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The Use of Construction Images in A Safety Assessment System

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Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made.

Signature: ……………………………

Date: ……………………………

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High above all be Allah, the King, the Truth! be not in haste with the Qur'an before its revelation to thee is completed but say, "O my Lord! Advance me in knowledge".

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LIST OF PUBLICATIONS

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Abstract

This thesis sets out research carried out to investigate the usefulness of a descriptive database of construction methods for safety assessment. In addition, it investigates the possibility of utilising construction images as sources of safety related information.

The construction industry has been recognized as a hazardous work environment with a high accident rate for years, hence, site safety is a problem. Nowadays, the use of construction images in the form of photographs is commonplace and they are used as sources of information. The literature review reveals that they have never been used as sources of information concerning construction safety practice.

A preliminary investigation is conducted to study the possibility of utilizing construction images as sources of safety related information. The findings revealed that it is possible to use construction images as sources of information for construction safety assessment however, there were problems related to image interpretation and dissimilar safety judgment. It was assumed that those problems were arising from lack of safety knowledge and experiences, also no safety assessment method existed that could be used when using images as sources of information.

To overcome problem related to the existence of safety assessment method, the research developed a method to assess safety by using information observed from images. As a similar safety judgment would be obtained from a same guideline therefore, a safety guideline was established, including safety checklist and safety scores. To give meaning of sets of safety score, two methods of conditional probability approach from Artificial Intelligence that quantitatively deal with uncertainty, the Bayes' Theorem and the Fuzzy Logic Theory, were employed. The

Bayes' Theorem formula was adopted for calculating a likelihood of a hypothesis being true based on evidence or *P(H/E)*. The hypothesis used in this research that a safe construction practice being used. The evidence used to test this hypothesis is information collected from construction images. This method allows construction practices shown in the images to be defined as having a high level of safety or low level of safety.

The construction practices with low level of safety do not need to analysed further. Fuzzy logic theory can then be used for further classifying those images identified as having a high level of safety into one of three classifications: "most likely safe", "fairly safe" or "most likely unsafe".

To overcome problem related to lack of safety knowledge and safety experience, one method of reasoning based on reuse past experience was employed, called the Case-Based Reasoning (CBR). The CBR method will allow safety information stored in database to be reused for reasoning process to give safety scores. As CBR works based on stored information from database therefore an image database has to be developed.

Following works (or researches) have been done to overcome problems revealed from preliminary investigation therefore those works have to organize in a structured and systematic system. The research was developed a safety assessment system called SAFE AS.

The safety assessment system worked in two processes, manual calculation and information storage into database. Manual calculation worked as follows: First, a construction practice judgment is given based on image data, safety checklist and using safety scores provided. Secondly, a construction practice is defined into one of two definitions provided: a high-level and a low-level of safety based on Bayes' Theorem formula and given safety scores. Third, a high-level of safety of construction practice is classified into one of three classifications: most likely safe, fairly safe and most likely unsafe, which are developed, based on fuzzy sets formula. Following manual calculation process, the result from the process then become an input for the second process: information storage. All information of images and their safety practices are stored in an image database. These two processes are done separately and manually.

Problem is arising from manual safety assessment system, that the processes are time-consuming. To overcome this problem, even to make a safety assessment system practically more benefit, the system is developed in a Web-based system, which allows safety assessment process and information storage process done comprehensively and automatically. All users can share their safety knowledge and experiences, and reuse stored experience as a basis of reasoning process from anywhere.

As a result, the research has developed a Web-based safety assessment system to show how to utilize construction images to assess safe construction practice, store information from assessment process, and reuse this information for safety knowledge enhancement. Two experiments using 69 images and a set of detailed images have confirmed the application of a Web-based safety assessment system and verified its reliability.

Another benefit from the safety assessment system is the safety likelihood scores obtained, which can be used to detect safety trends that are developing in construction project over time. These trends were used to predict the likely safety of the construction practices in use on the project in future so it can be used as indicators to monitor and control safety in construction projects. With this process construction images can be used as sources of safety related information and the safety assessment system can be used in future for predicting, monitoring and controlling of on-site safety.

Areas needing future research are suggested, including providing advance search features in the assessment system to retrieve closer relevant cases for case-based reasoning and automated hazard recognition and identification feature to avoid accident occurrence as the result of human carelessness.

