# A DECISION SUPPORT SYSTEM FOR DEMOLITION SAFETY RISK ASSESSMENT

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# A DECISION SUPPORT SYSTEM FOR DEMOLITION SAFETY RISK ASSESSMENT

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*This thesis lovingly dedicated to*
*my mother, Fatemeh Mashari. Her support,*
*encouragement, and constant love*
*have sustained me throughout my life.*

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## ABSTRACT

Demolition can be defined as dismantling, razing, destroying or wrecking of any building or structure or any part thereof. Demolition work involves many of the hazards associated with construction. However, demolition also involves additional hazards due to unknown factors which makes demolition work particularly dangerous. In order to make the demolition project safer, everyone at a demolition site must be fully aware of the hazards they may encounter and the safety precautions that they must take to protect themselves and their employees. Safety risk assessment is a planning tool that can be used to improve safety performance at demolition site. In the absence of a special tool for demolition safety risk assessment, a prototype *Decision Support System (DSS)* based on failure mode and effect analysis that enables decision makers to systematically and semi-quantitatively identify, analyze and evaluate safety risks factors in demolition project has been developed. The prototype is named *Hybrid Demolition Safety Risk Assessor (HDSRA)*. It has three modules; (i) safety risk identification, (ii) safety risk analysis and (iii) safety risk evaluation. Module one aids the decision makers to identify thirty-seven safety risks that is developed by reviewing safety literatures and forming consensus among Delphi panel of experts. In addition, the module introduces seven immediate causes that trigger occurrence of those thirty-seven safety risks. The second module comprised a hybrid decision making model based on *Decision Making Trial and Evaluation Laboratory (DEMATEL)* and *Analytic Network Process (ANP)* that relatively estimates likelihood of thirty-seven safety risks with respect to seven immediate causes. The third module evaluates and prioritizes the safety risks by using two ranking methods; *Analytic Hierarchy Process (AHP)* and *VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR)*. The HDSRA prototype is then developed by integrating module 1, 2 and 3 and evaluated by a group of demolition experts. HDSRA acts as information source that can be used by demolition contractors to identify safety risks in a systematic way. Therefore, possibility of raising error during risk identification process in the implementation of demolition work is reduced. Decision support system that is produced by the HDSRA prototype, proactively proposes action that should be taken by demolition safety experts to control risks at workplace. And finally, HDSRA can be also used as a training tool to raise safety awareness among demolition workers.

# ABSTRAK

Perobohan boleh ditakrifkan sebagai membuka, memotong, memusnah atau menghancurkan bangunan atau struktur atau mana-mana bahagiannya. Terdapat pelbagai bentuk bahaya dalam kerja perobohan yang berkait rapat dengan kerja pembinaan. Namun begitu kerja perobohan akan menjadi sangat bahaya sekiranya terdapat faktor-faktor lain yang tidak diketahui ketika perobohan dilaksanakan. Dalam usaha untuk memastikan projek perobohan yang lebih selamat, semua pihak yang terlibat di tapak perobohan perlu sedar sepenuhnya tentang bahaya yang mereka hadapi dan langkah-langkah keselamatan perlu ambil untuk melindungi diri dan pekerja. Penilaian risiko keselamatan adalah kaedah perancangan yang boleh digunakan untuk meningkatkan prestasi keselamatan di tapak perobohan. Disebabkan ketiadaan kaedah khas untuk penilaian risiko keselamatan perobohan, maka, kajian ini telah membangunkan prototaip *Decision Support System (DSS)* berdasarkan mod kegagalan dan analisis kesan. Prototaip yang dibangunkan membolehkan pembuat keputusan untuk mengenal pasti faktor-faktor keselamatan risiko dalam projek perobohan secara sistematik dan separa kuantitatif serta menganalisis dan menilai keselamatan risiko yang terlibat. Prototaip ini dinamakan *Hybrid Demolition Safety Risk Assessor (HDSRA).* Ia mengandungi tiga modul; (i) mengenal pasti risiko keselamatan, (ii) analisis risiko keselamatan dan (iii) penilaian risiko keselamatan. Modul pertama membolehkan pembuat keputusan untuk mengenal pasti tiga puluh tujuh risiko keselamatan yang telah dibangunkan dengan merujuk kepada literatur keselamatan dan maklumbalas daripada panel pakar Delphi. Di samping itu, modul yang dibangunkan turut mengenalpasti tujuh penyebab utama yang menghasilkan tiga puluh tujuh risiko keselamatan. Modul kedua terdiri daripada model membuat keputusan hibrid yang berasaskan kepada *Decision Making Trial and Evaluation Laboratory (DEMATEL)* dan *Analytic Network Process (ANP)* yang menganggarkan kemungkinan berlakunya tiga puluh tujuh risiko keselamatan daripada tujuh penyebab utama. Modul ketiga menilai dan menganggarkan risiko keselamatan dengan menggunakan dua kaedah ranking; *Analytic Hierarchy Process (AHP*) dan *VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR*). Prototaip HDSRA kemudiannya dibangunkan dengan mengintegrasikan modul 1, 2 dan 3 dan seterusnya dinilai oleh sekumpulan pakar perobohan. HDSRA berfungsi sebagai sumber maklumat yang boleh digunakan oleh kontraktor perobohan untuk mengenal pasti risiko keselamatan dengan cara yang sistematik. Ianya juga dapat mengurangkan kemungkinan berlakunya kesilapan dalam proses pengenalpastian risiko ketika kerja perobohan dilaksanakan. Prototaip ini turut menghasilkan satu sistem sokongan keputusan yang proaktif dengan mencadangkan tindakan yang perlu diambil oleh pakar keselamatan perobohan untuk mengawal risiko di tempat kerja. HDSRA juga boleh digunakan sebagai alat bantuan latihan untuk meningkatkan kesedaran keselamatan di kalangan pekerja perobohan.

