subject of further developments over the coming years.

Since the use of explosives to safely fell structures dates back over 300 years, many chemists, inventors, blasters and demolition experts worldwide have played important roles in the evolution of what has become the modern-day explosive demolition industry (Brent Blanchard, 2002b). ‘The Infamous Gunpowder Plot’, one of the first documented attempts to actually fell a building with explosives, occurred in 1605, when disgruntled Englishman Guy Fawkes placed barrels of explosive powder under the British Parliament in an attempt to blow-up the structure and kill King James I (Brent Blanchard, 2002a). In the 19th century, nitro-glycerine, dynamite and blasting caps were invented and made structural blasting a safe, efficient alternative to conventional demolition techniques. Later, in the 20th century, the shaped charge technology combined with portable seismology and non-electric delay systems were developed, allowing an ever-expanding variety of structures to be explosively felled by demolition experts throughout the country (Liss, 2000).

Today’s demolition contractors are increasingly turning to the use of hydraulic excavators, as the most productive, cost efficient solution to their equipment needs to reflect the changing demands. Excavators and mini excavators are used for almost every conceivable job from dismantling the roof to breaking up and removing the foundations, replacing almost totally the once dominant track loader and crawler crane and drop ball (Polman, 2000). Excavator design is heavily modified to match the demands of the demolition site and hydraulic systems can be adjusted to match the flows and pressures to different attachments. The majority of today’s high reach machines currently offer an upward reach of between 15 and 25 metres; larger units have already breached the psychological 40-metre barrier (Halberstadt, 1996). Equally common in the demolition industry today is the use of top-down techniques where mini excavators and skid steer loaders equipped with small, powerful hydraulic hammers are used to remove the upper floors of a high-rise structure.
The majority of today's urban construction is carried out on existing brown field sites, because of the steady depletion in available green field sites (Planning Policies Division, 1998). As a result, the demolition work may involve either the complete or partial redevelopment of the site and existing buildings. This situation, along with more stringent legislation and growing commercial and environmental pressures, has had a major impact on the selection of demolition techniques. In addition, demolition is becoming a more complex and demanding process, as contract periods become shorter, legislation more demanding, and the competition even tougher. This change requires a considerable research, training, preparation and the introduction of new techniques.

3.4 THE DEMOLITION PROCESS
The demolition process can be divided into four main stages: Tendering stage; Pre-demolition stage; Actual demolition stage; and Post-demolition stage (Figure 3.1). These are discussed below to provide a better understanding of the demolition process and the selection of demolition techniques.

![Figure 3.1: Demolition Process Flowchart](image-url)
3.4.1 Tendering Stage

The tendering stage in demolition process is outlined below:

- The demolition process starts when the client makes a decision to demolish a structure;

- Usually, a small number of demolition contractors are invited to bid their offers. The early selection of contractor either by evaluating the contractor's previous performance, or on the basis of competitiveness of an estimated preliminary cost given by contractors;

- Next, the contractor has to find out about the site before he/she can prepare a risk assessment. In the British standard code of practice for demolition, section 7.1 BS 6187: 2000 states that knowledge of the site should be elicited by an initial desk study and followed by an on-site survey to augment the desk study. Off-site features that can affect work on site should also be determined;

- The next step is to carry out the risk assessment, which identifies the risks associated with the work and planning the removal or reduction of the risks before the work commences;

- The demolition engineer then needs to select the demolition technique based on this risk assessment and other contributing factors such as technical and economical aspects;

- The next process is to produce a method statement. The method statement addresses the site's particular needs (i.e. site preparation) and details the planned sequences and demolition techniques selected in the previous process; and

- The tender document with the method statement will then be submitted to the client. If the contractor is selected by the client to do the job, they will continue to the next stage, which is the Pre-demolition stage. If the client does not select the contractor, then the contractor have to abandon the project and bid for another job.
3.4.2 Pre-Demolition Stage

From the demolition contractor's point of view, the pre-demolition stage involves the following process:

- The first process in the pre demolition stage is site preparation. The process may include the erection of security fencing and setting-up welfare facilities (e.g. site office, washing facilities and toilet).

- The second process is the decommissioning. It can be defined as the "process whereby an area is brought from its fully operational status to one where all live or charged systems are rendered dead or inert and reduced to the lowest possible hazard level" (BS 6187, 2000). The decommissioning activities include for example, removal of all asbestos, chemicals (e.g. battery acids, oils) and controlled release of stored energy in strong springs or suspended counterweights.

- The third process is soft stripping. It is the removal of non-structural items such as fixtures and fittings, windows, doors, frames, suspended ceilings and partitions.

- The forth process in the pre-demolition stage is reuse and recycling. Some of the product from the soft stripping process can be reused and recycle. Materials such as wood from windows or door panels can be reused as building lumber, landscape mulch, pulp chip and fuel, as these can be cleaned and reused. However, this is rarely done. Aluminium and stainless steel panels and copper are the typical recycled metals. Architectural artefacts such as sinks, doors, bathtubs and used building materials are usually resold. Even the industrial process equipment can be marketed both domestically and internationally (NADC, 1996).
3.4.3 Actual Demolition Stage

The actual demolition starts when the structural elements are demolished. There are three main types of structural demolitions, which include: Progressive demolition; deliberate collapse mechanisms and deconstruction. Those are the alternative techniques that can be selected by the contractor at the tendering stage.

The reuse and recycling process can be done after or concurrently with the structural demolition process. With current technologies such as hydraulic excavators attached with pulverizers, concrete crushing and screening machines, contractors are able to separate demolition debris. This process can maximise the use of resalable materials and subsequently reducing waste disposal costs. Typical recycled materials were metals and concrete debris. The recycled metals are scrap iron, reinforcement bars in concrete, aluminium, stainless steel and copper. Concrete debris is pulverised and can be used as fill material and sub-base (NADC, 1996).

3.4.4 Post-Demolition Stage

The final process is the site clearance; the site should be left in a clean, safe and secure condition. Any pits, sumps, trenches, or voids must be left filled, securely covered and the site drainage system must be thoroughly cleaned and tested to ensure that it continues to operate. All contaminants must be left or removed in a condition such that they represent no hazard to health or the environment. Finally, the planning supervisor should ensure that the health and safety file has been compiled and handed to the client on completion of the work.

3.5 TYPES OF STRUCTURAL DEMOLITION

There are three main types of structural demolition as reported in the ‘British Standard Code of Practice for Demolition’, BS 6187: 2000 and these are as follows:

1. Progressive Demolition.
2. Deliberate Collapse Mechanisms.
3. Deliberate Removal of Elements or Deconstruction.
3.5.1 Progressive Demolition
The progressive demolition is the controlled removal of sections of the structure, at the same time retaining the stability of the remainder and avoiding collapse of the whole or part of the structure to be demolished (BS 6187, 2000). Progressive demolition is particularly practical in confined and restricted areas and may be considered for the majority of sites. The progressive demolition includes progressive demolition by machine and progressive demolition by balling. In progressive demolition by machines, the excavator was attached with boom and hydraulic attachments such as pulverizers, crushers and shears. For progressive demolition by balling, a demolition ball is suspended from a lifting appliance and then released to knock the structure repeatedly in the same or different locations.

3.5.2 Deliberate Collapse Mechanism
Demolition by deliberate collapse is the removal of key structural members to cause complete collapse of the whole or part of the building or structure (BS 6187, 2000). This technique usually employed on detached, isolated, fairly level sites where the whole structure is to be demolished. A sufficient space must be allocated to enable removal of equipment and personnel to a safe distance. The demolition by deliberate collapse includes deliberate collapse by explosive and deliberate collapse by wire rope pulling.

3.5.3 Deliberate Removal of Elements or Deconstruction
The deliberate removal of element is the removal of selected parts of the structures by dismantling or deconstruction (BS 6187, 2000). Deconstruction is process reverses the sequence of construction, dismantling a structure that proceeds from roof to ground in a general trend. The structures are carefully dismantled in order to maximize the recovery of valuable building resources for reuse and recycling. This technique can be used, for example as part of renovation or modification work and prepare the way for deliberate collapse. The elements to be removed should be identified and the effects of removal on the remaining structure fully understood and included in the method statement, with the elements to be removed marked on site. If instability of any of the remainder might result in a possible risk to personnel on the site and to other people nearby, sections of the structure should not be removed. The deconstruction can be done by hand or machines.
3.6 TYPES OF DEMOLITION TECHNIQUES

There are many types of demolition techniques in the industry. Many of them are used together in the structural demolition method discussed in Section 3.5. Kasai et al., (1998) stated that the demolition techniques could be classified into eleven principles and mechanisms, while in code of practice for demolition BS 6187: 1998, the demolition techniques are listed into seven categories, which include:

- Hand demolition;
- Mechanical demolition by pusher arm;
- Mechanical demolition by deliberate collapse;
- Mechanical demolition by demolition ball,
- Mechanical demolition by wire rope pulling;
- Demolition by explosive; and
- Other techniques of demolition.

The new code of practice for demolition, BS 6187: 2000 have classified the demolition techniques into four main types. This includes demolition by machines; demolition by hand; demolition by chemical agents; and demolition by high pressure water jetting. This section will try to review all the demolition techniques available in the demolition industry so that it can be used as a reference for future steps in this research. Figure 3.2 shows the types of demolition techniques.

3.6.1 Demolition by Machines

Progressively demolished structures or elements of structures should generally be demolished in the reverse order to that of their construction. The structures can be demolished by operatives using hand-held tools, however, in term of safety, the risk assessments will usually demonstrate that using remote demolition techniques, e.g. by machine should be more appropriate. Therefore, this section will try to review various types of machines that can be used in the demolition process.
Demolition Techniques

Demolition by Machines

Demolition by Machines

Demolition by Chemical Agents

Demo by High Pressure Water Jetting

Demolition by Hand

Demolition by Chemical Agents

Hot Cutting

Explosive

Bursting

Mechanical Non-Hydraulic Attachments

Diamond Disc Cutter

Hand Hammer

Diamond Wire Saw

Hot Cutting

Explosive

Bursting

Gas Expansion Bursters

Hydraulic Bursters

Expanding Demolition Agent

Balling

Wire Rope Pulling

Diamond Core Drilling

Diamond Floor Sawing

Rock Sawing

Track Diamond Sawing

Hand Held Ring and Chain Sawing

Tungsten and Dry Cutting Methods

Diamond Wire Sawing

Explosive

Bursting

Figure 3.2: The types of demolition techniques
3.6.1.1 Tower and Other High Reach Cranes

The use of tower and other high reach cranes for deconstructing high rise structures should be considered for the removal of structural elements and transporting other equipment or debris to a specific location in the demolition site. For example, W&M Thomson a demolition contractors successfully remove the Tall Oil Plant at Birtley Co. Durham which includes four columns, 40m high weighing 120 tons each in three days using a 400te telescopic crane rigged on super lift and using 120te crane for tailing (Figure 3.3). Figure 3.4 shows other type of tower and high reach cranes that can be used in demolition process.

Figure 3.3: 400te telescopic crane rigged
(Tatten, 2001a)

Figure 3.4: Tower and high reach cranes
(Tatten, 2001a)
3.6.1.2 Mechanical Non-Hydraulic Attachments

Demolition techniques by mechanical (non-hydraulic) attachments can be classified into two sections, which include balling and wire rope pulling.

**Balling**

Demolition by ball involves the progressive demolition of a building by the use of a weight that is suspended from a lifting appliance and then released to impact the structure, repeatedly, in the same or different locations (BS 6187, 2000). During the process, the ball is either dropped onto or swung into the structure that is to be demolished. One of the oldest and most commonly used techniques for building demolition, the ball and crane uses a demolition ball weighing up to 6000 kg to demolish concrete and masonry structures (Brydon, 1991). The ball may be spherical, rectangular, pear-shaped or cylindrical. The pear shape has the advantage that it cannot roll away upon being dropped vertically. Balls are generally made of cast steel. Cylindrical balls are often made of steel. The suspension point of a ball is virtually always made of steel. A steel chain is often used as the first part of the suspension. Three types of guided ball may be distinguished, i.e. the pestle ball and the cylindrical ball, both of which are guided by a tube and the arrow drop ram, which has a rectangular ball with two U-shaped guides.

For demolition by balling, the auxiliary machine from which the ball is suspended must permit the ball to perform two types of motion: free fall and a swinging or ballistic motion. The choice of auxiliary machine depends on the object to be demolished, the direction of impact (horizontal or vertical), the size of ball required and the distances involved (including the height). The most common auxiliary machine is the dragline (Demolition X, 2001). For demolition purposes it is equipped with free-fall winches and can drop the weight vertically, impart a swinging motion to it in the longitudinal direction of the arm via the pulling cable and by moving the arm sideways, can impart an oscillatory motion perpendicular to the arm. Cranes with telescopic jibs, tower cranes and other high reach machines should not be used for demolition balling operations. Reference should be made to British standard code of practice for safe use of mobile crane (BS 7121-3, 2000). Figure 3.5 shows the balling machines and demolition ball.
The arrow drop ram is a fully automatic balling machine designed for the demolition of horizontal objects such as roads, runways, floors and carriageway (Demolition X, 2001). It is mounted on a driven chassis with four wheels with pneumatic tires. The rectangular ball is suspended in two U-shaped guides. The entire suspension can be displaced transversely across the width of the chassis. The automatic adjustments are the height of fall, the number of blows and the speed at which the machine is displaced. If required, the ball can be fitted with an impact tool in the form of a spike, knife-edge, or cylinder.

![Figure 3.5: Balling machine and Demolition Ball (Demolition X, 2001)](image)

**Wire Rope Pulling**

This technique of mechanical demolition involves attaching wire ropes to a structure, usually of steel and pulling the pre-weakened structure to the ground by winch or tracked plant (BS 6187, 2000).

The foot of a column or a smokestack is cut into a V-shape to the intended felling side. It is felled by the imbalance of weight and pulling with wire ropes. Structural members can be pulled down by means of steel wire ropes attached to them. The force applied must never exceed the permissible load for the rope. There are various possible ways of applying the pull to the rope, such as the use of independent winches or the winches of draglines or by traction. The rope may be passed through, for example, a double or triple pulley block in order to increase the pulling force. The arm of a hydraulic excavator can also provide the required force on the rope. This arrangement has the advantage that the machine operates at a suitable distance from the member to be demolished. Figure 3.6 shows the operation of wire rope pulling technique.
3.6.1.3 Cutting by Drilling and Sawing

Drilling and sawing techniques are used to weaken and/or remove parts of (or complete) structures, particularly where work is in confined spaces, in locations where a high degree of accuracy is needed, or where the noise, dust, smoke and vibration resulting from other techniques would be unacceptable or inappropriate (BS 6187, 2000). Drilling and sawing work should follow the guidance in the United Kingdom Drilling and Sawing Association Code of Safe Working Practice (Drilling & Sawing Association, 1999). This section will look into several examples of drilling and sawing techniques that can be considered in the demolition works. The techniques include:

Diamond Core Drilling
A quiet vibration-free technique of drilling that produces clean holes without spalling in reinforced concrete and other solid materials. A series of diamond-drilled holes are made to form slots using "stitch" drilling techniques (BS 6187, 2000). Core drill machines can be operated in either vertical or horizontal direction and can be powered by electric, hydraulic or air sources.

Diamond Floor Sawing
Self-propelled saws using diamond blades capable of cutting trenches, expansion joints, removal of slabs, including e.g. motorway repairs and airport works (BS 6187, 2000). For roads, runways, warehouse aprons and ground floors, this machine is ideal. Its limitations are it cannot be used in confined spaces; it is noisy, can only be used on flat horizontal surfaces and cannot get very close to walls.
Rock Sawing
Large "ride-on" rock saws used for cutting out large areas of concrete rapidly. The machine employs large tungsten-tipped wheels capable of cutting to depths in excess of 2000 mm (BS 6187, 2000).

Tracked Diamond Sawing
This equipment was developed to enable cutting of door and window openings through walls as well as through floors for stairways, lifts, etc., without the need to stitch drill i.e. a series of interlocking holes.

Hand-held Ring and Chain Sawing
This is a development of the wood chain saw and is hydraulically powered. It employs a chain fitted with diamond segments. It has not proved to be very successful in reinforced concrete. It is very useful for cutting window and doorway openings in brick and block because straight lines can be cut with right angle corners. The depth of cut is limited by the blade diameter, but up to 250mm can usually be managed depending upon the type of material being worked upon (Drilling & Sawing Association, 1999). It is fairly quiet and vibration free and the blades are diamond type. This unit can be used to form door and window openings in walls also openings in precast floors.

Tungsten and Dry Cutting Techniques
This technique used a hand held drills that have a range of tungsten-tipped for drilling holes in plain concrete, brick and block. It can also be hand-held cutting machines that have a dry cutting diamond blade for forming cut or holes where dust is not a hazard.

Diamond wire sawing
Developed some time in the mid 1990s, diamond wire sawing is exceptionally quiet, efficient and cuts fast through heavily reinforced concrete and steel bars (Hermansson, 2002). A concrete structure can easily be sawn into pieces and each block then lowered down to the ground for demolition. Compared with other concrete sawing techniques such as a wall saw, diamond wire sawing is normally easier to install and cuts openings faster. Diamond wire technique is very selective compared with breakers and crushers because only cuts out the material to be removed, and therefore reduces the risk of repairs to the surrounding area. Diamond wire sawing is also ideal for use on renovation projects.
3.6.1.4 Remote Controlled Machines and Robotic Device

In the situation of hazardous or potentially dangerous situations arise; consideration should be given to the use of remotely controlled machines and robotic devices. The operator can be removed from the dangers of working in a confined or hazardous area. The machines can be controlled by digital signalling system transmitted via cable or radio. One of the machines that used remote demolition technology is the 180 Model from Brokk (Figure 3.7). The machine is design for use in the regeneration and renewal of urban, commercial and industrial environments. It also had been design to better suit accessories, particularly heavier tools up to 230kg and either a 15 or 18.5kW electric motor to drive the machines. Its standard weight exclude accessories are 1,900kg with a basic work area radius of 4550mm, which can be increased depending on attachments (Tatten, 2000).

![Remote Demolition Machine Model Brokk 180](image)

Figure 3.7: Remote Demolition Machine Model Brokk 180
(Tatten, 2000)

3.6.1.5 High Reach Machines

Consideration should be made to use an appropriate machine e.g. excavator fitted with suitable booms and arms to mechanize the dismantling of high rise structures or building. The model R974B-VH Litronic is one of the examples of super long reach demolition machines. This model is the biggest specialist demolition machines in Liebherr range and equipped with the latest technology and capable of 41 metres working height (Tatten, 2001a). Figure 3.8 show the demolition of a tower block by using a high reach machines attached with concrete crusher.
3.6.1.6 Compact Machines

Compact machines e.g. mini-excavators and skid-steer loaders can be fitted with hydraulic attachments, which can be used, for cutting and breaking out, handling, processing and stripping on the upper floors of buildings (BS 6187, 2000). It is fast, agile and small enough to work inside structures. Examples of compact machines used in the demolition industry shows in Figure 3.9 and 3.10.

Figure 3.9: Wheeled Skid-Steer Loader 753 Bobcat (Halberstadt, 1996)

Figure 3.10: Tracked Skid-Steer Loader with Hydraulic Hammer Attachment (Tatten, 2000)
3.6.1.7 Hydraulic Attachments

Hydraulic attachments can be mounted onto the base machine or equipment for the progressive demolition of reinforced concrete or steel structures e.g. cut steel, crush or pulverize concrete, lift and handle material. This section will review some of the hydraulic attachment usually used in the demolition process, which include pusher arm; impact hammer; shears; grapple; pulverizers; crusher; demolition pole; and multi-purpose attachments.

**Pusher Arm**

Demolition by pusher arm involves the progressive demolition of a structure using a machine fitted with a pusher arm-exerting horizontal thrust (BS 6187, 2000). A demolition boom is used for pushing and pulling down parts of structures. The end portion of the boom is equipped with a claw attachment and is telescopically extendable. The whole assembly is mounted on a hydraulic excavator. The boom is particularly suitable for the demolition of comparatively light structures such as houses. Considerable dust formation may occur, especially when demolition work on a structure is being carried out at relatively great height. The height of the building should be reduced by hand demolition to a height to suit the machine being used. Then, reduced progressively by pushing small sections to the ground (Figure 3.11).

![Figure 3.11: Hydraulic excavator (Cat 325) as a base machine fitted with pusher arm (Tatten, 2001a)](image-url)
Impact Hammer
Demolition by impact hammer involves the progressive demolition of masonry and concrete structures by applying heavy blows to a point in contact with the material, and may be pneumatically or hydraulically operated (BS 6187, 2000). This large and powerful hammer is mounted on a crawler type or wheel type machine. There are two types of energy transmission to a hammering rod, one is pneumatic force and the other is hydraulic force.

The Pneumatic Hammer
The pneumatic hammer makes more noise than the hydraulic one, and therefore hydraulic hammer is widely used in urban areas. There are a number of advantages in using pneumatic hammers, these includes can be mounted on lighter carriers; mounting an air hammer requires only mechanical changes – no hydraulic connections, systems to service, or plumbing kits; Pneumatic hammers work better in confined spaces than hydraulic hammers due to their high weight-to-power ratio; and pneumatic hammers are more conducive to underwater use, having few, if any, seals.

Hydraulic Hammer
A hydraulic hammer should not be chosen strictly on the basis of the reach, stability, or hydraulic capacity necessary, but also on the vehicle on which the tool will be mounted. For a given reach, the heavier the hammer, the heavier the carrier vehicle must be. The weight of the carrier vehicle prevents overturning when the hammer is at the boom's maximum reach. Selecting a lightweight carrier decreases the boom's reach and could cause an overturning accident. While most hydraulic systems run 2000-psi pressure, the flow rate varies. For the light hammers, as little as 5 gallons per minute is required. For the heavy hammers, more than 100 gallons per minute must be supplied (Demolition X, 2001). For example, The Rammer E64 City Jet is a powerful, efficient hydraulic hammer for carriers in the 12 to 20 ton weight class (Figure 3.12). It also features the exclusive City sound suppression system, ideal for sensitive application where noise levels have to be kept to a minimum. Versatility is increased by the City jet water spray system that reduces the dust created by the breaking operations (Tatten, 2001a).
Shears

Where a wide range of materials, including metal sections and reinforced concrete are to be removed by cold cutting techniques, and where materials are to be cut in situ, machines fitted with hydraulic shears should be considered for use. Cold cutting can be defined as technique of cutting with the generation of no incendiary sparks and little or no heat (BS 6187, 2000). There are two types of hydraulic shears, which includes:

- **Mobile Hydraulic General Purpose Shears** – Patented angular shaped jaws draw material into the throat for maximum efficiency; 105° rotation provided by side mounted cylinder; can be supplied in rigid form, dipper or boom mounted; to fit machines from 5 to 75 tons. (Figure 3.13 and Figure 3.14).

- **Mobile Hydraulic Plate and Tank Cutting Shears** – Plate/tank cutting jaws fitted to Universal Processor; 360° hydraulic rotation; same attachment can be modified for other duties; to fit machines from 18 to 90 tons. (Figure 3.15 and Figure 3.16).
Figure 3.13: Cleaver mobile hydraulic general-purpose shears
(Allied Equipment, 2001)

Figure 3.14: LaBounty mobile hydraulic general-purpose shears
(Allied Equipment, 2001)
Figure 3.15: Cleaver mobile hydraulic plate and tank cutting shears
(Allied Equipment, 2001)

Figure 3.16: LaBounty mobile hydraulic plate and tank cutting Shears
(Allied Equipment, 2001)
Pulverizers

Mechanical demolition by machine-mounted pulverizers is the progressive demolition of reinforced concrete or brick structures by crushing the material with a powerful jaw action by closing the moving jaw against the material (BS 6187, 2000). The pulverizer attachment can be used for crushing beams, columns, floor slabs and in situ panels. It also can be used as an option for the lifting and loading of steel and concrete beams and other solid materials. Figure 3.17 show excavator mounted LaBounty Concrete Pulverizers for 180° and 360° Hydraulic Excavators. Some of the key features of the concrete pulverizer are listed below:

- No additional hydraulic services necessary;
- Mounts on to excavator arm in place of backhoe bucket;
- Upper moving jaw operated by bucket cylinder;
- Fitted with rebar cutting blades, larger models;
- Crushes reinforced concrete, removes rebar; and
- To fit machines from 2 to 200 tons.

Figure 3.17: Excavator mounted with LaBounty concrete pulverizers (Allied Equipment, 2001)
Crusher

The Concrete Crushers have a moving jaw operated by internally mounted hydraulic cylinder. The lower jaw screens material and can be fitted with rebar cutting blades. Breaks and Crushes most grades of reinforced concrete (Figure 3.18).

![Cleaver concrete crushers](Demolition X, 2001)

Demolition Pole

A telescopic or rigid demolition pole, to which attachments such as a claw or ripper hooks can be fixed, can be used to achieve a greater working height and distance from the base machine during the progressive dismantling of, e.g. roofs, walls, lintels of brick built structures. The fitting of an extended pole, which is mounted on the dipper arm, increases the working radius of the machine (BS 6187, 2000).

Figure 3.19 show, the super long reach demolition machine model R947B-VH Litronic from Liebherr can be fixed with 11m demolition boom, 2.7m intermediate boom, 6m boom extension, an 8.5m demolition stick and type 66 hydraulic quick-hitch system. With all the extension attached, a working height of 41 metres and forward reach of 22 metres can be achieved (Tatten, 2001b). Figure 3.20 show telescopic, rotating booms for 360° hydraulic excavators.
A grapple is designed for use in primary demolition and rehandling applications for, e.g. steel and concrete beams, columns, walls and floor sections and roof joists progressively to ground level. The jaws interlock to enable partial loads to be safely secured. The parallel-jaw closing action ensures that material is drawn into alignment during the dismantling, lifting and loading cycle as appropriate. Some key features for Allied-sorting grapple for 360° Hydraulic Excavators is listed below (see Figure 3.21):

- Parallel jaw;
- Heavy duty Sorting Grapple;
- Mounts on to the end of the dipper stick in place of the bucket;
- Serrated outer cutting edges;
- Enclosed body;
- Bolt on replaceable teeth;
- Interchangeable with Grapple and Concrete pulverizer brackets;
• Requires no additional hydraulic services; and
• To fit machines from 20 to 35 tons.

Figure 3.21: Allied sorting grapple
(Allied Equipment, 2001)

Multi-purpose Attachments
Multi-purpose attachments can be used to progressively demolish reinforced concrete or steel structures including chemical and oil storage tanks by the use of interchangeable jaws for steel cutting, concrete crushing, concrete pulverising or plate/tank cutting. Multi-purpose attachments can be mounted either directly to the boom or to the dipper arm. Excavator mounted with LaBounty Universal Processors has a modular design to utilize a standard body to accept a wide range of jaws for alternative duties. It also has a 360° power rotating head and can fit machines from 18 to 90 tons (Figure 3.22). The interchangeable jaws include Shear Jaws; Combination Demolition Jaws; Concrete Cracking Jaws; Pulverizer Jaws; Plate Cutting Jaws; and Wood Jaws.

Figure 3.22: Excavator mounted LaBounty Universal Processors
(Allied Equipment, 2001)
3.6.2 Demolition by Hand

Hand demolition involves the progressive demolition of a structure by operatives using hand-held tools and lifting appliances may be used for lifting and lowering members once they are released. Hand-held equipment defined in BS 6187:2000 as powered portable equipment or manual tools for operation in the hand of one or two operatives. The hand-held tools that can be used under this technique are listed below:

3.6.2.1 Diamond Disc Cutter

The disc cutter is capable of cutting reinforced concrete. A disc over 1000 mm in diameter is available. The main principle in diamond based demolition techniques is that they make use of diamond’s hardness properties to cut or grid concrete members of various sizes. Diamond blades are made by welding or brazing diamond segments to the perimeter of steel disk (Addison, 1987). The diamond segments are made of diamond particles held together by a metal bond. Blade saws are generally used to cut structural members into larger sections that can then be removed using an overhead crane. During a cutting operation, the blades get heated up and a water source is required to cool the blades which otherwise will cause the detachment of the diamond segments. Such type of blades that require water while operating is known as Wet-cutting diamond blades and are the most common type of blades used to cut concrete. It is recommended that while cutting a reinforcement bar, the blade and the pressure on the blade should be reduced and the flow of water increased (Fesseha, 1999). Dry cutting diamond saw blades are also available which should be used on low-horsepower saw. As diamond blades are very expensive, it is important that the operator of the machine is trained and experienced.