Chapter 1

INTRODUCTION

1.1. An Introduction to Construction Safety Research

All over the world, safety has always been a major issue and often a problem, especially in construction industries, where the working environment is constantly changing. Sites exist for a relatively short time and the activities and inherent risks change daily. Within a short time of a hazard being identified and dealt with, the work scene can change, bringing new hazards. Due to its nature, construction is one of the most dangerous industries, thousands of people are often killed, large numbers of people suffer disabling injuries and loss of properties can also be significant.

Xia et al. (2000) reported that there were 207 fatal work-related events in the construction industry in East Pujiang New Area (EPNA) in the 7-year period 1991-1997 result in the deaths of 235 workers, and more than half (55%) of all occupational deaths occurred in the construction industry. Report from the United States also quotes the number of construction fatalities was nearly one-fifth of all industrial fatalities in 2000 (BLS, 2001).

Recent statistical records in Australia, during the period 2006-2007, reveal the incidence rate for the construction industry is 22.1 per 1000 employees (NOSI, 2008). In the United Kingdom, for the period of 2007-2008, construction had the largest number of fatal injuries (3.4 per 100.000 workers) and the highest rate of major injury (599.2 per 100.000 workers) of the main industry groups (HSE, 2008). These accident figures at construction sites gained industry-wide attention.

An accident itself is an unexpected event in sequence of events that occurs through a combination of causes; it usually results in physical harm, injury, damage, a near miss, or loss, or any combination of these effects as stated by Bamber (Ridley and Channing, 1999). On the other hand, safety is the action of keeping safe and freedom from the occurrence of a risk of something bad and also personal harm. Safety is the outcome of processes designed to prevent the occurrence of accidents, injuries or avert danger as well. Therefore to be safe or keep free from the occurrence of a risk of accidents, injuries and danger, a good safety management system is needed.

1.2. Background

An increase in accident occurrences has raised awareness of the need for a system to manage construction safety. Accidents result from different causes. Kartam (1997) stated that these could generally be classified as physical incidents posing hazardous situations and behavioral incidents caused by unsafe acts. Toole (2002) stated that construction accidents are associated with unsafe conditions and this implies deficient safety management.

Unsafe conditions, such as a hazardous project environment or improper attitudes of personnel, are often not detected before an accident occurs. Unfortunately, as stated by Lee and Halpin (2003), very little research has focused on the assessment of accident potential before the consequents are apparent. There is a need to detect unsafe conditions before an accident occurs, therefore is necessary for safety hazard recognition to be undertaken before and during construction.

All construction projects need safety management on site. Like other management constraints (cost-time-quality), safety needs to be planned, organized, monitored, and controlled. In recent years, many countries have experienced the integration of computers into safety control programs.

Some researchers (Hadikusumo and Rowlinson, 2002; Whitaker et al., 2003; Arboleda and Abraham, 2004) have been using computerized database for developing models to control construction site safety. Most of the database work on construction site condition information is generated from 3-dimensional virtual models and paper-based incident files. These studies have been demonstrated to be useful to help predict problems that may occur during the actual construction. However, it is difficult to present realistically the actual situation on a site. Exact information of the situation after the beginning of the construction phase is indispensable for proper construction control (Kim and Kano, 2008). Therefore, more studies need to be conducted to create construction safety control using sources of information that are able to record real situations on construction sites.

1.3. Problem Statement and Research Objectives

Accident statistics play an important role in measuring safety performance. However, they are based on actual accident data and the compilation of post accident information. Post accident data provide facts that are not necessarily helpful in predicting accidents or assessing accident risk. Lack of accidents does not mean there is no risk of one occurring, rather, there is a need to estimate the risk level of accidents based on current safety practices (Lee and Halpin, 2003).

Learning from mistakes, successes in preventing accidents, and identifying potential hazards are important aspects of safety work. Efforts to improve safety on construction sites can take many forms and the builder has traditionally implemented safety hazard mitigation measures during the construction phase. Many believe that additional action can and should be taken throughout the project’s phases (Hacker et al., 2005).