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| | | |
|---|---|---|
| *AHP* | - | Analytic Hierarchy Process |
| *ANOVA* | - | Analysis of Variance |
| *ANP* | - | Analytic Network Process |
| *ARCTM* | - | Accident Root Cause Tracing Model |
| *BBS* | - | Behavioural Based Safety |
| *BOCR* | - | Benefit Opportunity Cost Risk |
| *BS* | - | British Standard |
| *CCA* | - | Cause Consequence Analysis |
| *CEO* | - | Chief Executive Officer |
| *CIDB* | - | Construction Industry Development Board |
| *CoCA* | - | Construction Accident Causality |
| *DEMATEL* | - | Decision Making Trial and Evaluation Laboratory |
| *DOI* | - | Degree of Influence Analysis |
| *DOSH* | - | Department of Safety and Health |
| *DSS* | - | Decision Support System |
| *EIS* | - | Executive Information Systems |
| *ERA* | - | Environmental Risk Assessment |
| *ETA* | - | Event Tree Analysis |
| *FMEA* | - | Failure Mode and Effect Analysis |
| *FTA* | - | Fault tree analysis |
| *GRRS* | - | Guided Rule Reduction System |
| *HAZOP* | - | Hazard and Operability Study |
| *HDSRA* | - | Hybrid Demolition Safety Risk assessor |
| *HIRARC* | - | Hazard Identification, Risk assessment and Risk Control |
| *HRA* | - | Human Reliability Assessment |
| *IRS* | - | Information Reporting System |
| *IS* | - | Information Systems |

| | | |
|---|---|---|
| *ISAS* | - | Independent Safety Audit Scheme |
| *ISM* | - | Interpretive Structural Modelling |
| *MCDA* | - | Multiple Criteria Decision Analysis |
| *MCDM* | - | Multiple Criteria Decision Methods |
| *MIS* | - | Management Information System |
| *MLID* | - | Canadian Labour and Immigration Division |
| *MS* | - | Malaysian Standard |
| *OHSAS* | - | Occupational Health and Safety Assessment Series |
| *OIS* | - | Operations Information Systems |
| *OSHA* | - | Occupational Safety and Health Act |
| *OSHA* | - | Occupational Safety and Health Administration |
| *PASS* | - | Performance Assessment Scoring System |
| *PSS* | - | Pay for Safety Schemes |
| *PHA* | - | Preliminary Hazard Analysis |
| *PPE* | - | Personal Protective Equipment |
| *PtD* | - | Prevention through Design |
| *QFD* | - | Quality Function Deployment |
| *RCA* | - | Root Cause Analysis |
| *RCM* | - | Reliability Centred Maintenance |
| *RIDDOR* | - | Reporting of Injuries, Diseases and Dangerous Occurrences Regulations |
| *RPN* | - | Risk Priority Number |
| *SDLC* | - | System Development Life Cycle |
| *SE* | - | Safety Education |
| *SMS* | - | Safety Management System |
| *SP* | - | Safety Performance |
| *SSC* | - | Site Safety Cycle |
| *SSSP* | - | Site Safety Supervision Plan System |
| *ST* | - | Safety Training |
| *TOPSIS* | - | Technique for Order of Preference by Similarity to Ideal Solution |
| *TQM* | - | Total Quality Management |
| *UK* | - | United Kingdom |
| *WORM* | - | Workgroup Occupational Risk Model |