3.6.2.2 Hand Hammer

There are four types of hand hammer, which are Electric, Pneumatic, Gasoline and Hydraulic powered hammer. Gloves must be worn when demolishing with hand tools. The eyes must be protected against flying materials by wearing goggles. Fitting pneumatic hand hammers with suppressors can reduce the noise. In this way, the noise at a distance of 7 m can be reduced to 80-90 dB (A). If the noise is louder than 80-dB (A), ear-defenders should be worn (Demolition X, 2001). Because of their large return stroke, hydraulic hand hammers are less suitable for continuous work than pneumatic hammers; this is certainly the case for heavy mechanical hand hammers. The vibrations of both types of hand hammers could, however, cause white finger disease if air-filled grips are
not being used. Mechanical hammers can all give rises to some degree of vibration. Whether vibration will occur depends on the size of the hammer, the material to be demolished and its mass. The hand tool generates very little dust. Pneumatic hammers disperse more dust than hydraulic hammers because of the escaping air. Figure 3.23 shows an example of electric hand hammer being used in demolition works.

![Electric hammer](image)

**Figure 3.23: Electric hand hammer**  
(Demolition X, 2001)

**Electric Hammer**

In these hammers, the stroke energy is obtained from an electric motor via an eccentric cam, which produces a reciprocating motion. They give lower stroke energy than comparable pneumatic or hydraulic hammers. These hammers are only occasionally used for demolition work; they can be used to demolish both vertical and horizontal objects.

**Pneumatic Hammer**

The impact energy of this hammer is obtained by allowing compressed air to expand in the cylinder of the hammer, driving the piston rapidly against the anvil, which transmits the released impact energy to the chisel. This arrangement exploits the ability of a gas (air) to be compressed and to produce movement upon expansion. The hammer is used in association with a compressor, which supplies it with compressed air at the appropriate working pressure. Most types of hammers can be provided with a mantle to suppress noise. All pneumatic hammers can be used under water. However, they must be pressurized before they are submerged and must be kept under pressure until they have been raised from the water. When working at greater depths a loss of efficiency (power loss) occurs owing to the counter pressure.
**Gasoline Power Hammer**

In these hammers, the stroke energy is obtained from the rotation of a gasoline motor, which is converted, to a reciprocating motion by an eccentric cam. They weigh from 10 to 40 kg. These hammers also give lower stroke energy than corresponding pneumatic or hydraulic hammers. If the hammer is fitted with a float less carburettor, it is also suitable for vertical demolition work.

**Hydraulic Hammer**

In these hammers, the impact energy is obtained from hydraulic oil supplied at a fairly high pressure. Since hydraulic oil is an incompressible fluid, the pressure cannot be converted into motion without an auxiliary medium. To make such motion possible, hydraulic hammers are equipped with a nitrogen bulb or a nitrogen chamber. The compressible nitrogen is separated from the oil by a diaphragm and provides the requisite conversion of pressure into motion. In this way, the piston of the hammer can be thrust rapidly against the anvil. The anvil transmits the released impact energy to the chisel. The used oil is returned at low pressure to the oil reservoir. The hydraulic hammer operates with a completely enclosed hydraulic system. Even so, unlike the pneumatic hammer, the hydraulic hammer is not suitable for working under water unless its supply has been adapted for that purpose. However, the hydraulic hammer can be switched on and off under water, which is not possible with the pneumatic hammer. Owing to the closed system, there is no pressure loss. Long supply and return hoses do introduce a pressure loss, but this can be compensated.

**3.6.2.3 Diamond Wire Saw**

Wire saws were first developed in the stone quarry industry in Italy, and diamond wire saws have been used in concrete demolishing work to cut reinforced concrete in United States of America since the early 1980s (Hulick and Beckham, 1989). A loop of diamond wire mounted on a flywheel driven by a hydraulic or electric motor. Hydraulic drives powered by electric, gasoline, or diesel units are usually preferred on wire saws when cutting reinforced concrete, since they are both reversible and provide continuously variable speed. Water is applied to the cut to provide cooling and to flush the cut. Diamond wire saws are more efficient than circular saws, able to cut concrete of almost any thickness. This makes them very useful for the kind of heavy demolition found in
bridges, dams and thick concrete structures. In addition, they create little dust, noise and vibration, making them ideal for demolition work within inhabited structures. The real force behind the diamond wire saw is the diamond wire itself – a steel carrier cable threaded through steel beads to which diamond is bonded.

3.6.3 Demolition by Chemical Agents
Demolition by chemical agents is highly specialized activity and must be undertaken only by, or under supervision of trained personnel. This section will cover three types of demolition by chemical agents based on BS 6187:2000, which includes hot cutting; demolition by explosive; and bursting.

3.6.3.1 Hot Cutting
Hot cutting techniques include any technique that can potentially generate sufficient heat, e.g. in the form of friction, sparks or flame. The techniques commonly use oxy-fuel gases and disc grinders. BS 6187:2000 defined hot cutting as technique of cutting where heat is applied, e.g. by flame, or is generated, and/or where there is potential for producing incendiary sparks.

Work on site using flame cutting equipment and compressed gas cylinders should be undertaken by people with the appropriate training and experience. Reference should be made to ‘safety in gas welding, cutting and similar processes’ published by Health and safety Executives (HSE, 1999) and ‘the safe use of compressed gases in welding, flame cutting and allied process’ (HSE, 1997). The ‘Thermic Lancing’ and ‘Thermic Reaction’ techniques of demolition are two techniques that use heat as a means of weakening or severing a structure in order to facilitate its removal.

Thermic Lancing
Thermic lancing used thermic lance to cut through materials including concrete. The tip of the lance is preheated to start an oxygen/ion reaction, which produces an intense heat source that is then applied to the material to be cut (BS 6187, 2000). For example, aluminium alloy or iron alloy wires are enclosed in a same metal pipe of about 14 mm or 18 mm in diameter. At first, the metal lance is ignited using acetylene gas flowing between the wires in the pipe. The acetylene gas is turned to oxygen gas and the metal
lance continues to burn. The heat of combustion can melt concrete and rebars (Concrete Network, 2001).

**Thermal Reaction**

The thermal reaction technique is typically used in conjunction with wire rope pulling to break up structural steel members (BS 6187, 2000). A metal oxide and a reducing agent will cover the member to be weekend that when ignited which may be remotely initiated electrically reacts to produce a large quantity of heat. After ignition, the steel becomes plastic or weekend and a small unbalancing force applied, which is a pulling rope, should normally enough to affect the collapse of the member.

3.6.3.2 **Explosive**

If explosives are to be used for demolition, the planning and execution, include pre-weakening, should be under the control of a person competent in these techniques. Recommendations on the use of explosives are given in the code of practice for the safe use of explosive in the construction industry (BS 5607, 1998). Only explosives engineers who can demonstrate that they have the necessary qualifications, experience and training in accordance with the code of practice should be employed on such work.

When the use of explosives is considered, it is usual to employ a technique that will ensure the total demolition of the whole building by staging a controlled collapse. The explosive charges are set and fired in a sequence that will weaken the structure in such a way that the building collapses in upon itself. Traditionally, the primary options for blasting techniques were blasting of high-rise structures such as high-rise buildings, towers, smoke stakes etc., and blasting of heavy concrete structures, e.g. foundations. Today many of these types of structures can be demolished by use of traditional mechanical techniques. However, blasting techniques have developed and new applications have been competitive and successful. For examples, the application includes:

- Blasting of structures, height more than 50 m;
- Demolition of special structures i.e. offshore structures;
- Fast demolition of bridges;
- Dismantling of concrete structures;
• Localized cutting of concrete structures; and
• Exposure of reinforcement bars.

Compared with mechanical demolition techniques the major advantages of blasting techniques are:

• Cost effective and time saving;
• Demolition process can be shortened;
• The use of heavy machinery can be limited; and
• Applicable in case of difficult access to the demolition site or narrow space.

It is very important to note that blasting technique is applicable for the demolition of all kinds of concrete structures, whereas all mechanical machines and techniques have some limitations with respect to size, height, thickness, accessibility etc. In spite of this, the use of blasting techniques requires special skills and experiences. Blasting contains a certain element of risk. This is why special insurance is needed and certain regulations and public laws must be complied.

3.6.3.3 Bursting

BS 6187: 2000 define bursting, as “the technique of bursting is analogous to the use of explosives in that it makes use of the expansion of a mass of gas or a mechanical device in a prepared crack in a mass in order to break it into fragments”. Where the use of explosives would not be possible because of site conditions, it may be possible to use this technique. Three forms of bursting will be described in the next section.

Gas Expansion Bursters

A gas expansion burster operates with explosive force. The effect of the burster is obtained by inserting it into a prepared cavity in the mass to be demolished. Upon being energised, the resultant increase in pressure of the gas ruptures a diaphragm, releasing the gas into crevices in the surrounding structure, which is then fractured (BS 6187, 2000).
Hydraulic Bursters

The same principles as gas expansion bursters apply with hydraulic bursters in that they use an expanding device to force apart a mass. The difference is that the process is not as rapid as in a gas expansion burster. Pistons or wedges are placed in a prepared cavity and are gradually jacked out under pressure; the resulting increase in size of the device fractures the surrounding material (BS 6187, 2000). This technique normally used to split plain concrete and masonry.

Expanding Demolition Agents

This technique of bursting employs the use of expanding chemicals that are mixed, e.g. with water to form a liquid or paste. The mixture is poured into pre-drilled holes in the material that is to be demolished, and expands to cause a fracture (BS 6187, 2000). For example, ‘unslaked lime’ or a white crystalline oxide used in the production of calcium hydroxide is mixed or absorbed with water and injected or charge into hole (Demolition X, 2001). The expansions of the mixture by hydration cause the splitting of the concrete.

3.6.4 Demolition by High Pressure Water Jetting

BS 6187:2000 defined high-pressure water jetting as “all water jetting processes including those using additives and abrasives where there is energy input to increase the pressure of water. In demolition the process is used, e.g. for cutting out concrete from around steel reinforcing bars where the latter are to remain”. For example, a high-pressure water jet about 250-300 MPa from a nozzle about 0.3-0.5 mm in diameter can cut through plain concrete by abrasion (Demolition X, 2001). This technique can minimise dust and fire hazards. Reference should be made accordance with the Water Jetting Association Code of Practice.

3.7 THE SELECTION OF DEMOLITION TECHNIQUES

Kasai et al. (1998) listed eight criteria which affect the choice of demolition techniques:

- **Structural form of the building** – The structural form of the building such as the material used, shape, size and stability of the structure could affect the selection of the demolition techniques. For example, a ten storey building compared to a single storey house will have a different demolition technique that is more appropriate depend on it shape and size;
• **Scale of construction** – The scale of construction for a structure whether it was big or small will affect the choice of demolition techniques. For example, a big scale construction may require a combination of several demolition techniques;

• **Location of the building** - A structure located at the centre of a town centre will require different demolition techniques compared to a structure located on a remote site;

• **Permitted levels of nuisance** – The noise, dust and vibration tolerance levels will vary from site to site. In selecting the demolition technique, the permitted level of nuisance must be considered in order to tolerate with the surrounding conditions. For example, when a structure located near a school, a demolition technique that has a lesser effect on noise should be selected;

• **Use of the building** – The previous used of the building could effect the chosen demolition techniques. For example, a contaminated building such as nuclear power plant will be treated differently to ordinary residential building;

• **Safety** – Ensuring the safety of operatives, the public and environment has an important influence on the choice of demolition techniques. In fact, the health and safety should be considered in all the criteria that affect the selection process; and

• **Time period** – Each demolition technique has it own estimated time in carrying out the demolition work. The choice of demolition techniques will affected when the client imposed a time-period to demolish a structure.

The physical aspects of the building to be demolished are the main concern for the first six criteria. The final two criteria indicate that the characteristics of the building are not the exclusive considerations when deciding on demolition techniques. The consideration of safety aspects will influence wider issues such as legislation and the environment,
while the inclusion of the time criterion shows that the contractual conditions can have an effect on the choice of demolition techniques.

According to Hurley et al. (2001), there were three more criteria, which also unrelated to the physical attributes of the building, could be added to the eight criteria listed above that includes:

- **The culture of the demolition firm carrying out the work** – The culture of the demolition company will to some extent affect their choice of demolition techniques. For example, a company that is familiar with a specific technique (e.g. deconstruction) is more likely to use this technique than search for another solution (e.g. explosives). If the problem falls outside the boundaries of their previous knowledge, they may then be forced into examining other options such as subcontracting the particular work;

- **The proposed fate of the building materials and components** – After the structure is demolished the fate of the building materials and components will probably affect the choice of demolition techniques to some extent. Some of the techniques available, for example, explosives, merely reduce a building into manageable pieces, taking little or no account of the separation of materials. Clearly, such techniques would be unsuitable for a project where a high degree of reuse of individual components was specified; and

- **Monetary cost** – If the demolition techniques proposed to be selected are going to place a big burden on the contractor, without presenting any other advantages, it is unlikely to be chosen. Similarly, a client will probably let a contract on the basis of the least cost option, although this is slowly changing as more clients look for the best value option, which may not always be the cheapest initially.

A study done by Fesseha (1999) reported that there are thirteen criteria that may affect the selection of demolition techniques. Few of the listed criteria for selecting demolition techniques were also identified by Abudayyeh et al. (1998), however with no mention of their scale of significance on demolition projects. The criteria listed by both researchers have been summarized and discussed as follows:
• **Client specification** – The demolition contractor, before embarking on any type of demolition technique, needs to be aware of the restrictions imposed by the client such as on the type of demolition technique that should not be used in a particular project;

• **Location, accessibility, shape and size of the structure** – The location, accessibility, shape and size of a structure are important factors, which can have an effect on the selection of demolition techniques on a demolition project. For example, a high-rise demolition project located at the centre of a busy town centre will require different demolition techniques to a demolition project located on a remote site. Also a ten-storey building will have different demolition techniques compared to a single storey building;

• **Stability of the Structure** – The stability of a structure is an important factor, which needs great consideration before selecting a demolition technique. For example, if a structure were highly unstable, then the demolition contractor would be expected to select a technique, which does not require site personnel operating within the structure. If the unstable structure is located on a confined site, the demolition contractor needs to stabilise the structure by providing appropriate temporary supports before selecting a particular demolition technique;

• **Presence of hazardous materials** – In the presence of hazardous materials, the contractor would be expected to assess the full extent of the risk that is involved with the work. The demolition contractor then needs to select safe demolition techniques to carry out the demolition work based on the presence of hazardous materials;

• **Time constraint** – A time limit is usually imposed on demolition projects just as in a construction project. However, demolition projects are generally required to be carried out as quickly as possible by the client who may want to develop the land as soon as the demolition work is complete. Where the time imposed on a
demolition project is short and the client is willing to pay for a quick demolition, the contractor is expected to select demolition techniques with little regard for cost;

- **Degree of confinement** – The degree of confinement of a demolition site refers to the number of existing features in close proximity of the structure. Therefore, it is essential for the demolition contractor to survey the site and assess the confinement of the structure before selecting demolition techniques. For example, city centre demolition works can be so confined that the demolition contractor is left with the option of deconstructing the structure, which is a slow, expensive option but a safe and more controlled demolition technique;

- **Transportation consideration** – The demolition contractor, unless he plans to use debris as infill material, should consider the transportation of the debris pile from site, before selecting a demolition technique. This criterion has to be considered because it may result in increased of costs;

- **Extent of demolition** – The extent of demolition of a structure may influence the selection of demolition techniques. For example, in partial demolition, the contractor must not only worry about the demolition work but must also consider the effect of the selected demolition techniques on the rest of the structure that is to be retained. Therefore, the contractor is expected to select appropriate techniques to demolish the building while at the same time needing to retain parts of the structure unlike in total demolition of structures;

- **Structural engineer approval** – Due to increasing complexity of construction techniques and structural forms, it is no longer easy for the demolition contractor to readily assess the likely collapse mechanisms of structures. Therefore, the structural engineer is actively involved in the demolition process of sophisticated structures and directly influences the contractor’s choice of demolition techniques;
• **Financial constraints** – The demolition contractor is expected to select a safe and financially feasible demolition technique. However, the demolition contractor should not, under any circumstance, compromise on safety while selecting a demolition technique despite the financial constraint that may be imposed on the demolition of a structure. Therefore, it is important that the demolition contractor considers the financial implications of the demolition techniques selected for a particular demolition work;

• **Recycling consideration** – Recycling of demolition materials is an important aspect of demolition projects that the contractor needs to consider when selecting demolition techniques. The more selective the demolition techniques that are used on a demolition project, the higher the value of the materials to be recycled. However, the use of more selective demolition techniques generally would mean a higher cost and more time to carry out the work. Therefore balances need to be struck between the agreed cost and time of the demolition work and the degree of selectivity of the demolition techniques that are to be used by the demolition contractor;

• **Environmental considerations** - Several environmental restrictions are imposed on demolition projects by local environmental authorities and by environmentally conscious clients. Therefore, the demolition contractor is expected to work closely with the local environmental services to fully assess the environmental risks before selecting demolition techniques; and

• **Health and Safety** – The demolition techniques selected by the contractor should not at any time pose any threat to the health and safety of site personnel and the general public.

As mentioned briefly in the demolition process, the selection of demolition techniques is carried out in the tender stage. In practice, the decision on the choice of demolition techniques is generally based on risk assessment and other factors such as technical aspects and economic considerations. Typically, the selection process is performed in an
unstructured intuitive manner with significant reliance on the experience, skill, knowledge, or judgement of the demolition engineer.

Although, the existing selection process proved reliable based on the past demolition projects, but in the coming years, it might not give the same results because the knowledge and expert judgments of the demolition engineer might be lost when the engineer retires or dies. The latest report from the Institute of Demolition Engineers United kingdom (IDE) revealed that only about 250 demolition practitioners are registered with the Institute (IDE, 2003). This figure shows that there is a shortage of expertise in the industry, and it is vital to capture the expert’s knowledge in some form, or it would be lost. This would adversely affect the selection process, which relies heavily on the expertise of demolition engineers.

3.8 COST ESTIMATION IN THE DEMOLITION INDUSTRY

There are several differences between cost estimation in the demolition industry compared to the construction industry. In construction, estimation normally involves ‘taking off’ from drawings, and transferring items to the Bill of Quantities, with rates of work taken from commercially available cost data resources. In the demolition industry, the estimation task involves with the structures and quantities that already exist. Despite the fact that drawings are used, they are not always a true reflection of the structure to be demolished. The estimator must be able to assess quantities in structures from visual inspection, relying on his experience and knowledge from previous demolition work.

From the researcher’s observation during the visit to several demolition companies in the United Kingdom, the demolition engineer also acts as the estimator for the company. This is typical for a small demolition company. In practice, the estimation or pricing of demolition work generally involves preliminary estimates that are based on the cubic capacity of the structure allied to the varying types of structure and their construction. However, when pricing a project, an estimator will consider most, if not all, of the following:

- Proximity of adjoining structures, which may restrict the working area;
- Accessibility to the site;
• Temporary work such as the propping of existing retaining or party walls or façade retention work;
• Demolition techniques to be selected;
• Labour cost;
• Tools and equipment cost;
• Transportation cost;
• Site overhead and profits;
• Reuse and recycling;
• Landfill tax;
• Insurance; and
• Protection of the public and others.

In the existing cost estimating approach, the demolition engineer only calculates the cost for the demolition technique selected and not for all the demolition techniques available. The weakness of this approach is that the demolition engineer cannot compare all the available techniques in terms of cost; this reduces the possibility of getting the most economical option for the project. In addition, it is important to include all the cost for each of the demolition techniques available so that the demolition engineer can make sound judgement in choosing the most appropriate demolition techniques.

3.9 SUMMARY
The chapter aimed to give an overall view of the demolition industry for a better understanding of the subject matter. The subjects reviewed include developments in the demolition industry; the characteristics of the demolition process; the type of structural demolition and demolition techniques; the selection of demolition techniques; and the cost estimation process in the demolition industry. In the next chapter, the decision making process is discussed in greater detail.
CHAPTER 4: REVIEW OF DECISION MAKING

4.1 INTRODUCTION
This chapter begins with reviewing the basic concept of decision-making including its definitions and phases. The chapter then describes Multicriteria Decision Making (MCDM) in terms of its methods and justifies why Analytic Hierarchy Process (AHP) as one of the MCDM methods was selected for the research. In addition the background and theoretical aspects of the AHP are presented to give a clear perspective of this powerful decision support tool. Next, the chapter reviews the basic concept of Decision Support System (DSS) and justifies why Expert Choice (EC) software was selected as the DSS tool used in the research.

4.2 DECISION MAKING
Turban and Aronson (1998) define decision making as “a process of choosing among alternative courses of action for the purpose of attaining a goal or goals”. According to Simon (1977), the decision making process involves four major phases as described below:

- **Intelligence Phase** – clarify the purpose of the decision by identifying and defining the problem occurring in the organization;

- **Design Phase** – this involves formulating a model that represents the decision problem. The model then validated and a set of criteria and alternatives for a possible course of action are determined;

- **Choice Phase** – it includes evaluating the criteria and alternatives, and recommending an appropriate solution to the model; and

- **Implementation Phase** – it can be described as putting the recommended solution to work.
Demolition engineers as decision makers are faced with decision problems in the selection of demolition techniques. In practice, the decision is based on experience, skill and knowledge of the demolition engineer. The demolition of any type of structure is unique due to the sheer number of parameters that govern the demolition process. Furthermore, there are many elements of the problems and the interrelationships among the elements are very complicated. Before selecting any type of demolition technique, the demolition contractor needs to consider a set of criteria and assess their relevance to the demolition work to be undertaken in order to arrive at the most appropriate demolition technique. Criteria that may be important on a particular demolition project may not necessarily be so on another project. Many factors have to be considered in selecting the best techniques for the demolition work and require the demolition engineers to have multicriteria decision-making (MCDM) ability. The next sections discuss the characteristics of the MCDM so that a decision model for selecting demolition techniques can be developed.

4.3 MULTICRITERIA DECISION MAKING (MCDM)

Multicriteria Decision Making (MCDM) is part of a more general area of research called Multicriteria Decision Aid (MCDA). MCDM has a descriptive approach and was mainly developed in United States of America (known as American School), while the MCDA has a constructivist approach and is the one adopted by most of the European researchers (French School) (Roy and Vanderpooten, 1996). The descriptive approach in MCDM aims to help decision-makers learn the problems and guide them in identifying a preferred course of action (Zeleny, 1982). The typical MCDM problem deals with the evaluation of a set of alternatives in term of a set of decision criteria to determine which are the best alternatives. On the other hand, MCDA, which has a constructive approach, develops tools to help decision makers in solving a decision problem with several points of view that have to be taken into account. MCDA intends to give tools that allow the decision maker to capture, analyse and understand these points of view, in order to find the way in which the decision process may be handled. Even if there are some distinctions between MCDM and MCDA the overall objective is the same, which are to help decision makers solve complex decision problems in a systematic, consistent and more productive way.

MCDM is a critical decision tool for many scientific and engineering challenges (Triantaphyllou and Mann, 1995). The applications of MCDM are diverse and some of
the applications that relates to this research include in the process of contractor selection (Fong and Choi, 2000; Jennings and Holt, 1998; Okoroh and Torrance, 1999); project procurement selection (Alhazmi and McCaffer, 2000; Kamal, 2001; Lee and Kim, 2001; Love et al., 1998; Wong et al., 2000); equipment selection (Amirkhanian and Baker, 1992; Naoum and Haidar, 2000); and other engineering problem (Hwang and Yoon, 1981b)

4.3.1 MCDM Analysis
As reported by Triantaphyllou (2000) and other authors such as (Hwang and Masud, 1979; Hwang and Yoon, 1981b; Triantaphyllou et al., 1998; Vincke, 1992; Zeleny, 1982), there are two types of analyses that can be used to resolve multicriteria problems:

1. Multi-Objective Decision Making (MODM) is used to solve problems that required selection from continuous sets of options. MODM is also known as Multiple Criteria Design Problem or Continuous Multiple Criteria Problem (Henig and Buchanan, 1996; Hwang and Masud, 1979; Keeney and Raiffa, 1976; Salomon and Montevichi, 2001).

2. Multi-Criteria Decision Making (MCDM) is used to solve problems that required selection from multicriteria discrete options. Other equivalent term of 'Criteria' is 'Attribute', and therefore, the terms MCDM and MADM have been used very often to mean the same class of models and denote the same concept (Triantaphyllou et al., 1998). MCDM is also known as Multiple Criteria Evaluation Problems and Discrete Multiple Criteria Problems (Montis et al., 2000; Roy and Vanderpooten, 1996; Vincke, 1992).

In MODM the decision space is continuous where the methods rely primarily on mathematical algorithms to analyse large, possibly infinite, sets of alternatives. Solutions are predominately defined around the identification of a situation's single optimum solution (Hwang and Masud, 1979). For analyzing this type of problem, methods like goal programming are used. Goal programming (GP) is a mathematical programming technique which is used to satisfy more than one goal simultaneously. According to Hillier and Lieberman (1980) the basic idea is to establish a numerical goal for each of the objectives, formulate an objective function for each objective, and then seek a solution
that minimizes the (weighted) sum of deviations of these objective functions from their respective goals. The aim is to rank ordered according to their priorities of achieving the aspiration levels assigned to them in the decision making context. The main advantage of a GP approach is that it leads to arrive at an acceptable compromise solution directly. However, the main weakness of GP is that the aspiration levels of the goals need to be specified precisely in making decision (Pal and Moitra, 2001).

In contrast, MCDM concentrates on problems with discrete decision space where the set of decision alternatives has been finite and predetermined. Depending on the type of decision problems, the outcome of a MCDM is either a recommendation to choose one alternative, or a subset of alternatives containing the most suitable alternatives. These recommendations were derived by either a ranking or sorting process (Hwang and Yoon, 1981a). A variety of standardised frameworks provide different analytical procedures and decision rules, enabling the actual decision makers, rather than modellers, to compile, analyse, and synthesis a situation's components (Hwang and Lin, 1987). According to Vincke (1992), the discrete MCDM problems can be analysed by using the following approaches: the single criterion synthesis approach and the outranking synthesis approach.

4.3.2 MCDM Methods

The MCDM methods can be classified in several ways (refer to Figure 4.1). One way is to classify them according to the number of decision maker involved in the decision process either it is a single decision maker or group decision maker (Triantaphyllou et al., 1998). Another way of classifying MCDM methods is according to the type of data involved in the decision-making problem. The classification distinguishes deterministic, stochastic and Fuzzy data. In the deterministic data, the decision-making problem (i.e. the goal, criteria and alternatives) are predetermined and defined before applying the decision method. In the stochastic data the criteria are viewed as random variables. Finally, fuzzy data deal with different types of uncertainty and imprecision in some of the elements of the decision making problem. However, there may be situations, which involve combinations of all the above data types.

MCDM methods can also be classified according to the operational approaches. As mentioned before, there are two operational approaches in MCDM, which include single
criterion synthesis approach based on the Multiple Attribute Utility Theory (MAUT) methods and Outranking synthesis approach based on Outranking Methods (Vincke, 1992). In the following sections the main ideas of these two approaches will be explained.

4.3.3 Single Criterion Synthesis Approach based on MAUT Method

Multiple Attribute Utility Theory (MAUT) is a widely used method to provide analytical support to the decision-making process and mainly started by Fishburn (1970) and Keeney and Raiffa (1976). The theory is based on the fundamental axiom: any decision-maker attempts unconsciously (or implicitly) to maximize some function aggregating all the different points of view, which are taken into account (Vincke, 1992).
Multi-attribute utility theory underlies a set of methods for making these choices. The set of methods in MAUT include (Keeney and Raiffa, 1976):

1. Define the alternatives and relevant alternative attributes;
2. Evaluate each alternative on each attribute;
3. Assign relative weights to the attributes to reflect preference;
4. Combine the attribute weights and evaluations to yield an overall satisfaction evaluation of each alternative; and
5. Perform sensitivity analysis and make a decision.