In recent years, construction information in the form of photographic images has increasingly been used as a source of information in the study and control of construction practices. In particular, they have been used for some time to provide information concerning the methods used, progress, damage, and the condition of the site (Brilakis and Soibelman, 2005; Brilakis et al., 2006; Memon et al., 2007; Brilakis et al., 2008).

Recently, research was conducted to study the possibility of obtaining information that represents construction concepts from construction images (Mursadin, 2008). It revealed that using the proposed approach retrieved information could be presented from a structure to enable future uses such as image retrieval and knowledge discovery. Some areas for future research have been suggested including the use of retrieved information for assessing construction operations.

Building on these ideas, the aim of this research is to investigate the usefulness of a descriptive database to be used for construction safety assessment, which will contain data such as photographic images, project names, and other data related to safety issues. The objectives of the research are as follows:

1. To investigate the potential used of construction images as data to assess safety.
2. To develop a safety assessment system using construction images as a source of information.
3. To develop a Web-based safety assessment system for automated safety assessment system.
4. To demonstrate the application and use of the developed safety assessment system.

These objectives are discussed and justified in Chapter 2, sections 2.5 and 2.6.

1.4. Scope of The Research

The intention of this research is to propose a system of construction safety assessment using photographic images of construction sites. In order to demonstrate the validity and reliability of the safety assessment system, sets of three construction activities images from four construction projects with different type have been used to demonstrate the applicability of the assessment system in which will be applicable for most other construction activities and project types.

1.5. Significance of The Research

Construction sites are hazardous environments, either things are being constructed or the environmental hazards. Based on that reality, it is important to make good and sound decisions about the construction methods chosen for projects. To avoid any increased potential of accident occurrence, project management must choose safe construction methods. These research findings will have significant value in contributing positively to this process. The first benefit is this research will develop a descriptive database that contains construction images with descriptions such as activities, safety level, safety class, hazard identification, and solutions of identified hazard. This database has been developed in a Web-based system to allow users to update information at their own workplace.

The second benefit is the sources of information used are construction images in which provide virtual real conditions of construction site. Every single case consists of construction image and description stored in the database that can be used to enhance safety knowledge of everyone who uses it. The more safety knowledge that people have, enable them to perform safer acts on construction sites and that can reduce accident occurrence.

The third benefit is this research has produced a method using construction images as sources of information that can be used to assess the safety of construction methods and give feedback on the effectiveness of safety processes. Result from the process also can be used to detect safety trends that may develop over time. Further, existing safety trends can be used to predict future safety to monitor and control safety in construction projects.

Finally, as an accident is an unexpected event that disrupts normal work leading to unwanted and undesirable outcomes including injury, damage, loss of property or life, the final expectation from this research is it may help reduce accident occurrence and save human lives.

1.6. Limitations of The Research

Despite the significance of this research, the demonstration of the safety assessment system application only uses a limited number of construction images as data. First, in the early stages, images were taken directly from construction sites or indirectly from several sources without any limitation regarding activity or a type of project. These images were used in the preliminary investigation.

Second, a number of these images were then used to demonstrate an application of the developed safety assessment system, including assessing construction practice for every image and storing the results into a database.

Third, after verifying a very limited number of construction images, a larger number were taken directly on a weekly basis from four construction sites to be used as data for the safety assessment system application.

Fourth, a set of construction images of one particular activity from one particular construction site was then used to demonstrate the application of the refined assessment system.

Overall, although the sites and construction activities included in the research were necessarily limited, these sampling procedures are deemed sufficient to demonstrate the applicability and the reliability of the system.

1.7. Thesis Outline

The thesis outline will give brief introduction to the chapters of this thesis is as follows:

Chapter 1 describes the background of the research, states its problems, scope, significance, and limitations.

Chapter 2 reviews images as a source of construction information and presents current safety-related information available for use on construction projects. This review includes the definition and the history of accidents and safety, theories of accident causation, a brief review of construction projects, management information systems, and studies carried out on construction project safety. The research objectives are developed and described.

Chapter 3 develops a research methodology that includes the compilation of relevant knowledge, preliminary investigation, data collection, the development of data analysis tools and data analysis.

Chapter 4 explains how construction images can be used as a source of information. The preliminary investigation used to study the concept of utilizing construction images is presented. Methods to overcome problems are also described. At the end of the chapter, the proposed approach to interpret information from construction images is described

Chapter 5 demonstrates the safety assessment system using the methods described in previous chapter and its results and problems are also discussed.