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Research Background

Construction and demolition industries have historically been linked together. Although they are major contributors to economy, yet considered unsafe and risky (Tam *et al.*, 2004). Continual change, dynamic nature, hazard prone working environment, concurrent use of different resources and coordinating multiple contractors, sub-contractors and labors that may have different degree of expertise and safety attitude increase risk of injury (Pinto *et al.*, 2011). Researches show in United Kingdom (UK) where safety performance is better than many countries construction workers are five times more likely to be killed than all industry average (Carter and Smith, 2006). In Malaysia, the increasing number of fatal and non-fatal injuries from construction occupational accident is alarming (Chong and Low, 2014). Poor safety performance not only threatens human life; it has negative influence on economics. Therefore, continues efforts have been put to improve health and safety performance. Construction industry in Malaysia, where is going to become a developed country in 2020, shall be a world-class, innovative, and knowledgeable global solution provider. To achieve this vision seven strategic thrusts have been designed; striving for the highest standard of quality, occupational safety and health and environmental practices is one of them.

Considering rapid infrastructure development that Malaysia is experiencing, old buildings are being replaced by skyscrapers. This has resulted in more demolition works and a bright future for demolition contractors. However, demolition sector is yet immature when it is compared with the UK, US and other developed countries. Inadequate safety and poor environmental performance are the major weaknesses; an example of which is Jaya Supermarket collapse (Hussein, 2013; Ismail and Kasim, 2013; Zaini *et al.*, 2012). A tragic accident that grabbed attention of public sector and authorities. This unfortunate accident was a turning point in history of demolition work. The definition oriented view towards demolition works, "tearing down" rather than "built", changed when the first Malaysia's demolition code of practice was developed. Malaysian Standard (MS 2318:2012) is a good practice that aims to minimize risks of causing damage to properties, keep neighboring environment safe and improve safety of site personnel. It mainly covers technical aspects of demolition work and shows the steps should be taken in order to safely demolish structural elements. Additionally, it legally makes practitioners responsible of carrying our risk assessment throughout the work. However, no further information is given on how demolition risk assessment should be carried out or what technique should be used for the purpose of assessment.

## 1.2 Problem Statement

Occurrence of occupational accident in construction or demolition site is due to failure in interaction of four immediate accident causes namely work team, workplace factors, equipment and materials (GIBB *et al.*, 2006; Hide *et al.*, 2003). Risk assessment is part of construction or demolition safety plan that if get implemented carefully by decision maker, prevents occurrence of those failures. Unfortunately, risk assessment is considered burdensome document and submitted to authorities as a proof to comply with legal requirement; only to escape from government fines (Saurin *et al.*, 2004). In practice safety risk assessment in construction or demolition projects is limited to qualitative methods (e.g., Preliminary Hazard Analysis (PHA), checklists) (Liu and Tsai, 2012; Pinto *et al.*, 2011b; Pinto *et al.*, 2010). Using qualitative methods are simple but the information obtained from such methods is subjective (Liu and Tsai, 2012). On the contrary, quantitative methods (e.g., Fault Tree Analysis (FTA), Event Tree Analysis (ETA)) produce reliable results but hard to use (Liu and Tsai, 2012). These methods are the best alternative for assessing safety risks in static environments where rich risk data is easily available and accessible.