Different models exist according to different expression for function $U$ in Eq. 4.1. In MAUT, data usually provided through a decision matrix, with criteria as columns and alternatives as rows (see Table 4.1).

$$U = U(c_1, c_2, \ldots, c_n)$$  \hspace{1cm} \text{Eq. 4.1}

<table>
<thead>
<tr>
<th></th>
<th>$c_1$</th>
<th>$c_2$</th>
<th>...</th>
<th>$c_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_1$</td>
<td>$v_{11}$</td>
<td>$v_{12}$</td>
<td>...</td>
<td>$v_{1n}$</td>
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<tr>
<td>$a_2$</td>
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<tr>
<td>...</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$a_n$</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

The additive model is the simplest model considered in MAUT, where $U$ is an additive combination of utility of the criteria. The function $U$ can be expressed as:

$$U(a) = \sum_{j=1}^{n} U_j(c_j(a))$$

Where $U_j$ is the utility function of criterion $c_j$. The purpose is to transform the criteria for them to follow the same scale, which allowed the criteria to be compared and added.
without problems with different units of measurement. According to (Vincke, 1992) additional conditions must be fulfilled to use this model such as each criterion must be a preference relation that induces a complete pre-order and any subset of criteria must be preferentially independent.

It is also possible to use other utility functions such as multiplicative utility, apart from the use of additive utility functions. The multiplicative model allows the consideration of the interactions among the different criteria. The function can be expressed as:

\[ U(a) = \prod_{j=1}^{n} U_j(c_j(a)) \]

Where, \( U_j \) is the utility function for criterion \( c_j \). After the \( U_j \) are known, MAUT methods consider two steps to be followed (Henig and Buchanan, 1996):

1. **Aggregation or rating** – a value for each alternative is computed, \( U(a) \). This gives a general idea of the utility of the alternative by considering all the criteria at the same time; and

2. **Ranking or sorting** – the utility values obtained in the first step are used to find the best alternative by ranking or classifying them into predefined groups.

The primary advantage of MAUT is that the problem becomes a single objective problem once the utility function has been assessed correctly, thus ensuring achievement of the best compromise solution. The main disadvantage of MAUT is the solution process becomes time consuming as the number of criteria increases because a single-attribute utility function must be defined for each criterion (attribute). Table 4.2, summarises some of the single criterion synthesis approach based on MAUT principles (Guitouni and Martel, 1998).
Table 4.2: MCDM Methods for Single Criterion Synthesis Approach

<table>
<thead>
<tr>
<th>Single Criterion Synthesis</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOPSIS</td>
<td>The chosen alternative should have the profile, which is the nearest (distance) to the ideal solution and farthest from the negative-ideal solution. (Hwang and Yoon, 1981b)</td>
</tr>
<tr>
<td>MAVT (multi-attribute value theory)</td>
<td>Aggregation of the values obtained by assessing partial value functions on each criterion to establish a global value function V. Under some conditions, such V can be obtained in an additive, multiplicative, or mixed manner. (Keeney and Raiffa, 1976)</td>
</tr>
<tr>
<td>UTA (utility theory additive)</td>
<td>Estimate the value functions on each criterion using ordinal regression. The global value function is obtained in an additive manner. (Jacquet-Lagreze and Siskos, 1982)</td>
</tr>
<tr>
<td>SMART (simple multi-attribute rating technique)</td>
<td>Simple way to implement the multiattribute utility theory by using the weighted linear averages, which give an extremely close approximation to utility functions. There are many improvements like SMARTS and SMARTER. (Edwards and Barron, 1994; Olson, 1996)</td>
</tr>
<tr>
<td>MAUT (multi-attribute utility theory)</td>
<td>Aggregation of the values obtained by assessing partial utility functions on each criterion to establish a global utility function U. Under some conditions, U can be obtained in an additive, multiplicative, or distributional manner. (Keeney and Raiffa, 1976; Vincke, 1992)</td>
</tr>
<tr>
<td>AHP (analytic hierarchy process)</td>
<td>Converting subjective assessments of relative importance into a set of weights. This technique applies the decomposition, the comparative judgments on comparative elements and measures of relative importance through pairwise comparison matrices, which are recombined into an overall rating of alternatives. (Saaty, 1980; Saaty, 1994a)</td>
</tr>
<tr>
<td>EVAMIX</td>
<td>Two dominance indexes are calculated: one for ordinal evaluations and the other one for cardinal evaluations. The combination of these two indexes leads to a measure of the dominance between each pair of alternatives. (Voogd, 1983)</td>
</tr>
<tr>
<td>Fuzzy weighted sum</td>
<td>These procedures use a-cut technique. The a level sets are used to derive fuzzy utilities based on the simple additive weighted method. (Dubois and Prade, 1982)</td>
</tr>
<tr>
<td>Fuzzy maximin</td>
<td>This procedure is based on the same principle as the standard maximin procedure. The evaluations of the alternatives are fuzzy numbers. (Bellman and Zadeh, 1970)</td>
</tr>
</tbody>
</table>

(Source: Guitouni and Martel, 1998)

4.3.4 Outranking Synthesis Approach based on the Outranking Method
Bernard Roy developed the Outranking method in 1968 (Vincke, 1992). It is a procedure that sequentially reduces the number of alternatives in a set of non-dominated alternatives. The concept of an outranking relation S is introduced as a binary relation defined on the set of alternatives A. Given two alternatives A_i and A_j, A_i outranks A_j, or A_iSA_j, if given all that is known about the two alternatives, there are enough arguments to decide that A_i is the least as good as A_j.
The goal of outranking methods is to find all alternatives that dominate other alternatives while they cannot be dominated by any other alternative. To find the best alternative, outranking also requires knowledge of the weight of the criteria. Each criterion $C_j \in C$ is assigned a subjective weight $w_j$, and every pair of alternatives $A_i$ and $A_j$ is assigned a concordance index $c(A_i, A_j)$ given by:

$$c(A_i, A_j) = \frac{1}{\sum_{k=1}^{n} w_k} \sum_{k=1}^{n} w_k$$

And the discordance index $d(A_i, A_j)$ is given by:

$$d(A_i, A_j) = \begin{cases} 0 & \text{if } g_k(A_i) \geq g_k(A_j) \text{ for all } k, \\ \frac{1}{\delta} \max \{g_k(A_i) - g_k(A_j)\} & \text{otherwise.} \end{cases}$$

Where, $\delta = \max \{g_i(A_i) - g_i(A_j)\}$. Obviously, the discordance index is only valid if the operation subtraction is well defined. Once the two indices are defined, an outranking relation $S$ is defined by:

$$A_i S A_j \text{ if and only if } \begin{cases} c(A_i, A_j) \geq \hat{c}, \\ d(A_i, A_j) \geq \hat{d}, \end{cases}$$

Where $\hat{c}$ and $\hat{d}$ are threshold set by decision maker. A problem with this discordance index is the requirement that criteria level be quantifiable. If that is not the case, then the discordance set $D_j$ is defined for each criterion $j$ for all the ordered pairs $(x_j, y_j)$ such that if $g_j(A) = x_j$ and $g_j(B) = x_j$ then the outranking of $B$ by $A$ is refused. The outranking relation is defined now by:
Given the outranking relation it is now possible to find the set alternatives $N \subseteq A$ for which:

$$\forall B \in A-N \quad \exists A \in N \text{ such that } ASB$$

The outranking relation determines the set of non-dominated alternatives. The alternatives in $N$ form the kernel of the graph defined by the alternatives (vertices) and the outranking relation (edges). Thus the alternative $A_i$ outranks alternative $A_j$, then a directed arc exists from $A_i$ to $A_j$: $A_i \rightarrow A_j$. The steps followed in the Outranking Methods are as follows:

- **Step 1:** Obtain the values of the attributes for every alternative with respect to the criteria;
- **Step 2:** Construct the outranking relations by following concordance and discordance definitions, and construct a graph representing these relations;
- **Step 3:** Obtain the minimum dominating subset. If a kernel exists, it is chosen as the minimum dominating subset; and
- **Step 4:** If the subset has a single element or is small enough to apply value judgement, select the final decision. Otherwise, steps 2 through 4 are repeated until a single element or small subset exists.

The outranking method is suitable for multi-criteria decision problems under certainty with a relatively small set of alternatives. The method also has the ability to consider both objective and subjective criteria (Roy and Vincke, 1981). The first and most obvious weak point is the arbitrariness of assigning weights to the criteria as well as assigning values to the attributes. It was always assumed in the literature review, that the decision maker had the capabilities to assign these values. The second shortcoming is that a complete ranking of alternatives may not be achieved because only a partial prioritization of alternatives is computed. The best the method can do is to reduce the number of
alternatives to a subset (i.e. minimal dominating subset) of solutions to the problem. The last weakness of the method is the ordinal way used to combine concordance and discordance that leaves one in doubt about the accuracy of its outcome (Roy, 1973). Table 4.3, summarise some of the outranking synthesis approach based on outranking method (Guitouni and Martel, 1998)

<table>
<thead>
<tr>
<th>Outranking Synthesis</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELECTRE I</td>
<td>The concept of outranking relationship is used. The procedure seeks to reduce the size of non-dominated set of alternatives (kernel). The idea is that an alternative can be eliminated if it is dominated by other alternatives to a specific degree. The procedure is the first one to seek to aggregate the preferences instead of the performances. (Roy, 1973)</td>
</tr>
<tr>
<td>ELECTRE IS</td>
<td>This procedure is exactly the same as ELECTRE I, but it introduces the indifference threshold. (Roy and Bouyssou, 1993)</td>
</tr>
<tr>
<td>ELECTRE II</td>
<td>ELECTRE II uses two outranking relations (strong and weak). (Roy, 1971)</td>
</tr>
<tr>
<td>ELECTRE III</td>
<td>The outranking is expressed through a credibility index. (Roy, 1978)</td>
</tr>
<tr>
<td>ELECTRE IV</td>
<td>This procedure is like ELECTRE III but did not use weights. (Roy and Hugonnard, 1982)</td>
</tr>
<tr>
<td>ELECTRE TRI</td>
<td>This procedure is like ELECTRE III and uses the conjunctive and disjunctive techniques to affect the alternatives to the different categories (ordered). (Roy and Bouyssou, 1993)</td>
</tr>
<tr>
<td>PROMETHEE I</td>
<td>PROMETHEE I is based on the same principles as ELECTRE and introduce six functions to describe the decision maker preferences along each criterion. This procedure provides a partial order of the alternatives using entering and leaving flows. (Brans et al., 1984)</td>
</tr>
<tr>
<td>PROMETHEE II</td>
<td>PROMETHEE II is based on the same principles as PROMETHEE I. This procedure provides a total preorder of the alternatives using an aggregation of the entering and leaving Flows. (Brans and Vincke, 1985)</td>
</tr>
<tr>
<td>MELCHIOR</td>
<td>MELCHIOR is an extension of ELECTRE IV. (Leclercq, 1984)</td>
</tr>
<tr>
<td>ORESTE</td>
<td>This procedure needs only ordinal evaluations of the alternatives and the ranking of the criteria in term of importance. (Roubens, 1980)</td>
</tr>
<tr>
<td>REGIME</td>
<td>A pairwise comparison matrix is built using +1 if there is dominance, 0 if the two alternatives are equivalent and -1 for the negative-dominance. The aggregation of these weighed scores provides a total preorder of the alternatives. (Hinloopen and Nijkamp, 1982)</td>
</tr>
<tr>
<td>NAIADE</td>
<td>This procedure uses a distance semantics operator to assess the pairwise comparisons among alternatives. The fuzzy evaluations are transformed in probabilities distributions and as PROMETHEE, this procedure compute entering and leaving flows. (Munda, 1995)</td>
</tr>
</tbody>
</table>

(Source: Guitouni and Martel, 1998)
4.3.5 MCDM Method Adopted for the Research

There are great numbers of MCDM methods, a situation that may be seen either as a strength or as a weakness (Bouyssou, 1990). The great variety of multicriteria methods makes it possible for the decision maker to choose the appropriate method for a certain decision-making situation. In particular each method shows its own properties with respect to the way of assessing criteria, the application and computation of weights, the mathematical algorithm utilised, the model to describe the system of preferences of the individual facing decision making, and the level of uncertainty embedded in the data set (Belton, 1990).

An important aspect to consider when choosing a MCDM method is by assessing the characteristics of the decision problem. The characteristics of the problem in this research involve:

- Type of problem – Multicriteria discrete options problem to select the most appropriate demolition techniques (the alternatives is finite or predetermined);

- Who makes the decision? – A demolition engineer who acts as a single decision maker (who can be one or more persons but having the same views) makes the decision to select the most appropriate demolition techniques;

- Type of data – Deterministic (goal, criteria and alternatives are predetermined and defined before applying the decision method by capturing it from the demolition experts). It also involves quantitative and qualitative information; and

- Output – Improving decision-making process by structured the selection process, ranked all the alternatives based on the criteria assessed and finally, recommended the most appropriate demolition techniques for the specified project. In addition, the selected method must be easily understood and applied by users.
With reference to the characteristics of the problem mentioned above, without any doubt a Multi-Criteria Decision-Making (MCDM) approach is required to resolve the problems. As mention in Section 4.3.2 there were two approaches categorized in this type of problem, which include single criterion synthesis approach and outranking synthesis approach. The single criterion synthesis approach matches the expected outcome of the research where the decision maker needs to have a good visualisation of the whole selection process before he/she can make a final decision. For example, by using this approach the decision maker can clearly visualise the goal and the criteria that influenced the selection process. In addition, all the ranked alternatives can be viewed at the end of the process. On the other hand the outranking synthesis approach will not give a complete ranking of all the alternatives because only partial prioritization of alternatives is computed, where it reduces the number of alternatives to a subset of solutions to the problem. Therefore, based on the expected outcome of the research, which is to provide a clear, structured view of the whole decision process, the single criterion synthesis approach was selected compared to the outranking synthesis approach.

With respect to Table 4.2, several methods are available to be selected based on the single criterion synthesis approach. After reviewing the characteristics of all the available methods, the AHP method was selected for the research compared to other methods due to a number of reasons, which include:

1. Improve the decision making process – the hierarchical structure used in formulating the AHP model enable the demolition engineer to visualise the selection problem systematically in term of relevant criteria, sub criteria and alternatives;

2. The capability to compare both qualitative and quantitative criteria by using informed judgement to derive weights and priorities. It also takes into consideration judgements based on people's feelings and emotions as well as their thoughts. This capability matches the nature of the decision made by demolition engineer where the decision to select a demolition technique is based on their experience and knowledge;
3. The AHP pairwise comparison scale makes it easy to create a pairwise comparison matrix for each relevant element of a problem;

4. It has the capability to measure inconsistency in subjective judgements by calculating the consistency ratio for each judgement;

5. The nature of numerical and pictorial results obtained from the synthesis stage gives a better understanding and a clear rationale for the choice selected in the decision-making process;

6. The availability of decision support system called Expert Choice software based on AHP theory makes it easily understood and applied by users; and

7. Results from previous studies by several researchers recommend AHP as a better decision-making method than most. These include:

- A research by Triantaphyllou and Mann (1989) which compared AHP with weighted sum model (WSM) and weighted product model (WPM) methods in term of processing the numerical values to determine a ranking of each alternative. In WSM, the global performance of an alternative is computed as the weighted sum of its evaluations along each criterion. The global performance is used to make a choice among all the alternatives (Guitouni and Martel, 1998). The WPM can be considered as modification of the WSM, and has been proposed in order to overcome some of its weakness. The results of their study recommend that for most of the cases of different weights of the two evaluative criteria AHP appears to be the best decision making method of all the methods examined;

- A research by Salomon and Montevechi (2001) compared AHP with other MCDM methods such as TOPSIS and ELECTRE. They suggested that the use of AHP would give good results or maybe the optimum solution; and

- Peniwati (1996) in her research for group decision-making compared and contrasted AHP with other approaches such as the Delphi Method, Matrix
Evaluation, Goal Programming and Outranking Method to problem structuring, ordering and ranking. She concluded that AHP was the most comprehensive compared to other techniques in structure analysis, mathematical validity and in producing accurate results.

4.4 ANALYTIC HIERARCHY PROCESS (AHP)

In practice the decision to select demolition techniques is based on experience, skill and knowledge of the demolition engineer. Furthermore, it involves a multicriteria decision making problem, where there are several demolition techniques (alternatives) need to be assessed against a number of influential criteria. To perform the operation successfully the decision maker must first organize and prioritize the problem. It then, requires an effective decision making technique to systematically evaluate demolition techniques against a number of criteria, which will help the individual to select the most appropriate demolition technique from the alternatives available. The Analytical Hierarchy Process (AHP) was chosen for this study to gives the decision maker the framework of logic needed to model a complex decision scenario that can integrate perceptions, feelings, judgements and experiences into hierarchy therefore allowing a better understanding of the problem, its criteria and possible choice. In this section, the background and theoretical aspects of the AHP will be presented to give clear perspective of this powerful decision support tool.

4.4.1 Background of AHP


Fundamentally, the AHP works by developing priorities for alternatives and the criteria used to judge the alternatives (Saaty, 1994a). In more details, AHP uses a multi-level hierarchical structure of goal, criteria, sub criteria and alternatives. It also takes into account judgements based on people’s feeling and emotions as well as their thoughts.
A set of pairwise comparison are then, used to obtain the weights of importance of the decision criteria and the relative importance measures of the alternatives in term of each individual decision criterion and towards the overall goal of the problem to select the best alternative. In addition, it provides a mechanism for improving consistency if the comparisons are not perfectly consistent. The strength of AHP is its ability to structure a complex, multi-criteria problem hierarchically and then to investigate each level separately, combining the results as the analysis progress (Mahdi et al., 2002).

Since its introduction, a number of criticisms have been launched at AHP. Belton and Gear (1983) observed that AHP could subject to rank reversal. Rank reversal means that the rank of an alternative resulting from AHP may change when another alternative is added to the initial group of alternatives compared. Saaty (1987) responded to this critique saying, that with introduction of new alternative also new information is included in the model. In this regard the decision problem has to be rethought, and the resulting ranks of alternatives may change. However, scholars have identified solution to cope with the problem in a methodological way. To overcome this problem, Belton and Gear introduced revised-AHP, which proposed each column of the AHP decision matrix to be divided by the maximum entry of that column. Later, Saaty (1994a; 1994b) accepted the variants of the original AHP and it is now called the Ideal Mode AHP. The latest software for AHP, 'Expert Choice 2000 Professional' includes an alternative "ideal synthesizing mode" which allows that the sum of alternative adds to more than one. In this respects it is not necessary to newly calculated priorities of existing alternatives when introducing a new alternative. Through this the rank reversal problem is excluded. Nevertheless, the original AHP or the ideal mode is the most broadly accepted method and is considered by many as the most reliable MCDM method (Triantaphyllou and Mann, 1995).

Since its introduction, AHP has been applied to many types of decision problems. Application can be found in such diverse fields as portfolio selection, transportation planning, manufacturing system design and artificial intelligence (Saaty, 1994a). Some of the selection problem solve by AHP methodology include its use in project procurement system selection model (Alhazmi and McCaffer, 2000), application of AHP in project management (Kamal, 2001), a multi-criteria approach to contractor selection (Mahdi et al., 2002), and also in other engineering problems (Saaty and Vargas, 2001). The majority
of these applications have introduced analytical solutions for problems involving both quantitative and qualitative criteria, which is similar to the selection process that is one of the objectives of this research.

### 4.4.2 AHP Principles

There are four basic principles used in the AHP for problem solving, which includes *decomposition*, prioritization procedure; *synthesis of results*; and *measuring inconsistency in decision maker's judgements*. These principles will be discussed in detail in the following sections.

#### 4.4.2.1 Decomposition

The first principle in the AHP is to decompose a problem into a hierarchy. A hierarchy is a tree-like structure that represents a complex problem on a number of levels (Saaty, 1994a). The first level is the goal to be achieved, followed by criteria, subcriteria and so on down to the last level at which alternatives are located. The number of levels in any hierarchy depends on the amount of information requested by the decision makers to evaluate the system and the complexity of the problem. Figure 4.2 presents a simple hierarchy, which consists of three levels: goal, criteria and alternatives.

![Figure 4.2: Hierarchic Structure](image)

Saaty (1994a) point out the fact that the hierarchic structure is beneficial to a decision-maker by providing an overall view of the complex relationships inherent in the situation and in the judgment process. It also allows the decision-maker to assess whether he or she is comparing issues of the same order of magnitude.
It is essential in constructing the hierarchy to include other people ideas and debate until the problem is clearly defined and decision makers fully convinced for the enrichment of the problem solving. If one decided to work based on one’s own perspectives the outcome will be limited to a number of alternatives that might not reflect the problem characteristics or the decision maker needs.

4.4.2.2 Prioritization Procedure

The second principle in the AHP is the establishment of priorities among the elements at each level of hierarchy. The decision maker make judgements, in pairwise comparison, the relative preferences, importance, or likelihood of each set of elements with respect to elements at the immediately higher level in the hierarchy. First pairwise comparisons of the relative preference for the alternatives are made with respect to each of the lowest level, (subcriteria). Next pairwise comparisons are made about the importance of subcriteria with respect to each criterion, and then for the relative importance of the top-level criteria with respect to the goal. For each set of pairwise comparisons, mathematical calculations are performed which produce priorities and include a measure of judgemental consistency (Saaty, 1994a).

A trustworthy decision support theory must be uniqueness in the representation of judgements, the scale derived from these judgements and the scale synthesized from these scale (Saaty, 1980). In the AHP pairwise comparison a nine-point scale is utilized in order to evaluate the preferences for each pair of items. AHP suggest the nine-point scale because of the psychological limit of 7 ± 2 items in simultaneous comparison are meaningful in practice and have an element of precision. The qualitative judgements are also well presented by five attributes: equal weak, strong, very strong and absolute. The recommended scale and its underlying numerical representation are shown in Table 4.4.

For pairwise comparison, a matrix is the preferred form. According to Saaty (1994a) the matrix is a simple and well-established tool that offers a framework for testing consistency, getting the necessary comparative data and providing sensitivity analysis of the overall priorities when judgements are changed. Generally, if there are various elements (say \(n\) elements) that need to be compared for a given matrix, a total of
\( n(n-1)/2 \) judgements are required. The pairwise comparison matrix may be better illustrated with the following examples.

Suppose we wish to compare a set of \( n \) objects in pairs according to their relative weights. The objects are denoted by \( A_1, A_2, \ldots, A_n \) which can be represented by forming \( n \times n \) matrix \( A \) that has elements \( a_{ij} \). If the relative weights of the elements of matrix \( A \) are represented as \( a_{ij} = w_i/w_j \), the following matrix may represent the pairwise comparison:

\[
A = \begin{pmatrix}
A_1 & A_2 & \cdots & A_n \\
\begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\
\vdots & \ddots & & \vdots \\
a_{n1} & \cdots & a_{nn}
\end{pmatrix}
& \begin{pmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\
w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\
\vdots & \ddots & \ddots & \vdots \\
w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n
\end{pmatrix}
\end{pmatrix}
\]

The pairwise comparison should be conducted for each level in the hierarchy with respect to the level above. The process can be done from the top of the hierarchy to downward in which the decision makers have to evaluate the importance of the criteria and their preference for the available alternatives. Otherwise, the pairwise comparison can proceed from the bottom upward by evaluating the preference of the alternatives with respect to each criterion before evaluating the importance of the criteria.

Table 4.4: AHP Pairwise Comparison Scale (Source: Saaty, 1994a)

<table>
<thead>
<tr>
<th>Intensity of Importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
<td>Two activities contribute equally to the objective</td>
</tr>
<tr>
<td>3</td>
<td>Weak importance of one over another</td>
<td>Experience and judgement slightly favour one activity over another</td>
</tr>
<tr>
<td>5</td>
<td>Essential or strong importance</td>
<td>Experience and judgement strongly favour one activity over another</td>
</tr>
<tr>
<td>7</td>
<td>Demonstrated importance</td>
<td>An activity is strongly favoured and its dominance demonstrate in practice</td>
</tr>
<tr>
<td>9</td>
<td>Absolute importance</td>
<td>The evidence favouring one activity over another is of the highest possible order of affirmation</td>
</tr>
<tr>
<td>2,4,6,8</td>
<td>Intermediate values between the two adjacent judgements</td>
<td>When compromise is needed</td>
</tr>
<tr>
<td>Reciprocals of above nonzero</td>
<td>If activity i has one of the above nonzero numbers assign to it when compared with activity j, then activity j has the reciprocal value when compared with i.</td>
<td>A Reasonable assumption</td>
</tr>
</tbody>
</table>
4.4.2.3 Synthesis of Results
Synthesis is the process of weighting and combining priorities through the constructed hierarchy that leads to the overall results. Synthesis must be performed for all matrices developed in the pairwise comparison stage to obtain the overall relative weights with respect to the main elements. The calculation process summarized by the following steps:

1. To get the normalized matrix, the value of each column should be added and then each entry in each column should be divided by the total of that column. These steps will give a meaningful comparison between the elements in the hierarchy.

2. To get the priority vector of all matrix elements with respects to the main elements, the row should be average, the value of each row of the normalised matrix should be added and dividing the rows by the number of entries in each.

3. The relative’s weights of various levels of the model should be aggregated to get a vector of composite weights, which serves as ratings of decision alternatives in achieving the most general objective of the problem. The repetitions of this aggregation produce the relative weights of elements at the lowest level of hierarchy with respect to the most general objectives at the first level. According to Zahedi (1986) the composite relative weight vector of elements at Ki th level with respect to that of the first level may be calculated from:

\[ C(I, K) = \prod_{i=2}^{K} Bi \]

\( C(I, K) \) = The vector of composite weights of elements at level Ki th with respect to the element on level 1;
\( Bi \) = The \( n_{i-1} \) by \( n_i \) matrix with row consisting of estimated eigenvectors;
\( n_i \) = The number of elements at level i.
4.4.2.4 Measuring Inconsistency in Decision Maker’s Judgements

AHP provides a measure to test out the degree of inconsistency called Consistency Index (CI) in the decision maker’s judgements. It helps decision makers to identify possible errors in expressing judgements as well as the actual inconsistencies in the judgement process. According to Saaty (1983) the CI can be calculated for each matrix as follows:

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1}
\]

\[n = \text{Matrix Size}\]
\[\lambda_{\text{max}} = \text{Eigenvalue Max}\]

The difference \((\lambda_{\text{max}} - n)\) can be employed to measure inconsistency. For perfect consistency \((\lambda_{\text{max}} - n)\) will be zero. But usually \((\lambda_{\text{max}} \geq n)\), where \(n\) is the dimension of the pairwise comparison matrix. The closer the CI to zero the better the overall consistency of the matrix of the judgemental comparison of the elements involved. To obtain \(\lambda_{\text{max}}\), first we have to calculate the weighted sum matrices by multiplying each weight in the pairwise comparison matrices with each of the priority vectors. Then \(\lambda_{\text{max}}\), could be obtained by dividing all the elements of the weighted sum matrices by their respective priority vector elements, and then compute the average of these values.

The consistency can be verified by taking the Consistency Ratio (CR) also term Inconsistency Ratio (IR). The IR is a measure of inconsistency in judgements, where:

\[
\text{Consistency Ratio, (CR) or Inconsistency Ratio, (IR)} = \frac{CI}{RI}
\]

The Random Index (RI) is a simulation of a large number of randomly generated pairwise comparisons for different sizes of matrices carried out by Saaty, with regard to calculations of the average consistency indices (CIs). The significance value of RI is that the ratio of the CI for a particular set of judgements to the RI of the same size of matrix. The values of such standard RI are given in Table 4.5 (Saaty, 1980; Saaty, 1990; Saaty, 1994a).

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Table 4.5: Random Index $RI$

<table>
<thead>
<tr>
<th>Size of Matrix</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random Index</td>
<td>0</td>
<td>0</td>
<td>0.58</td>
<td>0.9</td>
<td>1.12</td>
<td>1.24</td>
<td>1.32</td>
<td>1.41</td>
<td>1.45</td>
<td>1.49</td>
<td>1.51</td>
<td>1.54</td>
<td>1.56</td>
<td>1.57</td>
<td>1.58</td>
</tr>
</tbody>
</table>

Dyer (1990) reported that in AHP, decision makers should not expect perfect consistency but a percentage of inconsistency that is considered acceptable or tolerable in the expression of personal preferences. The Inconsistency Ratio ($IR$) between 0 and 0.10 or within 10 percents of what would be the outcome from random judgements is acceptable (Saaty, 1980; 1994a; Saaty and Vargas, 2001). A higher $IR$ (i.e. greater than 0.10) at any level or in the final synthesis revealed that the judgements are not consistent. Although it does not invalidate the entire model, but it does suggest that the judgement should be reinvestigated and try to find out the possible cause of inconsistency. If the modification of judgements fails to lead to an improvement of $IR$, then it is likely that the problem needs to be restructured by grouping the elements that are interrelated and have common characteristics (Saaty, 1983).