Chapter 6 explains the development of a Web-based safety assessment system, starting with a brief history of Active Server Pages; followed by Web-based database application architecture and the development of the system.

Chapter 7 describes the application of the safety assessment system (SAFE AS), describes and discusses a refined system that uses more detailed images, explains and discuss the use of the safety assessment system result, and discusses the use of the safety assessment system (SAFE AS) for monitoring and controlling project safety and for case-Based Reasoning. Areas of future research are suggested.

Chapter 8 concludes the research outcome based on the research objectives and makes recommendations for future research.

More detail explanation of the thesis will be given in following chapters with reference to the thesis outline.

Chapter 2

A REVIEW OF CONSTRUCTION IMAGES AS SOURCES OF INFORMATION IN CONSTRUCTION PROJECTS SAFETY

2.1. An Introduction to Construction Images as Sources of Information in Construction Project Safety

Chapter 1 outlined the background, research problems and objectives, scope, significance, limitations, and the organisation of the thesis.

This chapter is designed to critically review and explore the following issues:

a) The literature, theories, and written research on the concept of safety and accident causation.
b) A review of construction project management and safety.
c) A management information system.
d) An image as a source of construction-related information.

Issues related to the literature, theories, and research written on the concept of safety and accident causation is explained in several sections as follows.

Section 2.2 describes frequently used definitions for safety and accidents and gives a brief history of safety and accident causation with regard management approach also summarises of studies that have been done on accident causation. Section 2.3 mentions an overview of construction projects, studies that have been done on construction safety including construction accident causation and improve safety on construction project, and a critique of construction safety. Section 2.4 explains safety management and safety management information system, taking into account these issues: monitor and control as a function of safety management, construction safety management information system, an image as a source of construction related information. Section 2.5 gives an overview of the literature, leading to development and justification of the objectives of the research in section 2.6. Section 2.7 draws conclusion on construction images as sources of information in construction safety. All issues are briefly explained in the following sections.

2.2. Safety and Accidents – Definition and Brief History

The main purpose of safety is to reduce, ideally to zero, the number of accidents. In establishing what the practice of safety means and what the relationship between safety and accident, a clear understanding of the terms "safety" and "accident", and the history of accident causation needs to be realised. The following sub-sections define safety and accidents and briefly describe the history of accident causation.

2.2.1. Definitions of Safety and Accidents

The terms safety and accident, often poorly defined, are used interchangeably, however, they have very different meanings. The following definitions are presented:

> Safety is to be "safe" or free from something related with health problem. Safety is also to be "safe" or protected from personal harm. An accident is some occurrence that disrupts the flow of normal interactions and relationships. An accident may result in injury, property damage, or death (Miller, 1982)
>
> Safety is a freedom from danger of risks, including the danger of physical injury and to the risk of damage to health over a period of time (Davies and Tomasin, 1990)
>
> Safety is a state for which the risks are judged to be acceptable (Manuele, 1993)
>
> An accident is an unplanned and uncontrolled event in which the action or reaction of an object, substance, person, or radiation results in personal injury or the probability thereof (Heinrich, 1980)

> An accident is some occurrence that disrupts the flow of normal interactions and relationships, which may result in injury, property damage, or death (Miller, 1982)
>
> An accident is an event that is without apparent cause or is unexpected; an accident is also an unintentional act, chance, misfortune, especially one causing injury or damage (Viner, 1991)
>
> An accident is an unexpected event in sequence of events that occurs through a combination of causes; it usually results in physical harm, injury, damage, a near miss, or loss, or any combination of these effects as stated by Bamber (Ridley and Channing, 1999).
>
> An accident is a short, sudden, and unexpected event or occurrence that results in an unwanted and undesirable outcome (Hollnagel, 2004)

From these definitions, it can be seen that "safety" and "accidents" have many meanings. Safety is the state of being safe, freedom from the occurrence of a risk of something bad and also personal harm. Safety is the action of keeping safe and safety is a contrivance or device to prevent injury or avert danger as well. On the other hand, an accident is an unexpected event that disrupts the normal sequence of events that may result in an unwanted and undesirable outcome including injury, damage, or loss of property or life. However, in reality, an accident is caused, it does not just happen. Thus by finding the cause, steps might be taken to prevent it.