While construction and demolition works are project oriented, dynamic and unique, neither quantitative, nor qualitative methods of risk assessment seem to be a right choice for safety risk assessment (Liu and Tsai, 2012). The absence of systematic risk assessment method that not only produces reliable results, but also be simple and supported by strong methodology is considered a major problem. Taking into account the above limitations, this research proposes a semi-quantitative method for demolition safety risk assessment.

There are several formal semi-quantitative risk assessment methods. Failure mode and effect analysis (FMEA) is one of them. Although it is primarily a manufacturing quality assessment tool, it can be used as safety risk assessment tool in construction industry (Zeng *et al.*, 2015; Liu and Tsai, 2012; Abdelgawad and Fayek, 2010). However, this technique is not free from limitation. Over the last decade, a lot of research works have been conducted to improve FMEA. Among which using fuzzy set theory is worth mentioning. The latest method to improve FMEA is employing Multiple Criteria Decision Making (MCDM) methods. There are many MCDM methods available that can be used to solve FMEA limitations. Selecting the most appropriate method is a key contributing factor to the body of knowledge. This research however, proposes a hybrid solution that integers multiple MCDM methods in order to overcome conventional limitations associated with FMEA which ultimately make it more suitable and usable for assessing safety risks associated with demolition works.

## 1.3 Research Aim and Objectives

The aim of this research is to improve safety performance at demolition site. By developing a semi-quantitative risk assessment tool that identify, analyze and evaluate demolition safety risks. In this regards four objectives are designed.

- To identify demolition safety risk factors

- To determine available causal relationship among the safety risk factors

- To develop a safety risk assessment Decision Support System (DSS) that named Hybrid Demolition Safety Risk Assessor (HDSRA)

- To evaluate suitability and usability of Hybrid Demolition Safety Risk Assessor

## 1.4 Scope of Research

This research specifically focuses on demolition safety risks and does not cover health hazards. Based on the definition of risk assessment, identification, analysis and evaluation of safety risks are covered in this work; types of controlling measures that should be used and how they should be implemented are beyond the scope of this research. This research also focuses on full demolition and does not cover partial demolition or renovation works.

## 1.5 Research Justification

Improving construction and demolition safety record needs collaborative involvement of different parties such as authorities, client, consultant and contractor. In the absence of a special tool for demolition safety risk assessment, demolition contractors use unstructured and non-systematic risk assessment methods at site. These methods solely rely on experience and knowledge of risk assessor. In large scale projects especially when number of safety risks increases risks assessment which is considered a decision making process will be a complex task. Human brain with the aid of unstructured method may not successfully make a right decision; this includes risk identification, risk analysis and risk ranking. When risk assessment produces unreliable results, the controlling measures that should be put in place to prevent occurrence of safety accident may not be efficient. This finally imposes risk to human life and causes losing money. Therefore, there is a need to develop a decision support system that identify, analyze and rank demolition safety risks.

## 1.6 Research Framework and Thesis Layout

In line with Figure 1.1 which presents framework of research, this thesis is written in seven chapters.