### 4.5 DECISION SUPPORT SYSTEMS (DSS)

Decision Support Systems (DSS) are computer-based systems that provide interactive support to managers during the decision-making process. The advances in computer processing and database technology have extended the definition of a DSS to include software products that help users apply analytical and scientific methods decision-making (Turban and Aronson, 1998). DSS operate by using models and algorithms from disciplines such as decision analysis, mathematical programming and optimization, stochastic modelling, simulation and logic modelling. DSS can execute, interpret, visualize and interactively analyze these models over multiple scenarios. It also allows the decision-maker to retrieve data and test alternative solutions during the process of problem solving. When well implemented and used wisely, DSS can significantly improve the quality of the decision-making.

The ‘Intelligent Selection’ in this research is referred to the decision making process as described in Section 4.2. It involved capturing the demolition expert’s knowledge to
clarify the purpose of decision by identifying and defining the problem in selecting demolition techniques. DSS provide a structured framework to model the decision making process by incorporating the expert knowledge captured in the intelligence phase that mimics human intelligence. The next sections describe DSS concepts and justify the tool adopted for the research.

4.5.1 DSS Concepts
The concept of DSS is based on assumptions about the role of computers in supporting decision-making:

- DSS requires human intervention that cannot be solved by the computer alone. It must support the decision maker but not replace his/her judgment. It should therefore neither provide answers nor impose a predefined sequence of analysis.

- The main advantage of DSS is for semi-structured and unstructured problems, where the analysis can be systemized for the computer but the decision-maker's judgments are needed to control the process.

- Effective problem solving is interactive and is enhanced by dialogue between the user and system.

4.5.2 DSS Adopted for the Research
Several DSS products have emerged in the past few years and commercially available. For example the products that are based the decision analysis methods is listed in Table 4.6. These products let a developer build a DSS application simply by specifying the necessary models and data. They offer a visual and/or textual language for building model schemas, features for model solution and analysis and commands and representations for visualizing model results. They minimize development effort by offering a generic graphical user interface, generic data management features and generalized solution algorithms and analysis tools. Using these products, someone who knows the relevant modelling paradigm and the problem domain can develop a DSS application in a few hours or days a significantly shorter time than previously possible.
The DSS commercial products listed in Table 4.6 are based on one or more decision analysis methods and have their own strengths and limitations. Since the research used the AHP model to solve the MCDM problem in selecting the most appropriate demolition techniques, therefore the most suitable DSS based on the same methodology as AHP is the Expert Choice (EC) software package.

**Table 4.6: DSS Products Available Commercially**

<table>
<thead>
<tr>
<th>DSS Products</th>
<th>Vendor Name</th>
<th>URL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decide Right for Windows</td>
<td>Avantos Performance Systems Inc.</td>
<td>Not available</td>
</tr>
<tr>
<td>Decision Analysis</td>
<td>TreeAge (DATA) TreeAge Software Inc.</td>
<td><a href="http://www.treeage.com/">http://www.treeage.com/</a></td>
</tr>
<tr>
<td>Precision Tree</td>
<td>Palisade Corp.</td>
<td><a href="http://www.palisade.com/">http://www.palisade.com/</a></td>
</tr>
</tbody>
</table>

Source: (Bhargava et al., 1999)

In 1983, Dr. Saaty who introduced AHP joined Dr. Ernest Forman, a professor of management science at George Washington University, to co-found EC. EC is intended to make structuring the hierarchy and synthesizing judgments quick and simple, eliminating tedious calculations (Forman and Shvartsman, 2000). Some of the features of this software are:

- It offers user-friendly displays that make decision model building straightforward and simple;

- It offers a model view containing either a tree view or cluster view of the decision hierarchy;

- It does not require numerical judgment from the decision-maker; rather, pairwise comparisons may be performed numerically, verbally, or graphically. This is
because software converts subjective judgments into the one-to-nine scale prescribed by AHP theory and then into meaningful priority vectors;

- It works by examining judgments made by decision-makers, and measures the consistency of those judgments;

- It allows for re-examination and revision of judgments for all levels of the hierarchy, and shows where inconsistencies exist and how to minimize them in order to improve the decision; and

- It provides a mathematically rigorous application and proven process for prioritization and decision-making. By reducing complex decisions to a series of pairwise comparisons, then synthesizing the results, EC not only helps decision-makers arrive at the best decision, but also provides a clear rationale for the decision.

4.6 SUMMARY
The nature of the decision making process involves multicriteria decision-making (MCDM). Therefore the characteristics of MCDM were reviewed to give a basic understanding on the subject matter before a suitable method for solving the problem could be selected. From the review, Analytic Hierarchy Process (AHP) was selected apart from other MCDM methods because of its ability to overcome the entire problem characteristic in term of the type of data, the approaches and the expected outcome of the decision process. The research will also use Expert Choice (EC) software that based on AHP methodology as a Decision Support System (DSS) tools to assist in structuring the hierarchy and synthesizing judgments and make it quick and simple by eliminating tedious calculations. The next chapter discusses the Knowledge Acquisition (KA) process, which involved capturing the expert knowledge in order to develop a demolition techniques selection system based on AHP methodology.
CHAPTER 5: KNOWLEDGE ACQUISITION FOR MODEL DEVELOPMENT

5.1 INTRODUCTION
This chapter presents the results from the knowledge acquisition process described in Chapter 2. This chapter is split into three main sections: questionnaire survey; interviews; and protocol analysis. All the sections describe the method adopted present the results and finally discuss the findings.

5.2 QUESTIONNAIRE SURVEY
The aim of the survey was to obtain preliminary broad based knowledge from the demolition industry. Four specific objectives have been identified, which include:

- To identify what type of structures were most commonly demolished in the past 5 years;
- To identify what type of demolition techniques were being used in relation to the different types of structures;
- To identify and rank the criteria used in selecting the demolition techniques; and
- To raise awareness of this research within the demolition industry.

5.2.1 Questionnaire Design
The questionnaire was designed in three parts: the introduction (cover letter), demographic or background questions (Section A) and the body of the study (Section B). Appendix A shows a copy of the questionnaire. The majority of the questions were designed as closed type with sufficient space provided for respondents to give additional information. Limited numbers of open-ended questions were also included in the questionnaire to capture certain knowledge that needs further explanations or views.

5.2.2 Pilot Survey
In the research, a pilot survey was conducted to check the appropriateness and clarity of the questions and to capture the recipients' possible reactions to the questionnaire. Two groups of respondents were selected for this purpose. The first group consist of two demolition practitioners who will eventually complete the survey and the second group
consist of five research staffs within the department with substantial experience in
designing survey questionnaires. A meeting was set-up with each of the respondent to
ensure instant feedback and thorough comment on the questionnaire. With regards to the
comments and recommendations during the pilot survey, several modifications have been
made to improve the questionnaire. Some of the modifications were:

- The font’s size was reformatted for better viewing;
- Several questions was rephrased for clarity; and
- The length of the questionnaire was shortened from four pages to three pages.

5.2.3 Survey Sample

The demolition engineers and in some cases the top management of the demolition
contractor companies are the persons responsible in making decision to select the
demolition techniques. Therefore, the survey population was confined to these targeted
respondents in the United Kingdom (UK). The contact details listed in National
Federation of Demolition Contractors (NFDC) Yearbook 2000 (157 contact details) and
IDE WebPages (15 contact details) were used as the sampling frame for this survey
(Atkinson and Faulkner, 2000). As mentioned in Chapter 2, several techniques can be
used to determine the survey sample. The survey sample method used in this research was
based on Convenience sampling method, where the respondents who are willing and
available are selected. All the targeted respondents were contacted by telephone to make
sure of their willingness and confirmation of address before the questionnaires were sent
by post. Finally, 100 respondents were agreed to participate in the research.

The questionnaires were distributed by mail with a self-addressed, stamped returned
envelope. They were directed to the persons involved directly and technically with the
demolition process as identified during the telephone inquiries. A follow up telephone call
was made on a month later, to those who had not responded, reminding them about the
questionnaire and asking for a response.

5.2.4 Results

The following sections present the results of the postal questionnaire survey.
Responses

67 questionnaires were returned, out of a 100 questionnaires delivered (See Table 5.1). Of these 65 were usable, representing a response rate of 65%, which is very good considering of 20-30% response rate in postal questionnaire surveys in the construction industry (Akintoye et al., 2000). Two of the questionnaires returned were unusable because the respondents did not complete it.

<table>
<thead>
<tr>
<th>Number of questionnaire sent</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of replies received</td>
<td>67</td>
</tr>
<tr>
<td>Number of usable replies</td>
<td>65</td>
</tr>
<tr>
<td>Percentage of total replies</td>
<td>67%</td>
</tr>
<tr>
<td>Percentage of usable replies</td>
<td>65%</td>
</tr>
</tbody>
</table>

Table 5.1: Response from the Questionnaire Survey

Background Information

The survey indicated that there are three groups of respondents based on their position in the demolition companies (see Figure 5.1). The biggest group was the 'director' category, which represents 54%, followed by 'manager' with 34%, while 12% represented 'other' which includes, site agents and safety officers.

The respondents who had between 10 to 19 years of experience were the largest group constituting 34% of the total respondents (see Figure 5.2). 29% of the respondents had between 20 to 29 years of experience, while 22% had between 30 to 39 years of experience in the demolition industry. The lowest group of respondents, which had less than 10 years of experience, made up 15%.
Types of Structures Demolished in the Past 5 years

Figure 5.3 shows that buildings were most common type of structure demolished, which represents 41.6% of the respondents. The second most commonly demolished structure was bridge (15.9%) and closely followed by independent chimney (12.4%) and basement and retaining wall (11.2%). The fifth most common type of structure demolished was masonry and brick arches which represent 6.3% of the respondents and followed accordingly after this by vessels (4.5%), lattice towers and mast (3.7%), tunnel (2.0%), spires (1.0%), dams (0.7%) and ‘other’, which include coal mine (0.7%).
Types of Materials Used in the Demolished Structures

Figure 5.4 shows four of the most common types of structures demolished by the respondents with reference to the types of materials. In building, the main types of material used include, brickwork/stonework, steel, reinforced concrete, pre-tensioned RC structures and timber, which represent more than eighty percent (80%) of the respondents. Some of the buildings demolished were also made of post-tensioned RC or composite structures but in to a lower extent (54%). Glass Reinforced Plastic was the least common type of materials with only 17% of the respondents mentioning it. The respondents highlighted seven types of materials used in the bridges that they have demolished in the last 5 years. These include brickwork/stonework, reinforced concrete and steel, which represent more than fifty percent (50%) of the respondents. Other types of material used were pre-tensioned RC, pre-stressed RC, composite structures and timber with six to seventeen percent (6 -17%). The respondents demolished no bridge made of glass-reinforced plastic in the past five years. For Independent Chimneys, the respondents cite three main types of material: brickwork/stonework, steel and reinforced concrete. The respondents did not demolish any independent chimney made by any other types of material. Two main types of materials used in the demolished basements and retaining wall were reinforced concrete (70%) and brickwork/stonework (60%). The respondents also demolished basements and retaining walls made of pre-tensioned RC, steel, post-tension RC, composite structures and timber but the average percentage is below ten percent (10%).

Demolition Techniques Used for each Type of Structures

Figure 5.5 shows the demolition techniques used by the respondents on each type of structures. The respondents highlighted that demolition techniques by hand were used for most of the demolished structures except for dams. They also cited that demolition techniques by machines and chemical agents were used for all structures. Demolition by high pressure water jetting was used in bridges, independent chimney, basement and retaining wall, masonry and brick arches, vessels and tunnels. The results also indicated that the combinations of demolition techniques were used for all the structure demolished by respondents.
Figure 5.4: Types of materials used in the demolished structure

Figure 5.5: Type of demolition techniques used in the demolished structure
Condition for Use of Demolition Techniques

The respondents justified the condition for used the four main types of demolition techniques: demolition by hand, demolition by machines, demolition by chemical agents and demolition by high pressure water jetting. The responses have been edited to avoid duplication and are shown in Tables 5.2 to 5.5.

Table 5.2: Usage or application areas for demolition by hand

<table>
<thead>
<tr>
<th>No</th>
<th>Demolition Techniques</th>
<th>Usage / Application Area</th>
</tr>
</thead>
</table>
| 1. | Demolition by hand    | • To separate structure to be demolished from adjacent structures or from remaining adjoining  
|    |                       | • Work near to live services or public area  
|    |                       | • Where site or safety restrictions prevented mechanical demolitions  
|    |                       | • Where the demolition has to be carefully controlled  
|    |                       | • Site involving contamination  
|    |                       | • Stripping out soft strip material such as door/window frames |

Table 5.3: Usage or application areas for demolition by chemical agents

<table>
<thead>
<tr>
<th>No</th>
<th>Demolition Techniques</th>
<th>Usage / Application Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.</td>
<td>Demolition by chemical agents</td>
<td></td>
</tr>
</tbody>
</table>
| 3.1| Demolition by explosives | • High structures, tower blocks, chimneys, bridges, boiler house, chemical plant large steel and concrete structures  
|    |                       | • Quickest and effective way of getting structure to the floor  
|    |                       | • As long as authorities will allow and surrounding area will permit i.e. adjacent properties etc.  
|    |                       | • Isolated sites  
|    |                       | • Out of reach of long reach machines  
|    |                       | • Specialist projects  
|    |                       | • Unstable structures |
| 3.2| Bursting              | • Water towers, mass concrete e.g. foundations  
|    |                       | • Where noise is a problem  
|    |                       | • Rarely or hardly ever used  
|    |                       | • Commercially attractive  
|    |                       | • Specialist projects  
|    |                       | • Where vibration cannot be tolerated |
| 3.3| Hot cutting           | • Generally to cut steelwork for steel framed buildings, vessels and bridges  
|    |                       | • Hot work is allowed  
|    |                       | • No chemical contamination |
Table 5.4: Usage or application areas for demolition by machines

<table>
<thead>
<tr>
<th>No</th>
<th>Demolition Techniques</th>
<th>Usage / Application Area</th>
</tr>
</thead>
</table>
| 2. | Demolition by machines | • Wherever possible  
|    |                       | • Where structures are isolated  
|    |                       | • Where the machines can move around  
| 2.1| Remotely controlled machines and robotic devices | • Dangerous environments for operations e.g. unsafe structures or danger to personnel  
|    |                       | • Internal demolition e.g. Concrete floors in multi storey structure  
|    |                       | • Pre-weakening of structures for demolition by explosives  
|    |                       | • Confined areas and where there is danger of collapse or unstable structures  
|    |                       | • Nuclear contamination  
| 2.2| High reach machines | • Multi storey buildings or high structures where access permits  
|    |                       | • Quick and easy solution for demolition  
|    |                       | • Where structures are isolated  
|    |                       | • Restriction to deconstruct or use of explosive  
| 2.3| Tower and high reach cranes | • Multi storey buildings or high structures  
|    |                       | • Mobile cranes to lift out key structures or plant e.g. bridge beams, trusses  
|    |                       | • When structures come down on a floor by floor basis or deconstruction/de-build  
|    |                       | • In association with hand demolitions  
|    |                       | • Dismantle activities  
| 2.4| Hydraulic attachments | • In most situations wherever possible  
|    |                       | • Breaking and cutting of steel structures, RC structures, brick, foundations/slabs (pulverizer) and Cutting steel (shears)  
| 2.5| Mechanical (non-hydraulic) attachments e.g. Balling | • Very isolated or open areas  
|    |                       | • Hardly ever used  
|    |                       | • Where there are no restrictions  
|    |                       | • High rise structures  
|    |                       | • Cheap or to avoid high cost of specialised plant  
|    |                       | • In certain circumstances chimneys may be pulled down by steel hammer  
|    |                       | • Where little collateral damage can be caused  
| 2.6| Cutting by drilling and sawing | • Where separation needed from the retained structures  
|    |                       | • Partial demolition of concrete  
|    |                       | • Bridges, wall, slab or concrete floors removal  
|    |                       | • Where clean cut edge is required  

Table 5.5: Usage or application areas for demolition by high pressure water jetting

<table>
<thead>
<tr>
<th>No</th>
<th>Demolition Techniques</th>
<th>Usage / Application Area</th>
</tr>
</thead>
</table>
| 4. | Demolition by high pressure water jetting | • Where hot cutting or work is not allowed e.g. chemical plant  
|    |                       | • Where need to cold cut steel in areas such as refineries  
|    |                       | • Where vibration must be avoided  
|    |                       | • With contaminated equipment or explosive atmospheres  
|    |                       | • Bridges, vessels previously containing flammable or toxic material (radio active)  

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Ranking Selection Criteria

A total of 64 respondents answer this question. There are fourteen criteria for the selection of demolition techniques listed in the question B4. The following steps were used to rank the criteria for selection of demolition techniques (refer to Table 5.6). First, the raw score for each criterion was multiplied by the ranking number (1 to 14) to get the assigned score. Then the total assigned score for each criterion can be calculated by adding each of the assigned score on the same row. The lowest total assigned score is the most important criterion and ranked as 1. For example, Health & Safety (H&S) had a total assigned score of 124 and the calculation can be expressed as follows:

\[
As_{ij} = \text{Raw Score Each Criterion } (C_{ij}) \times \text{Ranking Number } (R_j)
\]

Total Assigned Score \( \sum_{i=1}^{n} As_{ij} = \sum_{i=1}^{n} C_{ij}R_j \), where \( n = 14 \)

\[
\text{Total } (AS) \text{ H & S} = \left[ \begin{array}{c}
(46 \times 1) + (10 \times 2) + (0 \times 3) + (2 \times 4) + (2 \times 5) + (0 \times 6) + (2 \times 7) \\
(0 \times 8) + (0 \times 9) + (0 \times 10) + (0 \times 11) + (0 \times 12) + (2 \times 13) + (0 \times 14)
\end{array} \right]
\]

\[
= 124
\]

Note: The same procedure was used to calculate the other 13 criteria.

Selection Procedure

Table 5.7 outlines the procedures used in selecting demolition techniques. It shows that several activities such as site visit and risk assessment were carried out before the selection process. It is also clear that, various demolition practitioners involved but no conclusion can be made on whom exactly made the final decision in the selection process. The selection procedures were also relied on experience and past projects.

<table>
<thead>
<tr>
<th>List of procedures given by respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Site visit, check constraints, hazards, nearby properties and roads, height of structure and access for plant</td>
</tr>
<tr>
<td>• Carry out a risk assessment and cost assessment for that particular activity and from that decide on appropriate techniques</td>
</tr>
<tr>
<td>• The project is assessed by a team (e.g. site supervisor, demolition engineer, managers or directors) who look at all aspects of the work</td>
</tr>
<tr>
<td>• Utilising experience of various professionals</td>
</tr>
<tr>
<td>• By referring to past contracts</td>
</tr>
</tbody>
</table>
Table 5.6: The ranking of the criteria in order of importance

| CRITERIA ($C_j$) | Raw Score at Rank 1 ($C_{1j}$) | Assigned Score ($C_{2j}$) | Raw Score at Rank 2 ($C_{2j}$) | Assigned Score ($C_{2j}$) | Raw Score at Rank 3 ($C_{3j}$) | Assigned Score ($C_{2j}$) | Raw Score at Rank 4 ($C_{4j}$) | Assigned Score ($C_{2j}$) | Raw Score at Rank 5 ($C_{5j}$) | Assigned Score ($C_{2j}$) | Raw Score at Rank 6 ($C_{6j}$) | Assigned Score ($C_{2j}$) | Raw Score at Rank 7 ($C_{7j}$) | Assigned Score ($C_{2j}$) | Raw Score at Rank 8 ($C_{8j}$) | Assigned Score ($C_{2j}$) | Raw Score at Rank 9 ($C_{9j}$) | Assigned Score ($C_{2j}$) | Raw Score at Rank 10 ($C_{10j}$) | Assigned Score ($C_{2j}$) | Raw Score at Rank 11 ($C_{11j}$) | Assigned Score ($C_{2j}$) | Raw Score at Rank 12 ($C_{12j}$) | Assigned Score ($C_{2j}$) | Raw Score at Rank 13 ($C_{13j}$) | Assigned Score ($C_{2j}$) | Raw Score at Rank 14 ($C_{14j}$) | Assigned Score ($C_{2j}$) | TOTAL ASSIGNED SCORE | RANKING |
|-----------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|----------------------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--|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|----------------------|---------------------------------|---------------------
Efficiency of Current Procedures

Figure 5.6 shows the efficiencies of the current procedures used by the respondents in selecting demolition techniques. Nearly half of the respondents (47%) indicated that the current procedures were very poor or poor. Only 24% consider it efficient and 18% very efficient. Eleven percent of the respondents viewed it as neutral.

![Figure 5.6: Efficiency of current procedures](image)

Key Stages in Demolition Process

Table 5.8 outlines the key stages involved in the demolition process. It shows that the demolition process involved several stages. The stages can be highlighted as: tendering, site survey, risk assessment, decommissioning, soft stripping, structural demolition, reuse and recycling and finally site clearance. This information will be used later in the research as a preliminary outline to construct a demolition process flowchart.

<table>
<thead>
<tr>
<th>List of key stages in demolition process</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Approvals, service terminations, scaffolding, soft strip, demolition, clearance</td>
</tr>
<tr>
<td>• Tender, asbestos removal, other hazardous removal, demolition</td>
</tr>
<tr>
<td>• Asbestos removal, soft strip, demolition of sub-structure</td>
</tr>
<tr>
<td>• Deciding safe method, soft stripping, machine demolition, disposal of materials</td>
</tr>
<tr>
<td>• Win contract, method statement, service notices, start date, soft strip, demolish, clear site</td>
</tr>
<tr>
<td>• Asbestos removal, salvage materials, soft strip, structural demolition, floor slab removal, site tidiness</td>
</tr>
<tr>
<td>• Contract award, hazard survey, termination of services submission, preparation of method statements, selection of equipment</td>
</tr>
<tr>
<td>• Client select contractor, agree objective, specify constraint, risk assessment, plant the work, communicate the plan, monitor the plan</td>
</tr>
<tr>
<td>• Obtained all approval, plan/organise, set up on site, remove contamination/prepare by hand or machine demolition, demolished structures, haul from site or crush on site, remove foundations, remove equipment</td>
</tr>
<tr>
<td>• Site survey, risk assessment, method statements, selected supervisors</td>
</tr>
<tr>
<td>• Survey, notices, decontamination, soft strip, structural demolition, recycling, site clearance</td>
</tr>
<tr>
<td>• Agree client requirements, review, health and safety consideration, review place, execute job,</td>
</tr>
<tr>
<td>• Asbestos, services, height work, hand work, remote demolition, clearing site</td>
</tr>
</tbody>
</table>
Guidance on the Choice of Appropriate Demolition Techniques

Results from Figure 5.7 shows that, more than half of the respondents (52%) did not have adequate guidance to select the demolition techniques. Most of the respondents (48%) indicated that, the main source of guidance came from BS 6187: 2000. Twenty three percent of the respondents used their in-house guide to select the appropriate demolition techniques. IDE and NFDC guide are used by only 13% and 10% of the respondents respectively. Only 6% of the respondents point out that they used ‘other’ type of guidance, which include Health and Safety Executive (HSE) approved code of practice and experience.

![Figure 5.7: Guidance on Selection of Demolition Techniques](image)

Decision Makers

Figure 5.8 shows the personnel responsible for deciding which demolition techniques will be used in a demolition project. The vast majority of the respondents (54%) point out that the demolition engineer is the person responsible for the decision-making. Eighteen percent of the respondent identified demolition manager, 12% director, 8% site manager and 5% contract manager as the decision makers. The ‘other’ decision makers identified by respondents were safety advisors and planning supervisors.

![Figure 5.8: Decision Makers on Demolition Techniques](image)
Basis for Selection Decision

When referred to the basis for the selection decision, five variety of answer given by respondents (see Table 5.9). The majority of the respondents (78%) agreed that the basis of the decision is 100% by experience/past cases. Other variations are when the decision was based on the combination of quantitative analysis, qualitative analysis and experience/past cases. The results reveal that, the decision based on experience/past cases is still the main contribution in the decision-making process for the rest of the variation respectively, where it represent 80%, 70%, 50% and 35% of the combination.

Table 5.9: Variation of decision used by respondents to select demolition techniques

<table>
<thead>
<tr>
<th>Type of Decision</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% by experience/past cases</td>
<td>78.3</td>
</tr>
<tr>
<td>Combination of quantitative analysis 10%, qualitative analysis 10% and experience/past cases 80%</td>
<td>3.3</td>
</tr>
<tr>
<td>Combination of quantitative analysis 15%, qualitative analysis 15% and experience/past cases 70%</td>
<td>8.3</td>
</tr>
<tr>
<td>Combination of quantitative analysis 25%, qualitative analysis 25% and experience/past cases 50%</td>
<td>8.3</td>
</tr>
<tr>
<td>Combination of quantitative analysis 30%, qualitative analysis 35% and experience/past cases 35%</td>
<td>1.7</td>
</tr>
</tbody>
</table>

N =60

Problems in Undertaking Demolition Work

Table 5.10 list the problems faces by the respondents in the demolition work. The respondent highlights several problems, which can be summarised as: the identification of risk; health and safety factors; planning; relationship among the parties involved in the demolition process; and finally no documented procedures that can be used as a guide in selecting demolition technique. The issue identified by the respondents is directly addressed by the research.

Table 5.10: Problems faces by the respondents in demolition work

<table>
<thead>
<tr>
<th>List of problems faces by the respondents in the demolition work</th>
</tr>
</thead>
<tbody>
<tr>
<td>• The identification of risk (i.e. contaminants, history of the structures and services)</td>
</tr>
<tr>
<td>• Health and safety factors (e.g. ensuring the demolition can be done safely)</td>
</tr>
<tr>
<td>• Co-ordination or planning numerous activities e.g. resources, time and costing for the project</td>
</tr>
<tr>
<td>• Demolition contractors and Client relationship e.g. client not giving enough information at tender stage, working with clients who are only interested in completion of the project and convincing clients on the demolition techniques selected</td>
</tr>
<tr>
<td>• Main contractor and sub-contractor relationships (e.g. being forced to carry out some work as a subcontractor with little or no experience in demolition work)</td>
</tr>
<tr>
<td>• No documented procedures on how to select the demolition techniques</td>
</tr>
</tbody>
</table>
Use of IT in Demolition

Figure 5.9 shows the respondents answer on the use of computers/IT in the demolition process. Majority of the respondents used computers/IT, which represents 76% and 25%, did not use it. Table 5.11 lists the IT tools used in the demolition process. It can be summarised that IT tools was used to produce report, access the Internet, compiling data base and running software program. The results reveal that, the respondents are well aware of the use of IT in their work.