This fact is strongly supported by Heinrich who states that an accident that results in injury is largely preventable. Safety is a mechanism to prevent its occurrence. For that purpose, accident causation models attempt to understand the factors and processes involved in accidents in order to develop strategies for their prevention (Mitropoulos et al., 2005).

Previous researchers have stated that accident prevention requires a comprehensive understanding of their cause (Suraji et al., 2001). They stated that to prevent an accident, it is important to analyse the sequence of events and underlying causes the same accident frequently occurs from the same cause.

David Hume argued that the concept of causality is a complex one and that it involved three components (Hollnagel, 2004): the first is that the cause must be prior in time to the effect, the second is cause and effect must be contiguous in time and space, and thirdly there must be a connection i.e., that there is a constant coincidence of cause and effect such that the same cause always has the same effect.

From these two studies, it can be stated that in explaining accident causation, two questions need to be addressed: how do accidents happen? and why do accident happen? The answers to the "how" question are concerned with an accident and circumstances preceding it. The answers to the "why" question are concerned with identifying the root causes.

To really understand these two questions, it is important to know something of the history of safety concerns and accident causation. In the following section (section 2.2.2) these two factors will be addressed.

2.2.2. Studies on Accident Causation, The Management Approach

In his book *Techniques of Safety Management.* New York: McGraw-Hill Book Company (Petersen, 1978) Petersen describes the history of safety and mentions that industrial safety history should be considered from 1911. Awareness of industrial safety before 1911 was practically nonexistent with no workmen's compensation laws. All industrial injuries were handled under common law that stated that management in industry would not pay for any accidents occurring on the job. In 1911, in the United States of America, the Wisconsin law was held to be constitutional and this move was then followed by all other states, the last being enacted in 1947. These laws require management to pay for injuries on the job. Since then, management has been motivated to prevent accidents from happening. Thus giving birth to organised industrial safety programmers.

Abdelhamid et al. (2000) mentioned the research of Heinrich in accident causation as follows. In 1930, Heinrich pioneered research in accident causation theory discussing it with regard to the interaction between man and machine, the relation between severity and frequency, the reason for unsafe acts, the management role in accident prevention, the costs of accidents, and finally the effect of safety on efficiency. In addition, he developed a domino theory in which an accident is presented as one of five factors in a sequence that results in an injury.

Following the work of Heinrich, many other researchers have tried to understand accidents by introducing accident causation models. Recently several have been introduced. According to Mitropoulos et al. (2005), some of the most influential accident causation models and methodologies are: the Single Event concept, the Determinant Variable concept, the Domino Theory, the Fault Tree analytical methodology, the Energy-Barriers-Targets model, the Management Oversight and Risk Tree, the Multiple Causation model by Petersen, and two models proposed by Reason's the 'Swiss Cheese' model of human error and the 'resident pathogens' or 'latent failures'. The differences between those models are basically based on different perception of the accident process.

From the accident causation models in Mitropoulos et al. (2005), two are based on management approach, the Domino Theory and the Multiple Causation Model. This research later will only discuss accident causation models that are based on the management approach, starting with an explanation of the Domino Theory and the Updated Domino Sequence, then follows an explanation of the Multiple Causation Model, and finally a discussion of recent studies on accident causation in the construction industry will be presented.

a. The Domino Theory and The Updated Domino Sequence

The fundamental concept of safety can be traced from Herbert W. Heinrich's research. In 1931 the first edition of his book, *Industrial Accident Prevention*, was published (Petersen, 1978) in which he proposed the idea of accident causation from physical conditions to unsafe acts. Heinrich expressed the phenomenon in this way (Petersen, 1978):

> The occurrence of an injury invariably results from a completed sequence of factors, the last one of these being the injury itself. The accident, which caused the injury, is in turn invariably caused or permitted directly by the unsafe act of a person and/or a mechanical or physical hazard.