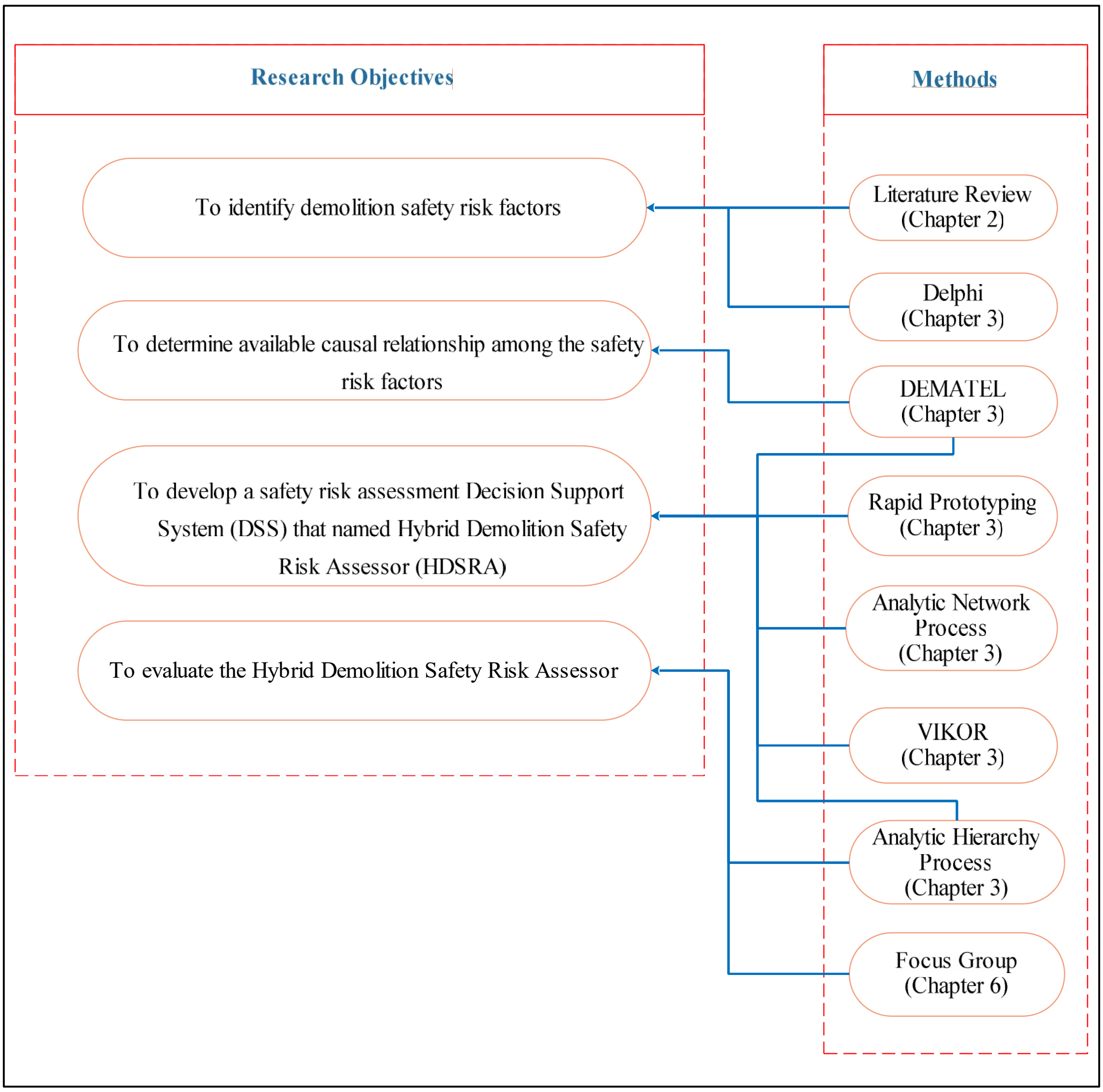


**Figure 1.1 :** Research Framework

Chapter 1, Introduction, introduces research background, problem statement, aim, objectives, scope of research, justification and thesis layout.

Chapter 2, Literature Review, presents safety and risk assessment literatures. In this chapter industrial and construction accident causation theories are presented to understand those causes that trigger occurrence of demolition safety risks. This chapter also aims to identify what accident may occur at demolition site. DSS is another issue that together with DSS development tools, techniques and DSS evaluation strategy are addressed in this chapter.

Chapter 3, Research Methodology, focuses on research methodology. It shows the process through which the four research objectives are achieved. Design and functional architecture of DSS are presented in this chapter. They are the road map that shows how researcher develops HDSRA. This chapter also presents prototype evaluation method that is adopted to verify and validate HDSRA.

Chapter 4, Data Collection and Analysis, presents Delphi and DEMATEL data collection and analysis strategy. In this chapter those accidents that occur in structural demolition environment are verified. In addition, this chapter determines the causal relationships among demolition safety risks factors.

Chapter 5, Prototype Design and Development, presents how researcher designs architecture of HDSRA with the aid of AHP, ANP, DEMATEL and VIKOR; and how this architecture is converted into a functional prototype.

Chapter 6, Prototype Evaluation is all about DSS evaluation. An evaluation toolkit is developed in this chapter and HDSRA with the aid of this toolkit (HDSRA-Evaluator) in focus group is evaluated. The strengths and weaknesses of system prototype are identified in this chapter. The results of this chapter are used to improve prototype.

Chapter 7, Conclusion and Recommendation closes the thesis by presenting research findings, research contributions, limitations of research and opportunities for future research.

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