![Figure 5.9: Respondents answers on the use of computers/IT in the demolition process](image)

<table>
<thead>
<tr>
<th>IT tools Used in Demolition Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Producing report using word processing software e.g. method statements, risk assessment, cost assessment, health and safety documents</td>
</tr>
<tr>
<td>• Internet e.g. emails software - sending and receiving of information, Internet explorer software - finding information about project, history of site, chemical used etc.</td>
</tr>
<tr>
<td>• Database e.g. recording contract data</td>
</tr>
<tr>
<td>• Running software programme e.g. structural analysis software, planning software, estimating software</td>
</tr>
</tbody>
</table>

Potential Improvements to Demolition Process

Suggestion for improving the demolition process are summarised in Table 5.12. Many of these relate to the need to improve the method of sharing the information or knowledge between the parties involved in the demolition process. The respondents also suggested that there is a need to learn from experience and past project in order to improve the demolition process. Other potential improvements include: planning; training; research; education; and awareness to reuse and recycling.
Table 5.12: Potential improvements to demolition process

<table>
<thead>
<tr>
<th>List of respondents suggestion to improve demolition process</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Sharing of knowledge</td>
</tr>
<tr>
<td>• Learning from experiences and previous project</td>
</tr>
<tr>
<td>• Changing all method statements into procedures</td>
</tr>
<tr>
<td>• Better site management and programming</td>
</tr>
<tr>
<td>• By continual revision of construction techniques which are then related to demolition techniques</td>
</tr>
<tr>
<td>• Minimise interface problem between sub-contractors e.g. ensure no overlap on involvement with incoming builders for the new replacement building</td>
</tr>
<tr>
<td>• More information on the structure of the building being demolished at tender stage from clients through structural survey</td>
</tr>
<tr>
<td>• Continual training and education e.g. HSE needs to educate clients about their responsibilities with regard to Construction Design &amp; Management (CDM) regulations</td>
</tr>
<tr>
<td>• More research in new demolition techniques i.e. new machineries and tools</td>
</tr>
<tr>
<td>• By becoming more aware on environmental considerations e.g. recycling and reuse of demolition debris</td>
</tr>
</tbody>
</table>

5.2.5 Discussion

The convenience sampling method adopted for the survey proved to be appropriate when a high response rate was achieved. The responses from the survey also showed that the majority of the respondents are very knowledgeable and had the expertise to answer the questions effectively by referring to their experience in the demolition industry.

Since building is the most commonly demolished structure in the past 5 years, the research is expected to get more information on demolished building compared to other types of structures from the industry. Based on this finding the research will now used building as the main example in the interview, protocol analysis and the model development, in the aim to get more material, feedback and comment from the experts.

Other important fact that can be discussed is on the demolition techniques. The four demolition techniques listed in the questionnaire have its own advantages and disadvantages and the respondents are likely to use combinations of those techniques to demolish a structure. It is important for the research to provide a list of demolition techniques available in the market and defines its advantages and disadvantages so that it can be used as guidance in selecting the most appropriate demolition techniques.

The respondent identified that the most important criteria that affect the selection of demolition techniques was health and safety followed by other 13 criteria. This finding
was used as a basis for structuring in-depth interviews with the demolition experts, since it is difficult to ask the respondents to justify their choice in the questionnaire survey.

The rest of the findings were designed to elicit knowledge from the respondents about the demolition industry in general. Several key points that can be highlighted are:

- Nearly half of the respondents indicated that the current procedures were poor;
- Several key stages were identified in the demolition process and the information provided by the respondent will be used to construct a demolition process flowchart;
- More than half of the respondents did not have adequate guidance to select the demolition techniques;
- The vast majority of the respondents point out that the demolition engineer is the person responsible for the decision making;
- The majority of the respondents agreed that the basis of the decision is 100% by experience/past cases;
- Majority of the respondents used computers/IT which represents which reveals that the respondents are well aware of the use of IT in their work;
- There was a need to improve the method of sharing the information or knowledge between the parties involved in the demolition process; and
- The respondents also suggested that there is a need to learn from experience and past project in order to improve the demolition process.

The industry survey through postal questionnaire gathered a considerable amount of information for the research project and at the same time raised several issues to be investigated in more detail. However there are limitations to this approach such as the limited number of questions that can be asked and it would be harder to describe or justifies certain information. The in-depth interviews, therefore, are needed to investigate these raised issues and overcome the limitations in the questionnaire survey.
5.3 INTERVIEWS
Several interviews with demolition experts were carried out after the entire postal questionnaire survey returned and analysed. The objective of the interview were:

- To define and justify the relevance of the identified criteria that resulted from the questionnaire survey; and
- To define and group the demolition techniques obtained from the questionnaire survey.

To achieve these objectives, semi-structured interview was selected. It was decided to use a semi-structured interview to encourage in depth discussions and greater interaction and at the same time maintained a level of comparability between interviewees. A semi-structured interview template (see Appendix B) was prepared prior to interview. In addition, a card sorting techniques was used during the interviews to group the criteria and demolition techniques in order to develop a hierarchy that represent the decision process in selecting demolition techniques. A detail methodology on how to conduct the interview was discussed in Chapter 2.

The demolition experts were carefully selected so that they could provide the researcher with the required knowledge and cooperation. Six experts were selected; they were all registered with the Institute of Demolition Engineers United Kingdom (UK) and had vast experience in the demolition industry. Each interview lasted approximately one and half-hours. All the interviewees had granted permission to record the interviews and a video recorder was used to record it.

5.3.1 Results
The following is a summary of the knowledge captured during the interviews.

Justification of the Identified Criteria
Table 5.13 summarised the justification of each criteria based on interviewees’ responses. All the interviewees agreed that Health and Safety should be considered as the primary criteria in selecting demolition techniques and through out the demolition process. They also point out that the past experienced of the demolition engineers play the biggest part
in the decision making process. The interviewees also reveal that the most appropriate
demolition technique is the one, which have the balance of its technical and economical
aspects with full awareness of the health and safety issues.

**Definition and Grouping the Demolition Techniques**

The interviewees agreed that the four demolition techniques: demolition by hand,
demolition by machines; demolition by chemical agents; and demolition by high pressure
water jetting listed in the survey were used in practice and the combinations of different
techniques are usually employed. The interviewees also point out that for structural
demolition, the techniques listed can be group together based on the definition given by
the ‘British Code of Practice for Demolition BS 6187:2000’, which include Progressive
Demolition; Deliberate Collapse Mechanisms; and Deliberate Removal of Elements. By
using the card sorting method, the group was established and shows in Figure 5.10. The
interviewees also define the sub-demolition techniques that have been group under the
main techniques.

**5.3.2 Discussions**

The criteria justified by the interviewees discussed in the following sections:

**Health and Safety**

Health and safety of persons on or off site is a key issue, which cannot be compromised
by the demolition engineer when selecting a demolition technique. It involved three
parties:

a) Those involved before demolition commences, e.g. those undertaking
preliminaries work, including surveys;

b) Those involved directly with the demolition process, e.g. demolition
contractors, including sub-contractors;

c) Those indirectly involved with (a) or (b) but could be affected e.g. members of
the public.

The responsibility for safety lies both on the contractor and the client but the contractor is
responsible for managing the health and safety risks on site. In general, the demolition
technique selected should not at any time pose any threat to the health and safety of site
personnel and members of the public. The scale of health and safety risks associated with
demolition projects vary enormously from one project to another. There are several health and safety regulations for demolition, which are expected to be followed strictly. Section 12, BS 6187:2000 should be referred to when considering health and safety aspects in every demolition project. The safest demolition technique would be one where the structure can be demolished from a remote area. However, this is not always possible due to site conditions.

**Stability of the Structure**

This criterion is important and needs adequate consideration before selecting a demolition technique. If a structure were highly unstable, then the demolition engineer would be expected to select a technique, which does not require site personnel operating within the structure. If the unstable structure is located on a confined site, the demolition engineer needs to stabilize the structure by providing appropriate temporary supports before selecting a particular demolition technique. Section 16, BS 6187:2000 provides guidance for stability and access to temporary structures. From various case studies done in this research and confirmed by the interviewees, usually, for low-rise unstable buildings and structures, machine mounted hydraulic or pneumatic breakers are ideal demolition techniques. For unstable high-rise buildings and structures on confined sites, the deconstruction or controlled blasting of the building or structure should be considered after full temporary supports are provided to stabilize the structure. The stability of a structure should also be checked when under load during demolition to avoid unplanned structural collapse.

**Location and Accessibility**

The location of the structure to be demolished plays a major part in the selection of a demolition technique. All demolition work should be provided with an exclusion zone. Section 3.14, BS 6187:2000 defined the exclusion zone as 'designated three-dimensional space from which all persons, including the public, are excluded during demolition activities. In certain circumstances, key site personnel may remain within the zone for a specific task provided they are adequately protected'. The distance between adjacent structures or services to the proposed structures for demolition should also be considered. For example, a high-rise demolition project located at the centre of a busy town centre will require a different demolition technique to a similar demolition project located on a remote site.
Presence of Hazardous Material

This criterion has relationship with the health and safety criterion. Hazardous material includes:

- Dirty or contaminated water;
- Asbestos e.g. asbestos insulating board, cladding or roofing (asbestos cement) etc.;
- Chemical e.g. radioactive luminous paint, lead paint etc.;
- Ionizing radiations or radioactive materials e.g. lightning conductor, smoke detectors etc.;
- Non-ionizing radiations e.g. ultraviolet and infrared radiation;
- Man-made mineral fibres e.g. mineral wool and glass fibres;
- Pathogens or organisms that cause diseases that can derive from dead animals;
- Gases e.g. carbon monoxide (fumes from combustion), methane (public gas supply, coal mines) and petrol fumes;

The removal a hazardous material such as asbestos, is a common type of task undertaken by demolition contractor when demolishing buildings but it is a specialised task and not all demolition contractors have the expertise to deal with such work. Therefore, the selection of demolition technique is also dictated by the presence of hazardous materials.

Environmental Considerations

Today, environmental issues are of great importance to the general public and especially to environmental groups. Demolition can be considered as a waste-generating activity, e.g. noise and dust generation. There are several environmental restrictions that are imposed on demolition projects by local Environment authorities and also by environmentally conscious clients e.g. The Environmental Protection Act (1990), which addresses many aspects of waste and other pollution control and The Noise and Statutory Nuisance Act (1993). The demolition engineer is expected to work closely with the local environmental services to fully assess the environmental risks before selecting a demolition technique. Demolition engineer are required to hand in a method statement where they have to describe their proposed method of tackling the various aspects of the demolition work including environmental issues which arise from the demolition process.
Shape and Size of the Structure
Shape and size of a structure are also important criteria, which can influence the selection of demolition techniques on a demolition project. Prior to demolition of any structure, it is important to have in depth knowledge of the structure in order to predict and plan its demolition. Understanding of the structure on any demolition project is the key factor behind any successful demolition projects, which makes the consultation of a structural engineer a high priority. The demolition engineer is expected to work closely with the structural engineer.

Client Specification
The client, as in the construction industry, is the single most important person on a demolition project. Clients usually impose restrictions on the type of demolition technique that should be used on particular demolition projects. The demolition engineer is then left to select other demolition techniques to demolish the structure in question. For example, if the client does not permit the blasting technique in the pre-tender stage, the demolition engineer has to choose other techniques. Therefore, the demolition engineer before embarking on any type of demolition technique needs to be aware of the restrictions imposed by the client.

Structural Engineers Approval
Due to the increasing complexity of construction techniques and structural forms, it is no longer easy for the demolition engineer to easily assess the possible collapse mechanisms of a structure. Therefore, the structural engineer is actively involved in the demolition process of sophisticated structures and directly influences the demolition engineer’s choice of demolition technique to be implemented on such demolition projects. Generally, the structural engineer will take on board the demolition engineer’s working method and then identify those aspects of any temporary works design that are sensitive to the proposed demolition technique or sequence so that the necessary temporary supports can be evaluated and designed (Stephenson, 1989). The structural engineer also assesses the behaviour of a structure during collapse, which is essential to the demolition engineer especially when making decisions on measures to protect adjacent properties. The structural engineer is expected to know the requirements and methods available to the demolition engineer so that together they can ensure the safe and efficient demolition of the structure.
Time Constraints
As on a construction project, a time limit is usually imposed on demolition projects. Nevertheless, demolition projects are generally required to be carried out as quickly as possible by the client who may wish to develop the land as soon as the demolition work is complete. Where the time imposed on a demolition project is short and the client is willing to pay for a quick demolition, the demolition engineer is expected to select a demolition technique with little regard for cost. Time constraint is not always imposed by the client on demolition projects but by a local authority who may be more concerned about the comfort and convenience of the general public comfortless.

Extent of Demolition
The extent of demolition or the degree of destruction (i.e. whether a full or partial demolition is to be carried out) is also considered in selecting demolition techniques. For example, for partial demolition or renovation/modification work, the removal of selected parts of a structure by dismantling and deconstruction is more suitable. The demolition engineer can choose either to use demolition by hand or machines or both rather than demolition by explosives by itself.

Financial Constraint
Financial constraints may also be imposed on demolition projects, just as in construction projects. The demolition engineer is expected to select a safe and financially feasible demolition technique. However, the demolition engineer should not, under any circumstance compromise on safety while selecting a demolition technique despite the financial constraint that may be imposed on the demolition of a structure. Clients generally do not want to spend much on demolition projects and usually the demolition engineer is expected to work with a small budget. Therefore, it is important that the demolition engineer considers the financial implication of the demolition techniques selected for a particular demolition work.

Recycling Considerations
Recycling of demolition materials is an important aspect in demolition projects, which the demolition engineer needs to consider when selecting a demolition technique. To minimize contaminated waste and to maximize the possibility for re-use and recycling,
demolition techniques should be selected for the optimal recovery of materials, but taking into account health and safety issues and cost.

**Transportation Considerations**
Transportation considerations are also one of the criteria that affect the demolition technique selection. For example, the transportation of structural elements such as beams or roof trusses from the demolition site to the recycling point needs appropriate equipment or machines that have to be considered.

**Availability of Plant and Equipment**
In practice, the plant and equipment for demolition work can be rented from the leasing company if the demolition engineer does not have it. Therefore, this criterion does not have much effect on the selection of the demolition technique.

The interviews have achieved its aim and objective, which is to capture experts knowledge on the criteria and demolition techniques used in the decision making process. These findings provided an important input for the development of the proposed demolition techniques selection system.
Table 5.13: Criteria for the selection of demolition techniques

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Justifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health and Safety (H&amp;S)</td>
<td>• H&amp;S should be considered throughout the demolition process</td>
</tr>
<tr>
<td></td>
<td>• The most important consideration</td>
</tr>
<tr>
<td></td>
<td>• H&amp;S aspects for the person on and off site need to be considered before selecting demolition techniques</td>
</tr>
<tr>
<td>Stability of the structure</td>
<td>• Different types of techniques need to be considered for stable or unstable structure</td>
</tr>
<tr>
<td></td>
<td>• Avoid the workers working inside the structure that was unstable</td>
</tr>
<tr>
<td></td>
<td>• If the structure was unstable, this will probably become the most important criteria in selecting demolition techniques</td>
</tr>
<tr>
<td>Location and accessibility</td>
<td>• Different locations have an effect in selecting demolition techniques</td>
</tr>
<tr>
<td></td>
<td>• The deconstruction techniques probably the best choice for structure that located in town centre</td>
</tr>
<tr>
<td></td>
<td>• All the demolition techniques available should be considered if the structure is located at remote area</td>
</tr>
<tr>
<td>Presence of hazardous material</td>
<td>• The material should be removed first before, carry out the structural demolition</td>
</tr>
<tr>
<td></td>
<td>• Not much effect in the selection of demolition techniques since it was done in the decommissioning stage</td>
</tr>
<tr>
<td>Environmental consideration</td>
<td>• The environmental consideration may affect the selection of demolition techniques when certain level of nuisance imposed by local authorities or based on specified regulation</td>
</tr>
<tr>
<td></td>
<td>• The choice of demolition techniques depend on the permitted level of noise, dust and vibration</td>
</tr>
<tr>
<td></td>
<td>• If possible, select the demolition techniques that can minimise the size of demolition debris. The smaller the size the easier to crush or to transport the debris to the landfill site</td>
</tr>
<tr>
<td>Shape and size of the structure</td>
<td>• A single demolition technique or a combination of techniques are selected depending on the shape and size of the structure</td>
</tr>
<tr>
<td></td>
<td>• A high-rise building probably needs to consider a combination of techniques. Deconstruction techniques are used for the top part of the building until certain level that can be reached by demolition excavator.</td>
</tr>
<tr>
<td></td>
<td>• The demolition engineer might only use a demolition excavator to demolish a single storey house</td>
</tr>
<tr>
<td>Client specification</td>
<td>• Sometimes the client restricted some types of demolition techniques, such as the use of explosive in the demolition project and therefore it may limited the choice of techniques that can be selected</td>
</tr>
</tbody>
</table>
### Table 5.13: Criteria for the selection of demolition techniques (continued)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Justifications</th>
</tr>
</thead>
</table>
| Structural engineer approval    | • The demolition engineer did not need any approval from the structural engineer  
• The structural engineer opinions was used a guide in selecting the demolition techniques. For example to determine the stability of the structure.                                                                 |
| Time constraint                 | • Each demolition techniques have its own duration to complete the job  
• By using explosive, the actual demolition work might take a few seconds, but the planning before the execution take considerable amount of time  
• The time constraints can be divided into three categories: designing the demolition techniques; site preparations; and actual demolition time |
| Extent of demolition            | • The extent of demolition can be divided into two categories: partial demolition; or complete demolition  
• The partial demolition usually used in conjunction with building refurbishments  
• The complete demolition usually used to make way for a new structure to be build in the same site  
• In partial demolition, the effect of the structure that is to be retained must be considered when selecting the demolition technique |
| Financial Constraint            | • The most appropriate demolition techniques is the one which have the balance of its technical ability and the economical consideration  
• Each demolition techniques have its own cost that effect the overall cost estimation of the demolition project  
• The demolition technique selected will either increase or decrease the profit margin  
• The costs involved include: machinery and manpower costs. |
| Recycling consideration         | • The level of reuse and recycling will effect the selection of demolition technique to some extent  
• Deconstruction technique is suitable when a high level of concern imposed by the client  
• The lesser the level of concern, the wider the options of the demolition technique that can be choose from |
| Transportation consideration    | • Not really affected the selection of demolition techniques unless, the condition of the demolition site restricted the accessibility of heavy machineries |
| Availability of plant or equipment | • Plant and equipment for demolition can either be purchase or rented  
• The availability of plant and equipment will effect to some extent the selection of demolition techniques  
• The demolition contractors be likely to use the plant and equipment that easily available and cost the least to them |
Long Reach Machine with Various Hydraulic Attachments
- The excavator attached with boom and hydraulic attachments such as crushers, impact hammer, shears etc.
- The crusher attachment breaks the concrete and the reinforcement by the hydraulic thrust through the long boom arm system.
- The hydraulic crusher could be operated from the ground outside the building.
- This technique is also suitable for dangerous buildings, silos and other industrial facilities.

Progressive Demolition
The progressive demolition is the controlled removal of sections of the structure, at the same time retaining the stability of the remainder and avoiding collapse of the whole or part of the structure to be demolished (BS6187: 2000).

Demolition Ball
- The demolition ball application consists of a crane equipped with a steel ball
- It involves the progressive demolition of a structure by the use of an iron ball that is suspended from a lifting appliance (crawler crane) and then released to impact the structure, repeatedly, in the same or different locations
- This technique is suitable for tumble down structure.

Deliberate Collapse Mechanism
Demolition by deliberate collapse is the removal of the key structural members to cause complete collapse of the whole or part of the building structures of the whole or part of the structure to be demolished (BS6187: 2000).

Explosive
- Use of explosive
- Restrictive entry to work area
- Adequate clear space of 2.5 the building height
- Qualified blaster
- Notification and evacuation of neighborhood
- Could shorten the work period and reduce labor
- Risk assessment required to be continued

Wire Rope Pulling
- Involves the use of an earth mover machine or mechanical winch device equipped with heavy steel wire for pulling down structural members
- Restrictive entry to work area
- Adequate clear space of 2.0 the building height
- Limited to building less than 15 m high
- Firm working ground
- Poor application for underground structure

Deconstruction by Hand
- Breaking away the concrete by hand held jack hammer or pneumatic breaker
- On a floor by floor downward sequence
- Effective in narrow and localised place
- Efficient for simple structure

Deconstruction by Machines
- Breaking away the structure by machine mounted percussive breaker
- On a floor by floor downward sequence
- Adequate floor support for machine

Figure 5.10: Type of demolition techniques
5.4 PROTOCOL ANALYSIS
One of the identified criteria from the questionnaire survey and interviews that affect the selection of demolition technique was cost. The knowledge on how the demolition estimation process was performed by the experts need to be captured to further evaluate this criterion against the available demolition techniques. Since the knowledge that need to be captured involved the ‘process’, therefore the most appropriate knowledge acquisition techniques was protocol analysis. The objectives of protocol analysis were:

- To investigate how the demolition experts estimate the demolition cost for their project; and
- To identify the costs involved for each type of demolition techniques.

The approach was conducted in this research by asking the demolition engineer to think aloud while estimating the cost when an example of a demolition project was given to them. Four experts were carefully selected for this process, based on their willingness to cooperate and their experience in costing demolition projects. The researcher used a video camera to record what was being said.

5.4.1 Results
The protocol was analysed, interpreted and structured into a list that contains the type of costs involved for each type of demolition technique. The list was then reviewed and validated by the other experts. A series of meetings were conducted for this purpose until a final list was developed (see Table 5.14).

5.4.2 Discussions
The experts have identified seven main demolition cost elements which include: site overhead; decommissioning; soft stripping, waste disposal; structural demolition; general overhead and profit. For the structural demolition, it was divided into three type of cost depend on three main demolition techniques: progressive demolition; deliberate collapse mechanism; and deconstruction. Each of the main demolition cost have its own sub costs as listed in Table 5.14. These findings will be used in developing a spreadsheet program, which estimates the cost to demolish a structure. The detail development of this spreadsheet discussed in Chapter 6.
### Table 5.14: Demolition cost elements

<table>
<thead>
<tr>
<th>Main Demolition Cost</th>
<th>Sub-Demolition Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Overhead Cost</td>
<td>Temporary structures, facilities and services</td>
</tr>
<tr>
<td></td>
<td>Personnel Protective Equipment</td>
</tr>
<tr>
<td></td>
<td>Site clearing and cleanup</td>
</tr>
<tr>
<td>Decommissioning Cost</td>
<td>Asbestos Removal</td>
</tr>
<tr>
<td></td>
<td>Contaminated substance removal</td>
</tr>
<tr>
<td></td>
<td>Disconnecting services</td>
</tr>
<tr>
<td>Soft Stripping Cost</td>
<td>Toilet</td>
</tr>
<tr>
<td></td>
<td>Sink</td>
</tr>
<tr>
<td></td>
<td>Roof tiles</td>
</tr>
<tr>
<td></td>
<td>Ceiling</td>
</tr>
<tr>
<td></td>
<td>Interior walls / partition</td>
</tr>
<tr>
<td></td>
<td>Doors</td>
</tr>
<tr>
<td></td>
<td>Windows</td>
</tr>
<tr>
<td>Waste Disposal Cost</td>
<td>Crushing on site cost</td>
</tr>
<tr>
<td></td>
<td>Trucking cost / tipping cost</td>
</tr>
<tr>
<td></td>
<td>Landfill cost</td>
</tr>
<tr>
<td>Structural Demolition Cost for Progressive Demolition</td>
<td>Labour cost</td>
</tr>
<tr>
<td></td>
<td>- General Labour, Site Supervisor, Site Managers</td>
</tr>
<tr>
<td></td>
<td>Equipment cost</td>
</tr>
<tr>
<td></td>
<td>- Demolition excavator with standard attachment</td>
</tr>
<tr>
<td></td>
<td>- Tracked mounted crane with demolition ball</td>
</tr>
<tr>
<td></td>
<td>- Other machinery with optional attachments</td>
</tr>
<tr>
<td></td>
<td>- Hand tools and scaffolding</td>
</tr>
<tr>
<td>Structural Demolition Cost for Deliberate Collapse Mechanism</td>
<td>Labour cost</td>
</tr>
<tr>
<td></td>
<td>- General Labour, Site Supervisor, Site Manager, Explosive Eng</td>
</tr>
<tr>
<td></td>
<td>Equipment cost</td>
</tr>
<tr>
<td></td>
<td>- Other machinery with optional attachments</td>
</tr>
<tr>
<td></td>
<td>- Hand tools and scaffolding</td>
</tr>
<tr>
<td></td>
<td>Implosion cost</td>
</tr>
<tr>
<td></td>
<td>- Drilling cost, explosive cost, initiation system, protection cost</td>
</tr>
<tr>
<td></td>
<td>- Special service cost, evacuation cost</td>
</tr>
<tr>
<td>Structural Demolition Cost for Deconstruction</td>
<td>Labour cost</td>
</tr>
<tr>
<td></td>
<td>- General Labour, Site Supervisor, Site Managers</td>
</tr>
<tr>
<td></td>
<td>Equipment cost</td>
</tr>
<tr>
<td></td>
<td>- Other machinery with optional attachments</td>
</tr>
<tr>
<td></td>
<td>- Hand tools and scaffolding</td>
</tr>
<tr>
<td></td>
<td>- Special techniques i.e. Hydrodemolition</td>
</tr>
<tr>
<td></td>
<td>- Propping and temporary ramp</td>
</tr>
<tr>
<td>General Overhead Cost</td>
<td>Insurance</td>
</tr>
<tr>
<td></td>
<td>Building Permit</td>
</tr>
<tr>
<td></td>
<td>Surety Bond</td>
</tr>
<tr>
<td></td>
<td>Office Administration</td>
</tr>
<tr>
<td>Profit</td>
<td>Percentage of total cost</td>
</tr>
</tbody>
</table>
5.5 SUMMARY
This chapter has discussed the knowledge acquisition (KA) process, in the development of the decision support system for demolition techniques selection. The KA process in this research involved capturing and transforming appropriate information from the demolition engineers into some manageable form that can be used in the development of the decision model. The KA methods adopted include a questionnaire survey, semi-structured interviews and protocol analysis.

The questionnaire survey was conducted to obtain preliminary knowledge from the demolition industry since there is little published information on the selection of demolition techniques. To complement the findings of the questionnaire survey, semi-structured interviews were conducted with selected experts. These resulted in a list of verified criteria and alternatives in selection of demolition techniques. The protocol analysis was used to capture expert knowledge in estimating the cost of demolition techniques. The outcome from this method was a list of demolition cost elements.

The next chapter discusses the development and operation of the prototype system based on the knowledge acquired.
CHAPTER 6: DEVELOPMENT AND OPERATION OF THE PROTOTYPE SYSTEM

6.1 INTRODUCTION
This chapter starts with reviewing the functional architecture of the prototype system. Then, it describes in detail the development process of the prototype system. It also demonstrates the operation of the prototype system and highlights the key features of the system.

6.2 FUNCTIONAL ARCHITECTURE OF THE PROTOTYPE SYSTEM
The proposed intelligent decision support system to help demolition engineers in selecting demolition techniques for their project is called 'Demolition Techniques Selection System' (DTSS). The prototype system consists of two stages. The first stage will assist the decision maker to select the most appropriate demolition techniques in terms of technical aspects by using Analytic Hierarchy Process (AHP) model. The second stage allows the decision maker to assess the demolition techniques in terms of cost by using the Demolition Cost Estimation model.

The AHP benefit/cost analysis procedures were followed to develop the functional architecture of the system. The results from the first stage are the priorities ranking for all the demolition techniques, which are also known as the 'Benefit Priority'. The highest priority ranking in this stage is considered the most appropriate demolition technique in terms of its technical capability. Then, these benefit priorities are compared to the actual costs of the demolition techniques from the second stage to get a measure of benefits per unit of expenditure. The objective here is to maximise benefit from each expenditure. The highest benefit/cost ratio is considered the most appropriate demolition technique that gives the highest return for monies expended. By incorporating these two stages, the demolition engineer can make sound judgements based on technical and economic considerations. Figure 6.1 presents the functional architecture of the proposed Demolition Techniques Selection System.
To select the most appropriate demolition techniques to demolish a structure

Stage 1

Problem Definition → The development of AHP hierarchy to decompose a decision problem → AHP Model based on Expert Choice Software

Pairwise comparison of the criteria that affect the selection process → Synthesis of the AHP model to get overall prioritization of the system → Sensitivity analysis to see how the alternatives change with respect to the importance of criteria

Stage 2

Identify the demolition cost elements → Development of the demolition cost estimation worksheet → Demolition Cost Estimation Model

Decision maker make cost estimation on each type of demolition techniques → Normalised the demolition cost for each of the demolition techniques → Benefit to Cost ratio

The most appropriate demolition techniques will be selected for the specified structure

Figure 6.1: The functional architecture of the proposed Demolition Techniques Selection System (DTSS)

6.3 DEVELOPMENT OF THE AHP MODEL

6.3.1 Problem Definition

The problems begin when the demolition engineer has a decision to select the most appropriate demolition technique for a specified demolition project. The decision was normally based on his/her experience. There are number of criteria that should be incorporated into the decision, to ensure that sound judgement can be made based on technical and economic considerations. Based on these problem, the proposed system
must have the capability to evaluate all the criteria that affect the selection of demolition techniques and stress the intuitive judgment in the decision making process. The next section describes the development of the proposed system that can help demolition engineer solving this problem.