Heinrich's philosophy stated "people, not things, cause accidents". Heinrich began work on the Domino Theory when he and his colleagues at the Travelers Insurance Company analysed 75,000 cases of accidents and reported that unsafe acts were the cause of 88 percent of all accidents. Unsafe conditions contributed to only 10 percent of them, while the remaining cases were unavoidable (Petersen, 1978; Heinrich, 1980; Viner, 1991).

Furthermore, utilising the data that was combined with industrial safety axioms presented in Table 2.1, Heinrich developed the first theory of accident causation by picturing this accident sequence as a series of five dominoes standing on edge. It has become known as the Domino Theory of accident causation.

The Domino Theory postulates that as the first domino is toppled over, it will knock down the other four dominoes, unless at some point a domino has been removed to stop the sequence. This model suggested that through inherited or acquired undesirable traits, people may commit unsafe acts or cause the existence of mechanical or physical hazards, which in turn cause injurious accidents (Abdelhamid et al., 2000).

Table 2.1 Heinrich's Theorems of Axioms of Industrial Safety

1. The occurrence of an injury invariably results from a completed sequence of factors – the last one of these being the accident itself. The accident in turn is invariably caused or permitted directly by the unsafe act of a person and or a mechanical or physical hazard
2. The unsafe acts of persons are responsible for a majority of accidents.
3. The person who suffers a disabling injury caused by an unsafe act, in the average case has had over 300 narrow escapes from serious injury as a result of committing the very same unsafe act. Likewise, persons are exposed to mechanical hazards hundreds of times before they suffer injury.
4. The severity of an injury is largely fortuitous – the occurrence of the accident that results in injury is largely preventable.
5. The four basic motives or reasons for the occurrence of unsafe acts provide a guide to the selection of appropriate corrective measures.
6. Four basic methods are available for preventing accidents – engineering revision, persuasion and appeal, personnel adjustment, and discipline.
7. Methods of the most value in accident prevention are analogous with the methods required for the control of the quality, cost, and quantity of production.
8. Management has the best opportunity and ability to initiate the work of prevention: therefore it should assume the responsibility.
9. The supervisor or foreman is the key man in industrial accident prevention. His application of the art of supervision to the control of worker performance is the factor of greatest influence in successful accident prevention. It can be expressed and taught as a simple four-step formula.
10. The humanitarian incentive for preventing accidental injury is supplemented by two powerful economic factors: (1) the safe establishment is efficient productively and the unsafe establishment is inefficient, (2) the direct employer cost of industrial injuries for compensation claims and for medical treatment is about one-fifth of the total cost which the employer must pay.

Source: Heinrich, H. W. (1980), *Industrial Accident Prevention: A Safety Management Approach,* New York: McGraw-Hill Book Company

The labels of the dominoes presented by Heinrich, the five sequential accident factors are: ancestry or social environment, fault of a person, unsafe act or condition, accident, and injury. These factors and their explanations are presented in Table 2.2.

Table 2.2 Accident Factors in Heinrich's Domino Theory of Accident Causation

Accident Factors	Explanation of Factors
1. Ancestry and social environment	Recklessness, stubbornness, avariciousness, and other undesirable traits of character may be passed along through inheritance. Environment may develop undesirable traits of character or may interfere with education. Both inheritance and environment cause faults of person.

Table 2.2 Accident Factors in Heinrich's Domino Theory of Accident Causation (continued)

Accident Factors	Explanation of Factors
2. Fault of a person	Inherited or acquired faults of person, such as recklessness, violent temper, nervousness, excitability, inconsiderateness, ignorance of safe practice, etc., constitute proximate reasons for committing unsafe acts or for the existence of mechanical or physical hazards.
3. Unsafe act and/or mechanical or physical hazard	Unsafe performance of persons, such as standing under suspended loads, starting machinery without warning, horseplay, and removal of safeguards; and mechanical or physical hazards, such as unguarded gears, unguarded point of operation, absence of rail guards, and insufficient light, result directly in accidents.
4. Accident	Events such as falls of person, striking of persons by flying object, etc., are typical accidents that cause injury.
5. Injury	Fractures, lacerations, etc., are injuries that result directly from accidents.

Source: Heinrich, H. W. (1980), *Industrial Accident Prevention: A Safety Management Approach*, New York: McGraw-Hill Book Company

According to Heinrich (1980) in his book "*Industrial Accident Prevention: A Safety Management Approach*", the explanation of accident factors presented in Table 2.2 as sequential domino is as follows:

First domino: *Ancestry and social environment*: If people are born with and/or are socialised to develop faulty personal characteristics such as recklessness, stubbornness, avariciousness, etc

Then

Second domino: *Fault of a person*: Result either inherited or acquired, such as recklessness, violent temper, nervousness, excitability, inconsiderateness, ignorance of unsafe practices, etc and these are proximate reason for committing unsafe acts or for the existence of mechanical or physical hazards

And

Third domino: *Unsafe act,* such as standing under suspended loads, starting machinery without warning, horseplay, removal of safeguards, *and/or mechanical or physical hazard*, such as unguarded gears, unguarded points of operation, absence of rail guards, insufficient lights

Resulting directly in

Fourth domino: *Accidents* that are events such as falls of persons, striking of persons by flying objects, etc

And

Fifth domino: It will cause an i*njury*, such as fractures, lacerations, etc.

Obviously, it is easiest and most effective to remove the centre domino – the one labeled "unsafe act or condition", as this factor statistically caused 98 percent of all accident. Table 2.3 lists the unsafe acts and conditions identified by Heinrich.

Table 2.3 Unsafe Acts and Conditions Identified by Heinrich

Unsafe acts of persons	Unsafe mechanical or physical conditions
1. Operating without clearance, failure to secure or warn.	1. Inadequately guarded, guards of improper height, strength, mesh, etc.
2. Operating or working at unsafe speed.	2. Unguarded, absence of required guards.
3. Making safety devices inoperative	3. Defective, rough, sharp, slippery, decayed, cracked, etc.
4. Using unsafe equipment, or equipment unsafely.	4. Unsafely designed machines, tools, etc.
5. Unsafe loading, placing, mixing, combining, etc.	5. Unsafely arranged, poor housekeeping congestion, blocked exits, etc.
6. Taking unsafe position or posture.	6. Inadequately lighted, sources of glare, etc.
7. Working on moving or dangerous equipment.	7. Inadequately ventilated, impure air source, etc.
8. Distracting, teasing, abusing, startling, etc.	8. Unsafely clothes, no goggles, gloves or masks, wearing high heels, etc.
9. Failure to use safe attire or personal protective devices	9. Unsafe processes, mechanical, chemical, electrical, nuclear, etc.

Source: Viner, D., (1991), *Accident Analysis and Risk Control*, Victoria: VRJ Delphi

It is clear that the Domino Theory is logical makes and sense, is easy to understand, and also has a very practical and pragmatic approach. The occurrence of a preventable injury is the natural culmination of a series of events which occur in a fixed and logical order. One is dependent on another and one follows because of another. If this sequence is interrupted by the elimination of even one of the several factors that constitutes it, the injury cannot possibly occur.

Over the years efforts have been made to update the Domino Theory with an emphasis on management as the primary cause of accidents and it is known as the updated domino sequence model, recognised as accident causation management models. Abdelhamid et al. (2000) stated that management models hold management responsible for accidents and the models try to identify failures in the management system.

b. The Updated Domino Sequence Model

A first effort to update domino sequences was presented by **Frank Bird, Jr**. in 1974. He discussed the factors in several of his publications explaining the five key losses of control factors in order of the five dominoes were lack of control by management, basic cause, immediate cause, the accident, and the loss (Heinrich, 1980).

Bird stated that ***lack of control of management*** involves: (1) the identification of the "work" activities in the program, (2) the establishment of "standards" for management's performance in each work activity identified, (3) "measuring" management performance by the established standards, and (4) "correcting" performance by improving and or expanding the existing program.

In effect, the absence of highly reliable control system will permit the existence of personal and job-related factors referred to as the ***basic or underlying causes*** of accidents. These include lack of knowledge or skill, improper motivation, physical or mental problems for personal factors, inadequate work standards, inadequate purchasing standards, and abnormal usage for job-related factors.

The existence of basic causes of accidents then leads to **an immediate cause of an accident**. Examples of immediate causes refer to unsafe acts or conditions and are recognised as the most important factor to attack. However, in reality, the immediate cause is usually only a symptom of the deeper underlying problem. If the manager only recognises the symptom and does not identify the basic underlying problem, the result will not optimised the potential for permanent control, and accidents will remain potentially occur.