6.3.2 Rapid Prototyping
The research used rapid prototyping methodology to develop the prototype system. The rapid prototyping is a strategy in system development in which an initial prototype was developed in a short time, tested and improved in several iterations until the final prototype is ready (see Chapter 2, Section 2.3.3 for detailed discussion). Expert Choice software was selected to be the environment for the development of the prototype because it offers a user-friendly display that makes decision model building based on AHP methodology simple and flexible for alteration. The decision model based on AHP involved four basic steps, which include:

1. Developing the hierarchy;
2. Pairwise comparisons;
3. Synthesis of the AHP model; and

The next section discusses these steps.

6.3.3 Developing the AHP Hierarchy
The AHP hierarchy is a representation of a complex problem on a number of levels whose first level is the goal to be achieved, followed by criteria, sub-criteria and so on down to the last level at which the alternatives are located. It is important in constructing the hierarchy to include the demolition expert's ideas and debate until the problem is clearly defined. For this reason the criteria and the alternatives resulted from the questionnaire survey and structured interview with the demolition experts were used to construct the hierarchy (refer to Chapter 5, Table 5.13 and Figure 5.10).

The laddering method was used to create the hierarchy in the Expert Choice software (see Chapter 2, Section 2.3.2.4). The same demolition experts who participated in the interviews and protocol analysis were again involved in the development process. The process involves creating, reviewing and modification of the decision hierarchy with the
experts until the final hierarchy was developed. Figure 6.2 illustrates the hierarchical structure, which consists of the goal, criteria, sub-criteria and alternatives.

The selection of the most appropriate demolition techniques, which is the goal of the decision makers, is located at level 0 of the model to serve as a goal node (see Figure 6.2). Factors affecting the demolition technique selection, which have been classified into five categories, were inserted in level 1 of the model to serve as the main criteria. Level 2 of the model (14 nodes) defines sub-criteria nodes for categories in level 1. Finally, the alternative solutions (demolition techniques) are located at level 3 to serve as the choice available for the decision makers.

6.3.4 The Pairwise Comparison

The second step is to define the priority (or weight) for each criterion based on the decision maker's judgment by pairwise comparisons. At each level, pairwise comparisons are undertaken for each category with the ones in the adjacent upper level, and the ratings are entered into a comparison matrix. The elements on the second level (Structure characteristics, site conditions, past experience, reuse and recycling and time) are arranged into a matrix, and the decision makers make judgments about the relative importance of the elements with respect to the overall goal of selecting the most appropriate demolition technique. The judgments are entered using the AHP pairwise comparisons scale (see Table 4.4 in Chapter 4). For example when judging the relative preference of factors located in level 1 with respect to the goal (level 0), a rating of 1 may be assigned in the comparison between structure characteristics and site conditions (Figure 6.3). This indicates equal importance between the two. The same procedure can be repeated and the rating of 7 may be assigned in comparing site conditions with time with respect to goal. This indicates that structure characteristics very strongly favoured when compared with time (Figure 6.4). All the remaining pairwise comparison matrices between the nodes in the hierarchy can be established by following the same procedure. Similar pairwise comparison tables exist for level 1 with level 2 and level 2 with level 3 and are shown in Appendix C.
Figure 6.2: Hierarchic structure for the demolition techniques selection model
(Source: Abdullah and Anumba, 2002)
Figure 6.3: Equal rating (1) in pairwise comparison between structure characteristics and site conditions (Level 1 with respect to the goal (level 0))

Figure 6.4: Rating of 7 in favour of structure characteristics in the pairwise comparison with time (Level 1 with respect to the goal (level 0))
6.3.5 Synthesis of the AHP Model

Synthesis involves the process of weighting and combining priorities throughout the model after judgments have been made to derive the final result. The synthesis process converts all the local priorities into global weights of the alternatives. The global priorities for each alternative are then summed up to produce overall or synthesized priorities. The preferred alternative is the one with the highest priority. In Expert Choice, the Distributive Mode and Ideal Mode are two synthesis methods that can be used to derive the results.

According to Forman and Shvartsman (2000), the Distributive Mode is suitable when all alternatives matter. The Distributive Mode distributes the weights of the criteria among the alternatives; thereby dividing the full criteria weights into proportions relative to the percentage of preference of each of the alternatives.

The Ideal Mode is more appropriate when the decision makers are concerned with choosing only one alternative and the other alternatives will no longer matter (Forman and Shvartsman, 2000). The Ideal Mode assigns the full weight of each covering criteria to the alternative that ranks highest under it. The other alternatives receive a weight in proportion to the highest alternative per covering criteria. The weights or priorities for all the alternatives are summed up to display the best alternative.

Since the priority rating of all the alternatives needs to be referred to again at the second stage of the demolition techniques selection system, the distributive mode is used to derive the final result.

6.3.6 Sensitivity Analysis

Expert Choice provides tools for performing sensitivity analysis. Sensitivity analysis helps the decision makers to see how the different weights assigned to each criterion could affect the outcomes of the model. The general purpose of the sensitivity analyses is to graphically see how the alternatives change with respect to the importance of the criteria or sub-criteria. There are five types of sensitivity analyses that can be carried out in Expert Choice:
• Performance Sensitivity: Displays how the alternatives perform with respect to all criteria;
• Dynamic Sensitivity: Displays how the choice priorities of alternatives changes when the priority of one criterion is varied;
• Gradient Sensitivity: Display the composite priority of the alternatives with respect to the priority of a single criterion;
• Head to Head Sensitivity: displays how any two alternatives compare with respect to each criterion and the goal; and
• Two Dimensional Sensitivity: Displays how alternatives perform with respect to any two criteria.

6.3.7 Developing the Information Document

Information Documents are rich text objects and can include Microsoft Office Files (Word, PowerPoint, Excel, Access), as well as other files that contain audio, pictures and video. The information document is primarily used as a way of communicating with users and for presentation purposes Figure 6.5 shows the screenshot of the information document developed in the AHP model. It contains several files including:

• Texts that describe the goal, give additional information as to why particular criteria or sub-criteria were selected, and how pair-wise comparisons were made;

• Microsoft word files that act as an information source on demolition techniques. There are three Microsoft word files that contain the detailed information on each type of demolition technique, namely ‘Progressive Demolition’, ‘Deliberate Collapse Mechanism’ and ‘Deconstruction’. The information captured during the literature review process was used to develop these files.

• Microsoft Excel file that acts as a data input workbook, which gathers all the necessary information into one manageable file. The information gathered is used to support decision making especially during the pairwise comparison process of the AHP model. Several spreadsheets were developed in the data input workbook (Appendix D), which contains:
⇒ General Information – Information on the demolition site location and project directory that give the contact information on who is the client, planning supervisors, principal contractors and consulting engineer;

⇒ Media Information – The user can insert photos or drawings relating to the demolition project;

⇒ Structure Characteristics – Information regarding the height, type and stability of the structure. It also gathers information on the extent of demolition and the previous use of the structure;

⇒ Site Conditions – The information gathering includes health and safety assessment depending on the demolition techniques selected. The environmental aspects (such as the acceptable level of noise, dust and vibration). The proximity of adjacent structures and assessment of the accessibility of the demolition site are all captured;

⇒ Past experience – Information on the user’s past experience, which including familiarity with specified demolition techniques, availability of plant and equipment and the availability of expertise to do the demolition work;

⇒ Reuse and Recycling – Information regarding the level of concern by the users on reuse and recycling for the specified demolition project; and

⇒ Time – Information on the estimated time to do the demolition work. The users have to estimate the time for designing the demolition techniques, time for structural preparation and time for the actual demolition. The spreadsheet automatically calculates the total time for the demolition project.
6.4 DEVELOPMENT OF THE DEMOLITION COST ESTIMATION MODEL

After the decision makers have assessed the demolition techniques against the technical considerations, they need to assess them in terms of cost. For this reason, the demolition cost estimation model was developed using Microsoft Excel 2000. The cost for each of the demolition techniques can be estimated using this model. The unit cost for each of the demolition techniques is then calculated to derive the priority in terms of cost. Finally, the benefit/cost ratio can be derived and the technique with the highest benefit/cost ratio is considered the most appropriate for that particular project. The model consists of preliminary estimation spreadsheets and detailed estimation spreadsheets.

The demolition engineer can use the preliminary estimation model as a quicker, but less accurate way to estimate demolition cost based on square meter or cubic meter measures. Detailed estimating is more accurate, but it takes more time to complete. The following section discusses the development of these two spreadsheets in details.
6.4.1 Development of the Preliminary Estimating Spreadsheets

The preliminary estimate is probably the most common kind of estimate the average demolition engineer will. According to Kackman (2001) in his book, 'Basics of Demolition Estimating', the accuracy of this estimate is around +/- 20%. The preliminary estimate can be used when demolition engineers are estimating for a project similar to one they have done before, and where the structures are in the same or similar condition as last time. There are two ways to calculate preliminary estimates: the square meter method and the cubic meter method. The only difference between them is that the cubic meter method is more appropriate for structures that have high roofs and take up a lot of volume. Figures 6.6 and 6.7 show the screen shot of the preliminary estimate spreadsheets based on the square meter estimate and the cubic meter estimate respectively.

The cost estimate for a new demolition project involves dividing the total price charged for a similar project that has been done before by the total area or volume of the structure. This provides the cost per square meter or cubic meter for the previous similar project. This is then multiplied by the total number area or volume of the new project. To establish the relative cost for each type of demolition technique, the total costs were normalised. Taking the value of the priority ranking from the AHP model as a benefit priority for each of the demolition techniques, the benefit/cost ratio can be calculated. The highest benefit/cost ratio is considered the most appropriate and cost-effective demolition technique.

![Image of preliminary estimate spreadsheet](image_url)

Figure 6.6: The preliminary estimate spreadsheets based on the square meter estimate
6.4.2 Development of the Detailed Estimating Spreadsheets

Demolition engineers need to undertake a ‘take-off’ exercise (i.e. establish the quantities of the key components of the structure) before they can proceed with the detailed estimate, which is required to be accurate and realistic. When performing take-off the demolition engineer must consider the structural conditions of the structure, study as-built drawings and specifications if available, and evaluate the risk, safety and environmental aspects of the project. Figure 6.8 shows the screen shot of the take-off spreadsheet developed.
The demolition cost elements obtained from the protocol analysis (see Chapter 5, Table 5.14), were used in the development of the detailed estimate spreadsheets. These were rearranged into groups that generate a specific set of costs called the ‘demolition cost hub’. Six demolition cost hubs were developed for each demolition technique: Site Overhead; Decommissioning; Soft Stripping; Waste Disposal; General Overhead; and Profit. Figures 6.9 to 6.13 shows the screen shot of these demolition cost hubs. One demolition cost hub that is different for each of the demolition techniques is ‘Structural demolition cost’ because it has different cost elements. For example, the progressive demolition technique has manpower cost and machinery cost as the demolition cost elements, but the deliberate collapse mechanism technique also includes implosion cost as one of its cost elements. Tables 6.1 to 6.3 show the structural demolition cost hub and how it varies with the demolition techniques.

The spreadsheets automatically collate all the demolition cost hubs and calculate the total cost. This is then normalised to establish the relative cost of each demolition technique. The user then has to input the prioritization value from the AHP model as a benefit priority for each of the demolition techniques before the model automatically calculates the benefit/cost ratio for each technique. The demolition technique with the highest benefit/cost ratio is considered the most appropriate and cost-effective solution. Table 6.4 gives a summary of the detailed estimate.

![Figure 6.9: Site Overhead cost hub](image)
Figure 6.10: Decommissioning cost hub

Figure 6.11: Soft stripping cost hub
### Waste Disposal Cost (T4)

<table>
<thead>
<tr>
<th>Waste Disposal Cost</th>
<th>Quantity</th>
<th>Unit</th>
<th>Labour &amp; Equipment Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushing on site cost for concrete, brick and steel (mobile crushing plant)</td>
<td>630</td>
<td>cubic-m</td>
<td>5.00</td>
</tr>
<tr>
<td>Trucking cost / Tipping Cost</td>
<td>50</td>
<td>load</td>
<td>5.00</td>
</tr>
<tr>
<td>Landfill Cost</td>
<td>15</td>
<td>ton</td>
<td>13.00</td>
</tr>
<tr>
<td>Others (Please specify)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Grand Total Waste Disposal Cost (T4)</strong></td>
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<td></td>
<td></td>
</tr>
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</table>

**Figure 6.12: Waste disposal cost hub**

### General Overhead and Profit

<table>
<thead>
<tr>
<th>General Overhead and Profit</th>
<th>Percentage of Total Cost</th>
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<tbody>
<tr>
<td>Insurance</td>
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</tr>
<tr>
<td>Building Permits</td>
<td>13</td>
</tr>
<tr>
<td>Section 80 - Local Authority</td>
<td>9</td>
</tr>
<tr>
<td>Surety Bonds</td>
<td>19</td>
</tr>
<tr>
<td>Bid Bonds</td>
<td>11</td>
</tr>
<tr>
<td>Payment Bonds</td>
<td>12</td>
</tr>
<tr>
<td>Performance Bonds</td>
<td>13</td>
</tr>
<tr>
<td>Office Administration</td>
<td>14</td>
</tr>
<tr>
<td>Rental</td>
<td>15</td>
</tr>
<tr>
<td>Stationeries</td>
<td>16</td>
</tr>
<tr>
<td>Others</td>
<td>17</td>
</tr>
</tbody>
</table>

**Figure 6.13: Structural demolition cost hub for general overhead and profit**
# Table 6.1: Structural demolition cost hub for progressive demolition technique

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<tr>
<th>Structural Demolition Cost for Progressive Demolition Technique (T5)</th>
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</thead>
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<td><strong>Item</strong></td>
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<td>----------</td>
</tr>
<tr>
<td><strong>Labour</strong></td>
</tr>
<tr>
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<td></td>
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<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td><strong>Total Labour</strong></td>
</tr>
<tr>
<td><strong>Equipment</strong></td>
</tr>
<tr>
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<tr>
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<tr>
<td></td>
</tr>
<tr>
<td><strong>Scaffolding</strong></td>
</tr>
<tr>
<td><strong>Total Equipment</strong></td>
</tr>
<tr>
<td><strong>Total cost (T5)</strong></td>
</tr>
</tbody>
</table>
Table 6.2: Structural demolition cost hub for deliberate collapse mechanism

<table>
<thead>
<tr>
<th>Item Description</th>
<th>No of items</th>
<th>Quantity</th>
<th>Unit</th>
<th>Price/unit</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour General labour</td>
<td>5</td>
<td>120</td>
<td>Hours</td>
<td>8.00</td>
<td>£4,800.00</td>
</tr>
<tr>
<td>Explosive engineer</td>
<td>3</td>
<td>80</td>
<td>Hours</td>
<td>15.00</td>
<td>£3,600.00</td>
</tr>
<tr>
<td>Site manager</td>
<td>1</td>
<td>160</td>
<td>Hours</td>
<td>15.00</td>
<td>£2,400.00</td>
</tr>
<tr>
<td>Site supervisor</td>
<td>2</td>
<td>160</td>
<td>Hours</td>
<td>12.00</td>
<td>£3,840.00</td>
</tr>
<tr>
<td>Others (please specify)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Labour</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>£14,640.00</td>
</tr>
<tr>
<td>Implosion Drilling cost</td>
<td>N/A</td>
<td>50</td>
<td>Holes</td>
<td>2.00</td>
<td>£100.00</td>
</tr>
<tr>
<td>Explosive cost including handling cost</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td>£0.00</td>
</tr>
<tr>
<td>Nitro-glycerine (NG) or gel-based stick explosives (masonry)</td>
<td>N/A</td>
<td>50</td>
<td>Kg</td>
<td>10.00</td>
<td>£500.00</td>
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<tr>
<td>Linear Shaped charges (steel)</td>
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<td></td>
<td></td>
<td></td>
<td>£0.00</td>
</tr>
<tr>
<td>Trinitrotoluene (TNT) based explosive</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td>£0.00</td>
</tr>
<tr>
<td>Cyclotrimethylene trinitramine (RDX), Plastic explosive</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td>£0.00</td>
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<tr>
<td>Sherry Explosive</td>
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<td></td>
<td></td>
<td></td>
<td>£0.00</td>
</tr>
<tr>
<td>Ammonium Nitrate/Fuel Oil (ANFO)</td>
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<td></td>
<td></td>
<td></td>
<td>£0.00</td>
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<tr>
<td>Detonating cord</td>
<td>N/A</td>
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<td></td>
<td></td>
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<tr>
<td>Initiation systems</td>
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<td>£0.00</td>
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<tr>
<td>Capped fuse</td>
<td>N/A</td>
<td>100</td>
<td>Piece(s)</td>
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<tr>
<td>Electric detonators</td>
<td>N/A</td>
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<td>Piece(s)</td>
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</tr>
<tr>
<td>Electronic detonators</td>
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<tr>
<td>Blasting machines</td>
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<td></td>
<td></td>
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<tr>
<td>Protection cost (Protection from flying debris/air blast)</td>
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<td></td>
<td></td>
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<td>£0.00</td>
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<tr>
<td>Earth bunds</td>
<td>N/A</td>
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<td></td>
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<tr>
<td>Solid screens</td>
<td>N/A</td>
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<tr>
<td>Tarpaulin screens</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td>£0.00</td>
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<tr>
<td>Protection at structural members</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td>£0.00</td>
</tr>
<tr>
<td>Protection at voids and openings</td>
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<td></td>
<td></td>
<td></td>
<td>£0.00</td>
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<tr>
<td>Flexible protection</td>
<td>N/A</td>
<td>200</td>
<td>Sq-m</td>
<td>1.50</td>
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<td>Blast mats</td>
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<td>100</td>
<td>Sq-m</td>
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<td>Special Services cost</td>
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<td>Evacuation cost</td>
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<td>Total Implosion</td>
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<td>£2,650.00</td>
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Continued next page
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<thead>
<tr>
<th>Equipment</th>
<th>Various Hand Tools:</th>
<th>3</th>
<th>1</th>
<th>Week(s)</th>
<th>15.00</th>
<th>£45.00</th>
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<tr>
<td>Hand held drills (i.e. Atlas Copco BBD 12, Broomwide)</td>
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<td>1</td>
<td>Week(s)</td>
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<td>Hand held breakers</td>
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<td>£15.00</td>
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<td>1</td>
<td>Week(s)</td>
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**Total cost (T6)**  
£18,025.00
Table 6.3: Structural demolition cost hub for deconstruction technique

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<th>No of</th>
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<th>Unit</th>
<th>Price/unit</th>
<th>Total</th>
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</tr>
<tr>
<td>Attachment 8: Ripper</td>
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<td></td>
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<td>Attachment 9: Others (please specify)</td>
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144
Table 6.4: Summary of detailed estimate

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<td>Decommissioning Cost</td>
<td>T2</td>
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<tr>
<td>Soft Stripping Cost</td>
<td>T3</td>
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<tr>
<td>Waste Disposal Cost</td>
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<td>Structural Demolition Cost</td>
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<td>Overhead (percentage of total price)</td>
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<td>Profit (percentage of total price)</td>
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</tr>
<tr>
<td>Decommissioning Cost</td>
<td>T2</td>
</tr>
<tr>
<td>Soft Stripping Cost</td>
<td>T3</td>
</tr>
<tr>
<td>Waste Disposal Cost</td>
<td>T4</td>
</tr>
<tr>
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<td>T6</td>
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<tr>
<td><strong>Total</strong></td>
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<tr>
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</tr>
<tr>
<td>Profit (percentage of total price)</td>
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<table>
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<td>Profit (percentage of total price)</td>
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<th>Definitive Estimates Summary</th>
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<th>DCM</th>
<th>DCON</th>
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Note:
PD - Progressive Demolition
DCM - Deliberate Collapse Mechanism
DCON - Deconstruction
6.5 OPERATION OF THE PROTOTYPE SYSTEM

The Demolition Techniques Selection System (DTSS) developed provides a decision support tool to help demolition engineer in selecting the most appropriate demolition technique for a specified project. It was designed to allow judgemental input from users in the decision making process. Figure 6.14 shows the system’s operational flowchart.

The operational objectives of the prototype system were to:

- Provide clear and structured framework of the decision-making process to help the users in selecting the most appropriate demolition technique when both technical and economical aspects of a decision need to be considered;
- Provide information on the demolition techniques to support the decision making process;
- Enable demolition engineers to make rational and justified decisions by using graphical reports and sensitivity analysis;
- Provide a demolition cost estimation spreadsheet that is customized to solve some of the estimating problems (such as reducing the time to do the estimate) that were faced by the engineers;

6.5.1 User Requirements

The end users of the prototype system will be demolition engineers who have the experience and considerable knowledge in selecting the demolition techniques in practice. This characteristic is important because the prototype system was designed to incorporate expert judgment in the selection process. Inexperienced demolition engineers can also use the prototype system as a training tool, since the selection process is well structured and the system has considerable information on the demolition techniques.

6.5.2 System Requirements

The prototype system has been designed to operate on a Personal Computer (PC) running Windows 2000 or better. It requires Expert Choice 2000, Microsoft Word 2000 (or above) and Microsoft Excel 2000 (or above) to be installed. About 37Mb of RAM is required to run the Expert Choice software (including 5Mb for data storage).
Figure 6.14: The prototype system operational flowchart
6.5.3 Starting the Prototype System

The DTSS application is stored as an Expert Choice file called ‘DTSS.ahp’ and is held in a directory named ‘Demolition’. To start the application from the Expert Choice menu, the user selects ‘File: Open’. When the file is opened, the first window that appears is a Model View. Figure 6.15 shows the Model View panel that is divided into three major sections or panes:

- **Tree View** – The hierarchy displayed in this pane consists of five main criteria and fourteen sub-criteria with the goal being to select the most appropriate demolition technique.
- **Alternatives** – The three demolition techniques are the alternatives.
- **Information Document** – This includes information on operating the system and links to other information document files, which were described in Section 6.3.6. To view the information document the user has to click on the red book icon on the toolbar.

![Information Document Icon](image)

![Figure 6.15: Demolition Technique Selection Model](image)
6.5.4 Data Input Workbook

Before the user can proceed with the pairwise comparison matrix, more information regarding the project needs to be collected to support the decision making process. DTSS provides a tool to perform this action by developing a data input workbook. To open this workbook, the user needs to go to the Information Document pane, by clicking the red book icon and double clicking on the specified link, as illustrated in Figure 6.16. Section 6.3.7 ‘Developing the information document’, and Appendix D provide a detailed discussion of the data input worksheet.

Figure 6.16: The link to the Data Input Workbook

6.5.5 Assigned Judgment in Pairwise Comparison

After completing the data input workbook, the user may then undertake the pairwise comparisons. One of the main strengths of AHP is the use of pairwise comparisons to derive accurate ratio scale priorities, instead of using traditional approaches of ‘assigning’ weights, which is difficult to justify. The pairwise comparison process compares the relative importance, preference, or likelihood of two elements with respect to each other. A judgment is made as to which is more important and by how much. Pairwise comparisons are carried out throughout an Expert Choice model to establish priorities.
Judgments about the relative importance of criteria are made with respect to the parent node in the hierarchy (either the Goal or a higher-level criterion). Judgments about relative preference of alternatives (demolition techniques) are made with respect to each criterion (the lowest level of criteria). For example, the user makes judgments about the preference of the demolition techniques with respect to the criterion, *Height* of the structure. The steps include:

1. Click on the sub-criteria *Height* under the first set of criteria in the hierarchy *Structure Characteristics* (refer to Figure 6.15).

2. From the menu select *Assessment*; then select *Pairwise*. The user will be taken to the Verbal comparison window (see Figure 6.17). Verbal judgments are used to make comparisons using the words Equal, Moderate, Strong, Very Strong and Extreme. Equal requires no explanation. Extreme means a rating of magnitude of about 9 or 10 to 1. Judgments between these words, such as ‘Moderate to Strong’ are also possible.

3. Since the user compares the alternatives with respect to the criteria, the judgment type is ‘preference’. The verbal scale indicator can be moved up or down to the appropriate position to make the judgement that best describes the user feeling. Figure 6.17 shows the example judgment; it means that *Progressive Demolition* is Strongly to Very Strongly preferred to *Deliberate Collapse Mechanism* with respect to *Height* of the structure. Note: If the user prefers *Deliberate Collapse Mechanism* to *Progressive Demolition*, then he/she has to drag the indicator down.

4. The process above repeated until all comparisons for *Height* have been made. Note: The Inconsistency, shown in the bottom left cell of the matrix. The inconsistency measure is useful for identifying possible errors in judgments as well as actual inconsistencies in the judgments themselves. In general, the inconsistency ratio should be less than 0.1 or so to be considered reasonably consistent. The user should only change an inconsistent judgment if they feel that their initial comparison was in error and did not truly represent their feeling.
5. After all the judgments have been made, the user will be prompted to "Record Judgments and Calculate", select Yes; the user will be returned to the Model View.

6. Priorities for the alternatives with respect to height have been calculated automatically and are displayed in the Alternative Pane of the Model View. Figure 6.18 shows the priorities for the alternatives with respect to the height. If the resulting relative priorities do not adequately represent the user’s feelings, the user can repeat the pairwise comparison process.

7. Processes 1 to 5 repeated until all comparisons for sub criteria (14 nodes, refer to Figure 6.2: Hierarchic structure for the demolition techniques selection model) have been made.

8. To assign judgement for the sub criteria against criteria, the user need to change the comparison type from Preference to Importance. To change the assessment type, select Assessment, Type, and then select Importance.

9. Process 1 to 5 repeated until all comparisons for criteria (5 nodes, refer to Figure 6.2) have been made. The user can begin assigning the criteria judgment with Structure Characteristics node and end with the Time node.

10. To assign judgment about the importance of the criteria with respect to the goal, click the goal node, and then select Assessment, followed by Pairwise and repeat processes 1 to 5 of the pair-wise comparison process.

Now the user should have made judgments for all factors (criteria, subcriteria and alternatives) in the AHP model. The next section describes how to synthesize the results and perform sensitivity analyses.
Progressive Demolition

Deliberate Collapse Mechanism

Compare the relative importance with respect to: Structure Characteristic \ Height

Figure 6.17: The Verbal Comparison Window

Figure 6.18: Derived Priorities of the alternatives with respect to height
6.5.6 Synthesize to get Results

A synthesis is automatically performed after all the judgments in the AHP model have been made and priorities have been calculated. When focus is returned to the Model View the priorities for the alternatives are shown in the Alternatives pane (see Figure 6.19). The priorities of the criteria are also shown in the Tree View in both graphical and numerical form.

![Model View showing the Synthesized Results with respect to the Goal](image)

Figure 6.19: Model View showing the Synthesized Results with respect to the Goal

To examine the synthesis: Select **Synthesize, With respect to the Goal** to produce the display shown in Figure 6.20. The difference in results obtained using the ideal or distributive synthesis modes is usually negligible and more of theoretical than practical interest. The Ideal Synthesis should be used when one is interested in only one alternative and the remaining alternatives are no longer relevant. Distributive Synthesis is used when the users are interested in prioritizing alternatives from which they may pick more than one alternative. Because each synthesis mode combines priorities differently, the user should note that each mode might yield different, although normally very similar, results. In DTSS, the distributive mode is more appropriate because all the priorities for the
alternatives will be used in the demolition cost estimation model to get the benefit/cost ratio. For more information about the Ideal and Distributive Modes, refer to section 6.3.5.

![Synthesis Window](image)

Figure 6.20: Synthesis Window

After examining the synthesis to get the priorities of the demolition techniques, the user can examine the graphical sensitivity analyses of the results. The user must close the synthesis window and return to the Model View.

Sensitivity analyses from the Goal node will show the sensitivity of the alternatives with respect to all the criteria below the goal. Because the AHP model developed has more than three levels, the sensitivity analysis can also be performed from the nodes under the goal to show the sensitivity of the alternatives with respect to criterion or sub-criterion. When performing a sensitivity analysis the user may change the priorities of the criteria and observe how the priorities of the alternatives would change. The users can use five types of graphical sensitivity analyses: Performance, Dynamic, Gradient, Head to Head and Two Dimensional Plot.
To see the Dynamic Sensitivity graph: from the Tree View, click on the Goal, and from the menu select **Sensitivity-Graphs**, then select **Dynamic**. Dynamic Sensitivity analysis is used to dynamically change the priorities of the objectives to determine how these changes affect the priorities of the alternative choices. By dragging the objective’s priorities back and forth in the left column, the priorities of the alternatives will change in the right column. If a decision-maker thinks a criterion might be more or less important than originally indicated, the decision-maker can drag that objective's bar to the right or left to increase or decrease the criterion priority and see the impact on alternatives. Figure 6.21 shows a Dynamic Sensitivity graph.

![Figure 6.21: Dynamic sensitivity graph](image)

The Performance Sensitivity analysis shows how the alternatives were prioritized relative to other alternatives with respect to each criterion as well as overall (see Figure 6.22). It displays how the alternatives (progressive demolition, deliberate collapse mechanism and deconstruction) perform with respect to all five main criteria and overall. Dragging the criteria bars up or down can temporarily alter the relationship between the alternatives and their criteria.
Figure 6.22: Performance sensitivity graph

Figure 6.23 shows the gradient sensitivity graph. This graph shows the alternatives' priorities with respect to one criterion at a time. The vertical solid line represents the priority of the selected criterion (structure characteristics) and is read from the X-Axis intersection. The priorities for the alternatives are read from the Y-Axis. To change an objective's priority, drag the vertical solid bar to either the left or right; then a vertical dotted bar showing the new objective's priority will be displayed.
Figure 6.24 shows how two alternatives compared to one another against the criteria in a decision. One alternative is listed on the left side of the graph and the other is listed on the right. The alternative on the left is fixed while the alternative on the right can be varied, by selecting a different tab on the graph. Down the middle of the graph are listed the criteria in the decision. If the left-hand alternative is preferred to the right-hand alternative with respect to a criterion, a horizontal bar is displayed towards the left. If the right-hand alternative is better, the horizontal bar will be on the right. If the two choices are equal, no bar is displayed. The overall result is displayed at the bottom of the graph and shows the overall percentage by which one alternative is better than the other; in this example, deliberate collapse mechanism is better than progressive demolition techniques.

![Figure 6.24: Head-to-Head graph](image)

Table 6.25 shows the two-dimensional sensitivity graph. This graph shows how well the alternatives perform with respect to any two criteria. In this example, structure characteristic is represented on X Axis and site condition on Y Axis. The alternatives represented by the circle. The area of the 2D plot is divided into quadrants. The most favorable alternatives as defined by the criteria and judgments in the model will be shown.
in the upper right quadrant (the closer to the upper right hand corner the better) in this case deliberate collapse mechanism, while in opposition, the least favorable alternatives will be shown in the lower left quadrant (progressive demolition and deconstruction). Alternatives located in the upper left and lower right quadrants indicate key tradeoffs where there is conflict between the two criteria.

![Two-dimensional plots sensitivity graph](image)

Figure 6.25: Two-dimensional plots sensitivity graph

### 6.5.7 Demolition Cost Estimation Model
The user can proceed by assessing the demolition techniques against the cost in the demolition cost estimation model when satisfied with the results from the AHP model. To open this model, the user needs to go to the Information Document pane, by clicking on the red book icon and double clicking at the specified link, as illustrated in Figure 6.26.
Goal:
To select the most appropriate demolition techniques with respect to influential criteria based on specified project characteristic.

There are 3 available demolition techniques to be selected as alternatives:
1. Progressive demolition
2. Deliberate collapse mechanisms
3. Deconstruction or Top-Down Technique

The 6 main criteria assess for the selection of demolition techniques includes:
1. Structure Characteristics
2. Site Conditions
3. Past Experience
4. Cost
5. Reuse & Recycling
6. Time

For demolition cost estimation model, please double click on the shortcut key below:

Figure 6.26: The link to Demolition Cost Estimation Model

6.5.8 Data Input in the Preliminary Estimate Spreadsheet
The user needs to input several data in the preliminary estimate spreadsheet in order to get the total cost for each demolition technique. Next, the total cost for each of the demolition techniques were normalised to derive the ranking in terms of cost. Finally, the benefit/cost ratio can be derived, with the highest benefit/cost ratio being considered as the most appropriate demolition technique. Refer to Figures 6.6 and 6.7 for square meter estimate and a cubic meter estimate respectively. The same procedures were followed, as described in Section 6.4.1 to calculate these estimates.

6.5.9 Data Input in the Detailed Estimate Spreadsheet
The user need to input several data in the detailed estimate spreadsheet in order to get the total cost for each of the demolition technique. The same procedures were followed, as described in Section 6.4.2 to calculate these estimates.
6.5.10 Demolition Techniques Information Source

There are three Microsoft word files that contain detailed information on each type of the demolition technique, namely 'Progressive Demolition'; Deliberate Collapse Mechanism; and Deconstruction were embedded in the ‘DTSS.ahp’ file. To access these files, the user needs to go to the Information Document pane, by clicking on the red book icon and double click on the specified link, as illustrated in Figure 6.27. Figures 6.28 to 6.30 show the screen shot of the demolition techniques information source.

![Figure 6.27: The link to demolition techniques information source](image)

![Figure 6.28: Information source on progressive demolition technique](image)
Figure 6.29: Information source on deliberate collapse mechanism technique

Figure 6.30: Information source on deconstruction technique
6.6 SUMMARY

The prototype system (DTSS) functional architecture was discussed to give an overview of the system at the beginning of the chapter. The chapter then described in detail the development process for the AHP model and the demolition cost estimation model. These two models were used to select the most appropriate demolition techniques in term of its technical capability and economical feasibility. Finally, the operational framework of the DTSS was presented to demonstrate the operation of the system. The next chapter discusses the evaluation of the prototype system.
CHAPTER 7: EVALUATION OF THE PROTOTYPE SYSTEM

7.1 INTRODUCTION
This chapter describes the evaluation of the prototype system. It includes the aim and objectives of the evaluation, methodology, results and discussions on the overall evaluation process. The chapter concludes with a summary.

7.2 EVALUATION AIM AND OBJECTIVES
The aim of the evaluation was to determine the usability and functionality of the finished prototype. To achieve this aim, the specific objectives of the evaluation were:

- To assess the performance of the prototype system and the accuracy of the output;
- To determine the applicability of the prototype system to the demolition industry;
- To assess the affect of interaction on the user with the prototypes system; and
- To obtain comments and recommendations for improving the prototype system.

7.3 EVALUATION METHODOLOGY
In this research, formative evaluation has been undertaken during the development process of the prototype system (refer to Section 6.3.2). A series of interviews was conducted with demolition experts with the intent to validate and verify several aspects of the prototype system at the development stage. Validation is a part of evaluation that deals with the performance of the system or building the right system that performs with an acceptable level of accuracy. Verification is building the system right, with the system correctly implemented to its specifications. The prototype went through several iterations with appropriate refinements to improve it. The process continues until the prototype is ready for a demonstration. Several experts and researchers were invited to attend the demonstration. Once the prototype was demonstrated, the summative evaluation was undertaken and the findings were used to improve the final prototype. The next section will discuss the evaluation approach adopted to achieve the aim and objective of the evaluation stated in section 7.2.
7.3.1 Evaluation Approach

The evaluation was carried out after the prototype was developed and involved two groups of participants. The first group consisted of five demolition experts, who were also indirectly involved in the development process. This group was selected to give feedback from the main end-user's (demolition experts) point of view. Their wide experience in the demolition industry and previous involvement in the development process provided a basic knowledge and understanding of the prototype system and therefore ensured their capability to evaluate the system thoroughly. The second group consisted of ten researchers (from the Department of Civil and Building Engineering, Loughborough University), who had a multidisciplinary background such as in construction management, civil engineering and software development. They were selected to provide feedback from the external end-user perspective.

The research adopted focus group and questionnaire techniques in the evaluation process. The focus group was adopted because the participants could discuss together and give appropriate comment on the prototype during the evaluation process and saved the researcher's time to travel to each demolition expert. The questionnaire technique was adopted to measure the usability of the prototype system.

Evaluation workshops were conducted for both groups. Both of the workshops were conducted in the Department of Civil and Building Engineering. Each workshop consisted of three parts and lasted approximately two hours. The workshop started with a presentation on the background to the prototype system. This was followed by a demonstration of the prototype system, which involved the use of one practical example of a structure to be demolished. The participants were encouraged to participate by giving their comments during the demonstration. The participants were then asked to complete the evaluation questionnaire, which was the last part of the workshop. Two of the demolition experts could not come due to time and date of the workshop. The researcher made special visits to both of them and used the same approach to evaluate the system.
7.3.2 Questionnaire Design

The questionnaire was designed based on the aim and objectives of the evaluation stated in Section 7.2. A sample of the evaluation questionnaire is provided in Appendix E. The questionnaire was divided into three sections as follows:

1. Section A requested information about the participant’s name, position in their organisation and experience.

2. Section B contained 19 questions about various aspects of the prototype system. For each question in section B, participants were asked to tick the box that best represents their assessment on the scale of 1 (poor), 2 (fair), 3 (satisfactory), 4 (good) and 5 (excellent). It was divided into the following three sub headings:
   - The System Performance
   - Applicability to Demolition Industry
   - General

3. Section C requested two comments, including the main benefits of the prototype system and ways to improve the system.

7.4 EVALUATION RESULTS

This section reports feedback from the evaluation participants that responses to the questions and give comments for further improvements. Table 7.1 shows the results from section B in the evaluation questionnaire. The table presents, the percentage (%) of respondents from group 1, Demolition Expert (DE.) and group 2, Researcher (Res.), with regard to the assessment scale for each question. There were a total number of five (5) respondents from group 1 and ten (10) respondents from group 2. Detailed discussions on the various sections of the questionnaire is presented in Section 7.5.

Table 7.2 presents the comments made by the evaluators from section C. These related to the benefits of the prototype system, suggestions on how to improve the system and other further comments. These comments are discussed further in Section 7.5.
<table>
<thead>
<tr>
<th>DTSS Evaluation Questions</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 (Poor)</td>
</tr>
<tr>
<td></td>
<td>2 (Fair)</td>
</tr>
<tr>
<td></td>
<td>3 (Satisfactory)</td>
</tr>
<tr>
<td></td>
<td>4 (Good)</td>
</tr>
<tr>
<td></td>
<td>5 (Excellent)</td>
</tr>
<tr>
<td></td>
<td>DE.</td>
</tr>
<tr>
<td><strong>The System Performance (overall rating, Figure 7.1)</strong></td>
<td>44%</td>
</tr>
<tr>
<td>1 How well does the system help in understanding how demolition techniques can be selected?</td>
<td>20%</td>
</tr>
<tr>
<td>2 How clearly are the selection criteria defined in the system?</td>
<td>20%</td>
</tr>
<tr>
<td>3 How well are the demolition techniques explained in the system?</td>
<td>20%</td>
</tr>
<tr>
<td>4 How useful will the system be in supporting communication between the demolition engineers and clients?</td>
<td>60%</td>
</tr>
<tr>
<td>5 How well does the Information Document help in making a decision?</td>
<td>60%</td>
</tr>
<tr>
<td>6 How appropriate is the Pairwise comparison aspect of the system?</td>
<td>60%</td>
</tr>
<tr>
<td>7 How well does the system reflect the decision-making ability in a real situation?</td>
<td>60%</td>
</tr>
<tr>
<td>8 How useful do you find the sensitivity analysis within the system?</td>
<td>60%</td>
</tr>
<tr>
<td>9 How accurately are the relative costs between demolitions options modelled in the system?</td>
<td>60%</td>
</tr>
<tr>
<td>10 How useful is the cost model in choosing a demolition technique?</td>
<td>60%</td>
</tr>
<tr>
<td><strong>Applicability (overall rating, Figure 7.2)</strong></td>
<td>16%</td>
</tr>
<tr>
<td>11 How effective/accurate is the system in the selection of demolition techniques?</td>
<td>20%</td>
</tr>
<tr>
<td>12 How convinced are you that demolition industry professionals will accept (or use) the system?</td>
<td>20%</td>
</tr>
<tr>
<td>13 How effectively will the system increase the speed of the decision making process?</td>
<td>20%</td>
</tr>
<tr>
<td>14 To what extent does it represent an improvement (or help) in the decision making process?</td>
<td>20%</td>
</tr>
<tr>
<td>15 To what extent is the system flexible in choosing the most appropriate demolition techniques?</td>
<td>60%</td>
</tr>
<tr>
<td><strong>General (Overall rating, Figure 7.3)</strong></td>
<td>20%</td>
</tr>
<tr>
<td>16 How well organized (designed) is the system?</td>
<td>20%</td>
</tr>
<tr>
<td>17 How user friendly is the system?</td>
<td>20%</td>
</tr>
<tr>
<td>18 How well integrated are the different components of the system?</td>
<td>20%</td>
</tr>
<tr>
<td>19 What is your overall rating of the prototype system?</td>
<td>20%</td>
</tr>
</tbody>
</table>
Table 7.2: Comments from evaluators regarding the prototype system

<table>
<thead>
<tr>
<th>Benefits of the prototype system</th>
<th>Suggestions for Improvement</th>
<th>Other Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>• As an outside aid to ensuring all criteria have been considered</td>
<td>• More detail in drop down boxes</td>
<td>• The system when used in the industry will improve by the input of further data as more projects are included</td>
</tr>
<tr>
<td>• As a marketing aid to impress potential clients</td>
<td>• With further information ‘drop panels’ with greater detail</td>
<td>• Have an interface that works well throughout the system</td>
</tr>
<tr>
<td>• As a teaching aid</td>
<td>• More explanation to the information document</td>
<td></td>
</tr>
<tr>
<td>• To provide information to young professionals coming into the demolition industry, where in practice there is very little information available</td>
<td>• More information on different aspects required in carrying out the works.</td>
<td></td>
</tr>
<tr>
<td>• Benefit to those who wants to step into demolition industry</td>
<td>• Suggested that the model is given to demolition contractors under a ‘confidentiality agreement’ to improve the prototype system</td>
<td></td>
</tr>
<tr>
<td>• Improve the current performance in the industry</td>
<td>• Developed a commercialised software</td>
<td></td>
</tr>
<tr>
<td>• It provides a systematic approach to selecting a demolition techniques, which is proved to be an improvement on ‘ad hoc’ decision making approaches</td>
<td>• Flexibility for example allows users to add the criteria that current model have not addressed</td>
<td></td>
</tr>
<tr>
<td>• Assisting in selecting and analysing the appropriate demolition techniques</td>
<td>• Should put it into industry to perform further testing/evaluation</td>
<td></td>
</tr>
<tr>
<td>• Good structured approach and more informed decision could be made in selecting demolition techniques</td>
<td>• A provision should be made in order for the user to understand the system limitation</td>
<td></td>
</tr>
</tbody>
</table>

7.5 DISCUSSION

The outcome from the evaluation of the prototype system are discussed below under five main headings: Results; Suggestions for Improvement; Benefits; Limitations; and Appropriateness of the Evaluation Approach.
7.5.1 Results

The participants in both groups were satisfied with the performance and effectiveness of the prototype system. Figure 7.1 shows the overall rating form Demolition Experts and Researchers on the systems performance when referred to question 1 to question 10 based on Table 7.1. From the demolition expert point of view, the system performance can be reflected as ‘Good’, ‘Satisfactory’ and ‘Excellent’. The researchers also agreed with the view from the demolition experts when they give the similar rating on the system performance. Based on this finding, it can be summarized that the prototype system gives an overall good performance.

![Pie chart showing ratings by demolition experts and researchers.]

Figure 7.1: Prototype system performance

The applicability of the prototype system to the demolition industry also demonstrates a positive view, both from the demolition experts and researchers groups. Figure 7.2 shows the overall rating given by demolition experts and researchers when asked about the applicability of the prototype system to the demolition industry (refer to Table 7.1, questions 11 to 15). The majority of demolition experts rated the applicability of the prototype system as ‘Good’ followed by ‘Satisfactory’ and ‘Fair’. The researchers also agreed with the rating by demolition experts and in addition, 20% of them rate the system as ‘Excellent’. Based on this finding, it can be summarized that the prototype system is applicable to the demolition industry.
Figure 7.2: Applicability of the prototype system to demolition industry

Figure 7.3 shows the overall rating given by demolition experts and researchers (refer to Table 7.1, question 16 to 19). The rating given by the demolition expert regarding this section is mainly ‘Good’ followed by ‘Satisfactory’ and ‘Excellent’. The researchers also give a similar view with the demolition engineers. Based on this finding, in general, most of the respondents from both groups agreed that the overall rating for the prototype system is ‘Good’.

Figure 7.3: Overall rating for the prototype system
7.5.2 Suggestions for Improvement
Almost all (93%) respondents made at least one comment in the evaluation questionnaire as presented in Table 7.2. The findings may demonstrate that the respondents had given their full cooperation during the evaluation process. The main suggestion is to provide more information on the drop down panel in the data input spreadsheet and more explanation in the information document. Three of the demolition experts also suggested that the prototype system should be given to their company with a ‘confidentiality agreement’ for further evaluation and improvement of the system. One of the respondents also suggested that the prototype system should be commercialised. Besides that, the respondent also suggested that a provision should be made in order for the user to know the system’s limitations. Some action have been taken based on the suggestion. For example, inputting further information and explanation in the prototype system and providing guidance on the use of the prototype system. The offer of further evaluation of the prototype system by demolition experts in other companies may demonstrate that they are interested in using the prototype for practical purposes and that it has the potential to be commercialised.

7.5.3 Benefits of the Prototype
Through the evaluation the respondents identified several practical benefits of the prototype system, which include:

- The prototype system demonstrated an effective and systematic approach to select demolition techniques, which proved to be an improvement on the ‘ad-hoc’ decision making approach in industry practice;

- The prototype system could act as a teaching aid for young professionals coming into the demolition industry by giving them basic information and understanding on demolition; and

- The prototype system also provides a benefit to demolition contractors as a marketing aid to impress potential clients because of its capability to give rational and structured guidance in selecting demolition techniques.
7.5.4 Limitations of the Prototype
The comments regarding the limitations of the prototype system were made during discussion session in the evaluation workshop. They highlighted that the prototype system cannot be used without guidance from an experienced demolition engineer who understands the effect of health and safety implications, when a specified demolition technique is selected.

7.5.5 Appropriateness of the Evaluation Approach
The evaluation approach adopted helped to test all aspects of the system identified in the evaluation objectives and was considerably successful. This was revealed by the positive feedback received from the evaluators. Although there were limitation, further evaluation and improvement of the system would facilitate the use of the prototype for practical purposes. The evaluation approach conducted highlighted several points including:

- The focus group conducted in the evaluation workshop provides a platform for the participants to discuss and give their views to the evaluated prototype.

- All the evaluators especially the demolition experts had considerable experience in demolition and this ensured a relatively thorough assessment on the practicality of the prototype.

- The questionnaire covered all the major aspects of the prototype that needed to be evaluated and was useful for obtaining essential feedback from the evaluators;

7.6 SUMMARY
This chapter has described the summative evaluation of the prototype system. The research adopted focus group and questionnaire techniques in evaluating the prototype system. The results from the evaluation show that the prototype system has a good performance and is suitable for use in the demolition industry, although there are some limitations. Finally, the comments and suggestions from the evaluation were used to refine the prototype system. The next chapter presents the conclusions and recommendations of the research.
CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS

8.1 INTRODUCTION
This chapter concludes the research project, which resulted in the development of a decision support system named 'Demolition Techniques Selection System' (DTSS). This chapter summarises the overall findings of the research, followed by the benefits and limitations of the prototype system. It also presents the conclusions and makes recommendations for further research.

8.2 SUMMARY
The rationale for undertaking this research was the need to improve the process for the selection of demolition techniques, which relies heavily on the knowledge and experience of demolition engineers. To fulfil this need, the aim of the research project was to develop a systematic approach that can help demolition engineers in selecting the most appropriate demolition technique in any given situation. The aim was achieved through several specific objectives:

- To understand the nature of the demolition industry and the characteristics of the demolition process;
- To explore the potential for using Artificial Intelligence (AI) techniques in improving the selection of demolition techniques;
- To investigate the range of demolition techniques available in the industry and the circumstances in which they are used;
- To investigate and define the criteria which affect the selection of demolition techniques;
- To develop and evaluate a decision support system to assist the demolition engineers in selecting the most appropriate demolition techniques in any given situation; and
- To make recommendation on how demolition considerations can be taken into account at the design stage.
Various research methodologies and strategies were adopted to achieve the defined objectives of the research. The initial strategies include extensive literature review; participation at workshop, seminars and conferences to interact with other researchers and professional in similar research areas; and discussions with practitioners in the demolition industry. The knowledge acquisition process was undertaken after the initial stage to capture the demolition expert’s knowledge in selecting demolition techniques. The methods used include an industry survey through postal questionnaire, semi-structured interviews and protocol analysis. After the knowledge captured, the rapid prototyping methodology was used in developing the prototype system. The prototype was evaluated during and after the development process to verifies, validates and improves the prototype. Chapter 2 described the basic concepts and principles of the research methodology.

Literature review on demolition industry presented in Chapter 3 revealed that demolition engineers do not have a systematic procedure on the selection of demolition techniques, although this is the critical part of the demolition process. They make judgments based on their skills, relevant knowledge on the techniques and experience. Furthermore, demolition projects today have become more complex and there are many criteria that need to be considered before they can select the appropriate techniques for that project. It is also important that all these relevant criteria be thoroughly examined in order to have a safe demolition. With the current practice, the demolition engineer may mistakenly leave out important criteria, as there is no written or structured procedure that they can follow. This chapter also discussed various aspects of the demolition industry, which include: the criteria that may affect the selection of demolition techniques; the types of structural demolition; the types of demolition techniques available in the industry; and the demolition cost estimation process. The subjects discussed were used later in the development of the proposed prototype system.

A potential Artificial Intelligent (AI) technique that can be used as Decision Support System (DSS) for the proposed prototype was reviewed in Chapter 4. The review revealed that the Analytic Hierarchy Process (AHP) could provide the framework of logic needed to model a complex decision scenario. AHP can integrate perceptions, feelings, judgments and experiences of the demolition experts into a hierarchy therefore allowing a better understanding of the problem, its criteria and possible choice. Since the research
used AHP model to solve the problem in selecting the most appropriate demolition techniques, therefore the most suitable development environment based on the AHP methodology was the Expert Choice software package. Expert Choice was used to structure the decision problem into a hierarchy and synthesized judgments. This made system development simple by eliminating tedious calculations.

Knowledge Acquisition (KA) is a necessary part of the development of an intelligent system for the selection of demolition techniques. The decision making process of the demolition experts needed to be captured in order to develop a decision model for the system. For this reason, the Knowledge Acquisition (KA) process was presented in Chapter 5. The KA process involved capturing and transforming appropriate knowledge from demolition experts into some manageable form to develop the decision model. The knowledge that needed to be captured included the relevant criteria, which may affect the selection of demolition techniques and the demolition techniques available as the alternatives. The criteria and alternatives captured from the experts were then represented by a decision tree based on AHP approach to develop a decision model. The research adopts three approaches to knowledge acquisition: questionnaire survey, semi-structured interview and protocol analysis.

An industry survey through postal questionnaires was used as an approach to obtaining preliminary knowledge from the demolition industry. The aims of the survey were to identify a list of factors that may affect the selection of demolition techniques and a list of available demolition techniques in the industry. The semi-structured interview was adopted to validate and refine the results captured from the questionnaire survey. The objective of the semi-structured interviews included: to define and justify the relevance of the identified criteria that resulted from the questionnaire survey; and to define and group the demolition techniques obtained from the questionnaire survey. The researcher used the findings from these two approaches as a guide to developing a complete hierarchical structure that simplifies the decision process of selecting the most appropriate demolition techniques.

Protocol analysis was used to capture the expert knowledge to develop the demolition cost estimation model. The demolition cost estimation model is one of the tool used in the proposed demolition techniques selection system, to assess the demolition techniques
from the economic point of view. The objective of the protocol analysis was to develop a list of cost items involved in the estimation process for each type of demolition techniques. The list was then reviewed and validated by the other experts. Several meetings were conducted for this purpose until a final list was developed.

The proposed prototype system was named ‘Demolition Techniques Selection System’ (DTSS). The development and operation of the DTSS was described in Chapter 6. It consists of two stages. The first stage focused on assisting the decision maker in selecting the most appropriate demolition techniques in term of technical aspects by using Expert Choice Software based on Analytic Hierarchy Process (AHP) model. The second stage allowed the decision maker to assess the demolition techniques in term of cost by using the Demolition Cost Estimation model.

The functional architecture of the DTSS was developed based on the AHP benefit/cost analysis procedures. The first stage gave the priorities of benefits for all the demolition techniques in term of its technical capability. The second stage gave the priorities of cost for all the demolition techniques in term of its economical value. The highest benefit/cost ratio was considered the most appropriate demolition technique. By incorporating these two stages, the demolition engineer can make sound judgments based on technical and economic considerations.

The evaluation of the prototype system after it has been developed was described in Chapter 7. The research adopted focus group and questionnaire techniques in evaluating the prototype system using evaluation workshops. There were two groups of participants involved in the workshops. The first group was selected to give feedback from the end-user (demolition experts) point of view. The second group was selected to give feedback from the external end-user (researcher) point of view. The evaluation confirmed that, even though there were some improvements required to make the system more effective, it does provide many benefits, demonstrates good performance and is highly applicable for use in the industry.

It can be seen from the above, that the objectives of the research project have generally been achieved.
8.3 BENEFITS
The prototype system offers many benefits to demolition engineers and other users involved in the selection of demolition techniques.

- It provides a clear and structured framework of the decision-making process to help the users in selecting the most appropriate demolition techniques when both technical and economical aspects of a decision need to be considered;

- It serve as an information source that contains a variety of information on demolition techniques to support the decision making process;

- It represents an easy to use prototype system that is capable in making rational and justifiable decisions using graphical reports and sensitivity analysis;

- It incorporates a computerized demolition cost estimation model that is intended to solve some of the estimating problems (such as reducing the time to do the estimate) that is faced by demolition engineers;

- The system can act as a teaching aid for young professionals coming into the demolition industry by giving them a basic information and understanding of demolition; and

- Demolition contractors can use the system as a marketing aid to impress potential clients to win a project because of its capability to give rational and structured decisions with the capability of generating graphical reports and sensitivity analysis.

8.4 LIMITATIONS
The limitations of the prototype system include:

- The prototype system cannot be adequately used without guidance from an experienced demolition engineer who understands the effect of health and safety on persons on and off site, when a specified demolition technique is selected.
The system was designed to act as a tool that supports the decision making process by structuring and systematically evaluating each criteria that may affect the selection of demolition techniques. The system relies on expert judgement to assess all the criteria based on the framework developed.

- Although the formative evaluation carried out during the development process and summative evaluation after the prototype was developed have been done by demolition experts (as internal users) and researchers (as external users), the system still needs further evaluation to improve its performance and applicability to the industry. The prototype system needs to be tested in a real life demolition project to ensure its accuracy and effectiveness.

8.5 CONCLUSIONS

Several conclusions can be drawn from the research. These include:

- The current demolition techniques selection process is typically performed in an unstructured intuitive manner with considerable reliance on the experience, skill, knowledge, or judgement of the demolition engineer. There is scope for error and inconsistencies in this approach. The prototype system developed provides users with a clear, systematic and structured framework that could improve the decision making process. It still requires the judgments of the decision makers and therefore ensures the users, total control of the decision making process especially in the final selection. Both technical and economical aspects of a decision were considered to ensure that a sound and rational judgement is made in selecting the most appropriate demolition technique in a given situation.

- Most of the cost estimating programs available commercially are focussed on new construction, with nothing available for demolition projects. The prototype system developed provides the user with a computerized demolition cost estimation model that is specially customized to the demolition industry.

- There are six main criteria must be considered that may affect the selection of demolition techniques. These include structure characteristics; site conditions;
past experience; reuse and recycling; time; and cost. When assessing these criteria against the available demolition techniques, it is recognised that the demolition engineer must keep in mind that health and safety of persons on and off site remain the highest priority.

- There are three main types of demolition techniques for structural demolition used in the industry. These include: Progressive Demolition; Deliberate Collapse Mechanism; and Deconstruction. These can be further sub-divided into: Progressive demolition by long reach machines with various hydraulic attachments; Progressive demolition by demolition ball; Deliberate collapse mechanism by explosive; Deliberate collapse by wire rope pulling; Deconstruction by hand; and Deconstruction by machines.

- The research also revealed that deconstruction techniques have the characteristics to maintain the highest possible value for materials in existing buildings by dismantling buildings in a manner that will allow the reuse or efficient recycling of the materials that comprise the structure. In general, the main problem facing deconstruction today is the fact that architects and builders of the past visualized their creations as being permanent and did not make provisions for their future disassembly. But this is changing, because of the growing importance of sustainability. As a result, deconstruction is emerging as real alternative to demolition around United Kingdom and the rest of the world. Techniques and tools for dismantling existing structures are under development, research to support deconstruction is ongoing at institutions around the world, and government policy is beginning to address the advantages of deconstruction by increasing disposal costs or in some cases, forbidding the disposal of otherwise useful materials. Designing buildings to build for future deconstruction is beginning to receive more attention and architects and other designers are starting to consider this factor for new buildings.

- In this research, the Analytic Hierarchy Process (AHP) provides a convenient approach for solving complex Multiple Criteria Decision Making (MCDM) problems in selecting demolition techniques. It should be noted that Expert Choice software package has significantly contributed to the wide acceptance of
the AHP methodology. MCDM concepts have proven to be useful in choice analysis, by taking account of the wide variety of aspects inherent in any decision problem and by offering an operational framework for a multidisciplinary approach to practical choice problem. The research concluded that MCDM methods should be used as decision support tools and not as the means for deriving final answer. The conclusion of the solution should be used only as indications to what may be the best answer. Although the search for finding the best MCDM method may never end, research in this area of decision-making is still critical and very important in many scientific and engineering applications.

- **The Analytic Hierarchy Process (AHP)** was an appropriate method to use for a number of reasons:
  
  ⇒ It improves the decision making process – the hierarchical structure used in formulating the AHP model enables the demolition engineer to visualise the selection problem systematically in terms of relevant criteria, sub-criteria and alternatives;
  
  ⇒ It provides the capability to compare both qualitative and quantitative criteria by using informed judgment to derive weights and priorities. It also takes into consideration judgments based on people’s feelings and emotions as well as their thoughts. This capability matches the nature of the decision making process that demolition engineers go through in selecting demolition techniques;
  
  ⇒ It has a capability for measuring inconsistency in subjective judgments by calculating the consistency ratio for each judgement;
  
  ⇒ The nature of numerical and pictorial results obtained from the synthesis stage gives a better understanding and a clear rationale for the choice selected in the decision-making process;
  
  ⇒ The availability of the Expert Choice software based on AHP theory made it easy to understand and apply in this domain; and
  
  ⇒ The results obtained mirror results from previous studies by several researchers, which recommend AHP for multi-criteria decision-making.
8.6 RECOMMENDATIONS FOR FURTHER RESEARCH

This research project has revealed a number of areas for further research and development, including:

1. Further improvements to the prototype system with respect to:
   - Adding more information in the ‘Information Document’ with several case studies on various types of demolished structures;
   - Regularly updating the existing ‘Information Document’ with new and latest demolition techniques available in the industry; and
   - Improving the user interface in the Data Input Spreadsheets and Demolition Cost Estimation Model through better screen layout and better user guidance.

2. Further testing of the prototype on real demolition cases with various types of structure is considered necessary. The feedback from these can further demonstrate the system’s applicability to different types of decision scenario.

3. Integrate both of the models, AHP Model with Demolition Cost Estimation Model by developing a standalone programme. This will enhance the user-friendliness of the prototype system and could lead to commercialisation of the prototype system.

4. Further research should be carried out to improve the prototype, so that it can be use as teaching tools not only for young demolition engineers coming to the industry but also for higher education, especially for students in architecture and civil and building engineering.

5. From the observations during the research project, it seems that the demolition industry is left behind in term of Research and Development. The literature on the demolition techniques available is also limited. Therefore, more research should be done in the industry, especially on the development of new demolition techniques so that the industry can benefit from these.

6. The research has explored in detailed and gathered various types of information regarding the demolition, which can be used as a basis to do further research on ‘Design for Deconstruction’. The reason for this is that the ease with which a
structure can be demolished is strongly related to its design. Designers therefore, need to make adequate provisions in their designed to enable structures to be demolished safely, economically and in an environmentally sustainable manner. In particular, design determines the extent to which building components can be recycled and reused.

8.7 CLOSING REMARKS

The research has revealed that, the current demolition techniques selection process performed by demolition engineers are based on their knowledge and experience without any systematic procedure that can be followed to support the decision making process. This research has demonstrated how the prototype system developed provide the users with a clear, systematic and structured framework that could improve the current decision making process. AHP in particular, with the use of Expert Choice software and the Demolition Cost Estimation Model developed could enhance the decisions made by demolition engineers. The demolition industry practitioners should take advantage of the prototype system developed in this research as it presents many benefits in terms of technical and economical aspects.
REFERENCES


Belton, V. (1990), *Multiple Criteria Decision Analysis: practicality the only way to choose*, Working Paper, Department of Management Science, pp. 1-49.


Building Department Hong Kong (1998), Code of Practice for Demolition of Buildings, Building Department Hong Kong.


HSE (1999), Safety in Gas Welding, Cutting and Similar Processes, HSE Books, Sudbury.


Appendix A

A copy of the Questionnaire Survey
survey is part of a research programme at Loughborough University to establish the selection criteria for demolition techniques within the UK demolition industry. Structured questions have been formulated to achieve this goal. Although you are required to respond to most questions by ticking in a box, there is also the opportunity for you to add your comments. Your response to this questionnaire is highly valued and will be treated the strictest confidence. It will be used for academic purposes only. Thank you.

**BACKGROUND INFORMATION**

**Name of Respondent (optional):** __________________________

**Position:** __________________________

**What is your experience in the demolition industry (in years):** ________ (years)

**Company Name and Address (optional):** __________________________

---

**Fax:** __________________________

5. Email / URL: __________________________

**DEMOLITION TECHNIQUES**

Predicate your involvement in the type of structures being demolished in the past 5 years.

**LEAVE TICK OR SPECIFY NUMBER OF CASES WHEREVER APPROPRIATE**

<table>
<thead>
<tr>
<th>No</th>
<th>Type of Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Buildings</td>
</tr>
<tr>
<td>2.</td>
<td>Bridges</td>
</tr>
<tr>
<td>3.</td>
<td>Masonry and Brick Arches</td>
</tr>
<tr>
<td>4.</td>
<td>Independent Chimneys</td>
</tr>
<tr>
<td>5.</td>
<td>Lattice Towers and Mast</td>
</tr>
<tr>
<td>6.</td>
<td>Vessels</td>
</tr>
<tr>
<td>7.</td>
<td>Basement and Retaining Wall</td>
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<tr>
<td>8.</td>
<td>Spires</td>
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<tr>
<td>9.</td>
<td>Tunnel</td>
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<tr>
<td>10.</td>
<td>Dams</td>
</tr>
<tr>
<td>11.</td>
<td>Other (specify)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mainly made of ...</th>
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</thead>
<tbody>
<tr>
<td>Brickwork / Stonework</td>
</tr>
<tr>
<td>Steel</td>
</tr>
<tr>
<td>Reinforced Concrete</td>
</tr>
<tr>
<td>Pre-tensioned RC structures</td>
</tr>
<tr>
<td>Post-tensioned RC structures</td>
</tr>
<tr>
<td>Composite Structures</td>
</tr>
<tr>
<td>Timber</td>
</tr>
<tr>
<td>Glass reinforced plastics</td>
</tr>
<tr>
<td>Other (specify)</td>
</tr>
</tbody>
</table>
Please indicate the type of structure for which you would use the following demolition techniques.

**Demolition Techniques**

<table>
<thead>
<tr>
<th>Demolition Techniques</th>
<th>Building</th>
<th>Bridges</th>
<th>Masonry and Brick Arches</th>
<th>Independent Chimneys</th>
<th>Lattice Towers and Mast</th>
<th>Vessels</th>
<th>Basement and Retaining Wall</th>
<th>Spires</th>
<th>Tunnels</th>
<th>Dams</th>
<th>Other (specify)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demolition by hand</td>
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<tr>
<td>Demolition by machines</td>
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<tr>
<td>2.1 Remotely controlled machines and robotic device</td>
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<td>2.2 High reach machines</td>
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<tr>
<td>2.3 Tower and high reach cranes</td>
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<td>2.4 Hydraulic attachments</td>
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<tr>
<td>2.5 Mechanical (non-hydraulic) attachments e.g. Balling etc.</td>
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<tr>
<td>2.6 Cutting by drilling and sawing</td>
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<tr>
<td>Demolition by chemical agents</td>
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<tr>
<td>3.1 Demolition by explosive</td>
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<tr>
<td>3.2 Bursting</td>
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<tr>
<td>3.3 Hot cutting</td>
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<tr>
<td>Demolition by high pressure water jetting</td>
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<tr>
<td>Other (specify)</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

What circumstances would you generally use the following techniques? *(Please specify)*

<table>
<thead>
<tr>
<th>Demolition Techniques</th>
<th>Usage / Application Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demolition by hand</td>
<td></td>
</tr>
<tr>
<td>Demolition by machines</td>
<td></td>
</tr>
<tr>
<td>2.1 Remotely controlled machines and robotic device</td>
<td></td>
</tr>
<tr>
<td>2.2 High reach machines</td>
<td></td>
</tr>
<tr>
<td>2.3 Tower and high reach cranes</td>
<td></td>
</tr>
<tr>
<td>2.4 Hydraulic attachments</td>
<td></td>
</tr>
<tr>
<td>2.5 Mechanical (non-hydraulic) attachments e.g. Balling etc.</td>
<td></td>
</tr>
<tr>
<td>2.6 Cutting by drilling and sawing</td>
<td></td>
</tr>
<tr>
<td>Demolition by chemical agents</td>
<td></td>
</tr>
<tr>
<td>3.1 Demolition by explosive</td>
<td></td>
</tr>
<tr>
<td>3.2 Bursting</td>
<td></td>
</tr>
<tr>
<td>3.3 Hot cutting</td>
<td></td>
</tr>
<tr>
<td>Demolition by high pressure water jetting</td>
<td></td>
</tr>
<tr>
<td>Other (specify)</td>
<td></td>
</tr>
</tbody>
</table>
select the following selection criteria of demolition techniques in order of importance. (1 is most important & 14 or 15 is least important)

<table>
<thead>
<tr>
<th>Selection Criteria for Demolition Techniques</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenant Specification</td>
<td></td>
</tr>
<tr>
<td>Location and/or accessibility</td>
<td></td>
</tr>
<tr>
<td>Shape and size of the structure</td>
<td></td>
</tr>
<tr>
<td>Stability of the Structure</td>
<td></td>
</tr>
<tr>
<td>Time Constraint</td>
<td></td>
</tr>
<tr>
<td>Environmental Consideration</td>
<td></td>
</tr>
<tr>
<td>Transportation Consideration</td>
<td></td>
</tr>
<tr>
<td>Extent of Demolition</td>
<td></td>
</tr>
<tr>
<td>Structural Engineer Approval</td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td></td>
</tr>
<tr>
<td>Recycling Consideration</td>
<td></td>
</tr>
<tr>
<td>Presence of Hazardous material</td>
<td></td>
</tr>
<tr>
<td>Health and safety</td>
<td></td>
</tr>
<tr>
<td>Availability of plant / equipment</td>
<td></td>
</tr>
<tr>
<td>Other (specify)</td>
<td></td>
</tr>
</tbody>
</table>

What procedure do you currently follow in selecting a technique for a given demolition project?

- [ ] Very poor
- [ ] Poor
- [ ] Neutral
- [ ] Efficient
- [ ] Very Efficient

What are the key stages in the demolition process? (List or provide sketch / flow chart)

What have you have adequate guidance on the choice of appropriate demolition techniques? [ ] Yes [ ] No

- [ ] BS 6187:2000
- [ ] In-house guide
- [ ] The Institute of Demolition Engineers guide
- [ ] NFDC guide e.g. Guidance for Deconstruction of Tower Blocks etc.
- [ ] Other (specify)

Who decides on the technique to use?

- [ ] Demolition Manager
- [ ] Demolition Engineer
- [ ] Contract Manager
- [ ] Site Manager
- [ ] Director
- [ ] Client
- [ ] Design Consultant
- [ ] Other (specify)

What is the decision based on? (Please specify in percentage of cases)

<table>
<thead>
<tr>
<th>Intuitive Analysis</th>
<th>%</th>
<th>Qualitative Analysis</th>
<th>%</th>
<th>Experience / Past cases</th>
<th>%</th>
<th>Other (specify)</th>
</tr>
</thead>
</table>

What are your biggest problems in undertaking demolition work?

Do you use computers/information technology (IT) at any stages of the demolition process? [ ] Yes [ ] No

- [ ] Yes
- [ ] No

What for?

How can your demolition process be improved?

Your co-operation in completing the above questionnaire has greatly appreciated. Please send the completed questionnaire in the stamped addressed envelope provided to: Mr Arham Abdullah, Department of Civil & Building Engineering, Loughborough University, Loughborough, Leicestershire, LE11 3TU, UK. Thank you.
Appendix B

Template for Semi-Structured Interviews
SEMI-STRUCTURED INTERVIEW FORM

Name of respondent : 

Position : 

Company name and address : 

Contact no/email : 

Date : 

Introduction:
My Name is Arham Abdullah and I'm a Ph.D. Research Student at Civil & Building Engineering Department Loughborough University. My Supervisor is Professor Chimay Anumba. My Research title is Intelligent Selection of Demolition Techniques.

The proposed project is to do with investigating the range of demolition techniques and plant available and determining the criteria that are used for selecting them in a given situation. It will also involve the development of a decision support system to enable demolition managers choose the most appropriate technique and/or plant in practice.

The interview will investigate the range of demolition techniques and plant available and determine the criteria that are used for selecting them in a given situation.

The Interview will take about one hour to complete. Your answers to this interview will be treated in the strictest confidence and will be used for academic purposes only. Your response will be highly appreciated.

Objectives:

1. To define and justify the relevance of the identified criteria that resulted from the questionnaire survey.

2. To define and group the demolition techniques obtained from the questionnaire survey.
Could you please justify the relevance of the identified criteria that resulted from the questionnaire survey:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Justifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health and Safety (H&amp;S)</td>
<td></td>
</tr>
<tr>
<td>Stability of the structure</td>
<td></td>
</tr>
<tr>
<td>Location and accessibility</td>
<td></td>
</tr>
<tr>
<td>Presence of hazardous material</td>
<td></td>
</tr>
<tr>
<td>Environmental consideration</td>
<td></td>
</tr>
<tr>
<td>Shape and size of the structure</td>
<td></td>
</tr>
<tr>
<td>Client specification</td>
<td></td>
</tr>
<tr>
<td>Structural engineer approval</td>
<td></td>
</tr>
<tr>
<td>Time constraint</td>
<td></td>
</tr>
<tr>
<td>Extent of demolition</td>
<td></td>
</tr>
<tr>
<td>Financial Constraint</td>
<td></td>
</tr>
<tr>
<td>Recycling consideration</td>
<td></td>
</tr>
<tr>
<td>Transportation consideration</td>
<td></td>
</tr>
<tr>
<td>Availability of plant or equipment</td>
<td></td>
</tr>
</tbody>
</table>
2.0 Could you please arrange the card in order to group the demolition techniques based on the structural demolition?

<table>
<thead>
<tr>
<th>Progressive Demolition</th>
<th>Deliberate Collapse Mechanism</th>
<th>Deliberate Removal of Elements or Deconstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>The progressive demolition is the controlled removal of sections of the structure, at the same time retaining the stability of the remainder and avoiding collapse of the whole or part of the structure to be demolished (BS6187: 2000)</td>
<td>Demolition by deliberate collapse is the removal of the key structural members to cause complete collapse of the whole or part of the building structures of the whole or part of the structure to be demolished (BS6187: 2000)</td>
<td>Deconstruction or Top-down Technique is those techniques that proceed from the roof to ground in a general trend. On a floor-by-floor downward sequence, depending on site conditions and structural elements to be demolished (BS6187: 2000)</td>
</tr>
<tr>
<td>Long Reach Machine with Various Hydraulic Attachments</td>
<td>Demolition Ball</td>
<td>Demolition by Hand</td>
</tr>
<tr>
<td>Wire Rope Pulling</td>
<td>Explosive</td>
<td>Demolition by Machines</td>
</tr>
<tr>
<td>Remotely controlled machines and robotic device</td>
<td>Demolition by high pressure water jetting</td>
<td>Demolition by chemical agents</td>
</tr>
<tr>
<td>Tower and high reach cranes</td>
<td>Bursting</td>
<td>Hot cutting</td>
</tr>
<tr>
<td>Cutting by drilling and sawing</td>
<td></td>
<td>Others</td>
</tr>
</tbody>
</table>

Others
Appendix C

Pairwise Comparison Matrices for each Level of the Hierarchy
Figure 6.31: Pairwise Comparison Matrix: Level 1 with respect to level 0 (goal)

Figure 6.32: Pairwise Comparison Matrix: Level 2 with respect to level 1 (structure characteristics)

Figure 6.33: Pairwise Comparison Matrix: Level 3 with respect to level 2 (height of structure)
Figure 6.34: Pairwise Comparison Matrix: Level 3 with respect to level 2 (type of structure)

Figure 6.35: Pairwise Comparison Matrix: Level 3 with respect to level 2 (stability of structure)

Figure 6.36: Pairwise Comparison Matrix: Level 3 with respect to level 2 (degree of demolition)
Figure 6.37: Pairwise Comparison Matrix: Level 3 with respect to level 2 (previous used of structure)

Figure 6.38: Pairwise Comparison Matrix: Level 2 with respect to level 1 (site conditions)

Figure 6.39: Pairwise Comparison Matrix: Level 3 with respect to level 2 (health and safety)
Progressive Demolition

Deliberate Collapse Mechanism

Figure 6.40: Pairwise Comparison Matrix: Level 3 with respect to level 2 (acceptable level of nuisance)

Progressive Demolition

Deliberate Collapse Mechanism

Figure 6.41: Pairwise Comparison Matrix: Level 3 with respect to level 2 (Proximity of the nearest adjacent structure)

Progressive Demolition

Deliberate Collapse Mechanism

Figure 6.42: Pairwise Comparison Matrix: Level 3 with respect to level 2 (site accessibility)
Figure 6.43: Pairwise Comparison Matrix: Level 2 with respect to level 1 (past experience)

Figure 6.44: Pairwise Comparison Matrix: Level 3 with respect to level 2 (familiarity with a specified technique)

Figure 6.45: Pairwise Comparison Matrix: Level 2 with respect to level 1 (availability of plant and equipment)
Figure 6.46: Pairwise Comparison Matrix: Level 2 with respect to level 1 (availability of expertise)

Figure 6.47: Pairwise Comparison Matrix: Level 3 with respect to level 2 (level of reuse and recycling)

Figure 6.48: Pairwise Comparison Matrix: Level 3 with respect to level 2 (total demolition time)
Appendix D

Data Input Workbook
### Demolition Techniques Selection System

The document is a worksheet for a desk study and on-site survey. It contains fields for general information, project directory, and consulting engineer details. The worksheet is designed to be filled out with specific data for each section.

#### A. SITE INFO
- **Building Name or No:** Multi-Storey Car Park
- **Street Address:** Market Street
- **Town:** Kidderminster
- **County:** Leicestershire
- **Post Code:** DY10 1LX
- **Country:** United Kingdom

#### B. PROJECT DIRECTORY

**THE CLIENT**
- **Client Name:** ABC
- **Building Name or No:** 21
- **Street Address:** Hoo Road
- **Town:** Kidderminster
- **County:** Worcestershire
- **Post Code:** DY10 2LP
- **Country:** United Kingdom
- **Person in charge:** Mr. McDonald
- **Tel No:** 01509-567656
- **Fax No:** 01509-452543
- **Email Address:** Mcdonald@ntlworld.com

**PLANNING SUPERVISOR**
- **Company Name:** DGM Associates
- **Building Name or No:** 40
- **Street Address:** Dearby Road
- **Town:** Loughborough
- **County:** Leicestershire
- **Post Code:** Le11 2Hg
- **Country:** United Kingdom
- **Person in charge:** Mr. Bruce Willis
- **Tel No:** 01509-452554
- **Fax No:** 01509-452554
- **Email Address:** W.Bruce@btoworld.com

**PRINCIPAL CONTRACTORS**
- **Company Name:** XYZ Demolition
- **Building Name or No:** 58
- **Street Address:** Nottingham Road
- **Town:** Loughborough
- **County:** Leicestershire
- **Post Code:** Le11 4DL
- **Country:** United Kingdom
- **Person in charge:** Mr. Cristiano Ronaldo
- **Tel No:** 01509-678768
- **Fax No:** 01509-345276
- **Email Address:** V.Rosoo@btoworld.ac.uk

**CONSULTING ENGINEER**
- **Company Name:** GeoBina Consultant
- **Building Name or No:** 88
- **Street Address:** Leicester Road
- **Town:** Loughborough
- **County:** Leicestershire
- **Post Code:** Le11 2Bj
- **Country:** United Kingdom
- **Person in charge:** Mr. Zinedine Zidane
- **Tel No:** 01509-450777
- **Fax No:** 01509-654346
- **Email Address:** T.Adams@ntworld.com.ac.uk

---

Don't Forget to IMMEDIATELY save your spreadsheet under a different name. Then frequently save your spreadsheet when entering data.

---
### 1.0 DATA INPUT FOR STRUCTURE CHARACTERISTICS:

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.1 HEIGHT OF THE STRUCTURE</strong></td>
<td>4 Storey</td>
<td>14.00 Meters</td>
</tr>
<tr>
<td><strong>1.2 TYPE OF THE STRUCTURE</strong></td>
<td>Others please specify</td>
<td>MAINLY MADE OF</td>
</tr>
<tr>
<td></td>
<td>Multi-storey Car Park</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Brickwork / Stonework</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Steel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Reinforced Concrete</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Pre-stressed RC Structure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Post-tensioned RC Structure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Pre-tensioned RC Structure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Composite Structure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Timber</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Pre-cast Panel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Other (specify) ——— Flat Slab Design</td>
</tr>
<tr>
<td><strong>1.3 STABILITY OF THE STRUCTURE</strong></td>
<td>Stable</td>
<td></td>
</tr>
<tr>
<td><strong>1.4 DEGREE OF DEMOLITION</strong></td>
<td>Full demolition</td>
<td></td>
</tr>
<tr>
<td><strong>1.5 PREVIOUS USE OF THE STRUCTURE</strong></td>
<td>Car park since 1980 and cattle market for the previous 100 years</td>
<td></td>
</tr>
</tbody>
</table>
2.0 DATA INPUT FOR SITE CONDITIONS:

2.1 HEALTH AND SAFETY: THE PERSON ON AND OFF SITE

2.1.1 RISK OF DANGER TO DEMOLITION WORKERS AND TO MEMBERS OF PUBLIC

<table>
<thead>
<tr>
<th></th>
<th>PD</th>
<th>DCM</th>
<th>DC</th>
</tr>
</thead>
<tbody>
<tr>
<td>RISK</td>
<td>Medium Risk</td>
<td>Low Risk</td>
<td>Medium Risk</td>
</tr>
</tbody>
</table>

Note: PD - Progressive Demolition; DCM - Deliberate Collapse Mechanism; DC - Deconstruction

2.2 ENVIRONMENTAL: ACCEPTED LEVEL OF NUISANCE

2.2.1 ACCEPTED LEVEL OF NOISE

- 80 db(A) or above

2.2.2 ACCEPTED LEVEL OF DUST

- Significant amount of dust

2.2.3 ACCEPTED LEVEL OF VIBRATION

- Significant effect on human body

3.0 PROXIMITY OF NEAREST ADJACENT STRUCTURE

- 20 Meters

- Clear space of 1/2 the building height or = 7 meter

- Clear space of 2.5 the building height or ≤ 35 meter

- Clear space of 2.5 the building height or > 35 meter

4.0 ACCESSIBILITY: Accessibility of the workers and plant to the work place

- Accessible
## 4.0 PAST EXPERIENCE

<table>
<thead>
<tr>
<th></th>
<th>Progressive Demolition</th>
<th>Deliberate Collapse Mechanism</th>
<th>Deconstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>4.10 FAMILIARITY WITH SPECIFIED TECHNIQUES</strong></td>
<td>Familiar ▼ Not Familiar ▼ Familiar ▼</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>4.20 AVAILABILITY OF PLANT &amp; Equipment</strong></td>
<td>Available ▼ Available ▼ Available ▼</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>4.30 AVAILABILITY OF EXPERTISE</strong></td>
<td>Available ▼ Available ▼ Available ▼</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0 REUSE &amp; RECYCLING</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5.1 LEVEL OF CONCERN FOR REUSE &amp; RECYCLING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate level of concern</td>
</tr>
</tbody>
</table>
### 6.0 TIME

<table>
<thead>
<tr>
<th></th>
<th>Progressive Demolition (DAYS)</th>
<th>Deliberate Collapse Mechanism (DAYS)</th>
<th>Deconstruction (DAYS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1 TIME FOR DESIGNING THE DEMOLITION TECHNIQUES</td>
<td>5</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>6.1 TIME FOR STRUCTURAL PREPARATION</td>
<td>7</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>6.2 TIME FOR ACTUAL DEMOLITION</td>
<td>20</td>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td>TOTAL DURATION</td>
<td>32</td>
<td>22</td>
<td>46</td>
</tr>
</tbody>
</table>
Appendix E

Evaluation Questionnaire
Demolition Techniques Selection System (DTSS)

Evaluation Questionnaire

This evaluation questionnaire should be completed following a demonstration of the prototype system.

A. Information about the participant

Name (optional): _______________________________

Your position (e.g. demolition engineer, researcher): ____________________

Experience in/with demolition industry (years): ______________________

B. Evaluation of the Prototype System

(Please put a tick in the box that best represents your assessment of a question)
(1 is Poor, 2 is Fair, 3 is Satisfactory, 4 is Good, and 5 is Excellent)

<table>
<thead>
<tr>
<th>Questions</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>THE SYSTEM PERFORMANCE</strong></td>
<td>1</td>
</tr>
<tr>
<td>1. How well does the system help in understanding how demolition techniques can be selected?</td>
<td>2</td>
</tr>
<tr>
<td>2. How clearly are the selection criteria defined in the system?</td>
<td>3</td>
</tr>
<tr>
<td>3. How well are the demolition techniques explained in the system?</td>
<td>4</td>
</tr>
<tr>
<td>4. How useful will the system be in supporting communication between the demolition engineers and clients?</td>
<td>5</td>
</tr>
<tr>
<td>5. How well does the Information Document help in making a decision?</td>
<td></td>
</tr>
<tr>
<td>6. How appropriate is the Pairwise comparison aspect of the system?</td>
<td></td>
</tr>
<tr>
<td>7. How well does the system reflect the decision-making ability in a real situation?</td>
<td></td>
</tr>
<tr>
<td>8. How useful do you find the sensitivity analysis within the system?</td>
<td></td>
</tr>
<tr>
<td>9. How accurately are the relative costs between demolition options modelled in the system?</td>
<td></td>
</tr>
<tr>
<td>10. How useful is the cost model in choosing a demolition technique?</td>
<td></td>
</tr>
<tr>
<td>Additional comments:</td>
<td></td>
</tr>
</tbody>
</table>

| **APPLICABILITY TO DEMOLITION INDUSTRY**                                 | 1      |
| 11. How effective/accurate is the system in the selection of demolition techniques? | 2      |
| 12. How convinced are you that demolition industry professionals will accept (or use) the system? | 3      |
| 13. How effectively will the system increase the speed of the decision making process? | 4      |
| 14. To what extent does it represent an improvement (or help) in the decision making process? | 5      |
| 15. To what extent is the system flexible in choosing the most appropriate demolition techniques? |        |
| Additional comments:                                                     |        |
### GENERAL

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>How well organized (designed) is the system?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>How user friendly is the system?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>How well integrated are the different components of the system?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>What is your overall rating of the prototype system?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Additional comments:

### C. General Comments

1. What do you consider the main benefits of the prototype system?

   
   
   
   

2. In what ways can the system be improved?

   
   
   
   

3. Further comments:

   
   
   
   

   

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