An ***accident*** is describes as an undesired event, "contact" with a source of energy (electrical, chemical, kinetic, thermal, ionising, radiation, etc) that results in physical harm, injury, and property damage. The word "injury" has been used to describe ***loss*** results that terminate in personal physical harm of a variety of types. The word "damage" used in this factor of the sequence is intended to cover all types of property damage, including fire.

Edward Adams offered a second update of the domino theory in 1976. He stated the accident sequence which was similar to the updated domino sequence of Frank Bird in which he explained that the 4^{th} and 5^{th} dominoes remain essentially the same. The immediate cause of the accident in Bird's domino sequence, or the 3^{rd} domino, has been re-titled "Tactical Errors" to draw attention to the nature of unsafe acts and unsafe conditions within the management system to draw attention to the nature of the decisions and work involved in their identification and correction.

The major contribution of this management theory lies in the redefinition of the causes underlying the tactical errors of employee's behaviour and work conditions are seen as arising from "Operational Errors" made by managers and supervisors. This is the 2^{nd} domino. These errors derive from the "Management Structure": the objectives of the organisation, how the management work is organised, and how operations are planned and carried out. This is the 1^{st} domino. In this updated theory, the priorities, the standards, and the guidelines for manager and supervisor behaviour were established.

D. A. Weaver (1971) has provided the third update of the domino theory explaining the concept of operational errors and symptoms in which the cause and corrective action in supervisory-management practice a combination of two sets of ideas: the idea of locates and defining operational error and the idea of domino format. This mating produces the principle that accident and injuries, as well as unsafe acts and unsafe conditions, are all symptoms of operational error. The input of safety technology and immediate correction are still achieved by identifying unsafe acts and unsafe conditions.

In identifying unsafe acts and unsafe condition, the "what-why-whether" process was introduced. The first question is: "What are unsafe acts and/or conditions?" In terms of safety technology, a reply was received, but for the term "operational error", two further questions should be addressed: "Why were the unsafe acts and/or conditions permitted?" and "Did supervisory-management have safety knowledge to prevent the accident?" The "why" question asks why knowledge was not effectively applied, and the "whether" question asks whether the laws, codes, and standards applicable to the circumstances were known.

From this explanation of the Domino Theory and the Updated Domino Sequence, it can be summarised that although people are the fundamental reason behind accidents management has the ability to control and responsible for their prevention. These two factors will be considered to carry forward in this research.

Besides the Domino Theory and the Updated Domino Sequence, Dan Petersen has presented another model of accident causation. He introduced a management non-domino-based model in his book "*Technique of Safety Management*" in 1971. He believes that behind every accident there lie many contributing factors, causes, and sub-causes, which combine in random fashion, causing accidents, a model he named a Multiple Causation Model which will be briefly explained as follows:

c. The Multiple Causation Model

Petersen presented his thoughts on the accident causation model in 1971 quoting a good example of the use of the Multiple Causation model for investigating a person falling off a stepladder in contrast to the use of the Domino Theory for doing so. In the Domino Theory Petersen concludes that:

a) There is the unsafe act: climbing a defective ladder
b) There is the unsafe condition: a defective ladder
c) There is the correction: getting rid of the defective ladder

Under the Multiple-Causation Model, however an investigator will make every effort to ascertain all contributing factors and causes by asking a series of questions, such as:

a) Why was the defective ladder not found in normal inspection?
b) Why did the supervisor allow its use?
c) Didn’t the injured employee know he shouldn’t use it?
d) Was he trained properly?
e) Was he reminded?
f) Did supervision examine the job first?

The answers to these and other questions can lead to these kinds of correction:

a) Improved inspection procedures
b) Improved training
c) A better definition of responsibilities
d) Pre-job planning by supervisors

Petersen asserted that trying to find unsafe acts or conditions, or the “proximate cause” deals only at symptomatic level and he emphasized that root causes, or the “immediate cause”, must be found to effect permanent improvement. He indicated that root causes often relate to the management system and may be due to management policies, procedures, supervision, effectiveness, training, etc. Root causes would effect permanent results when corrected, would affect the single accident being investigated and many other future accidents and operational problems.

It can be thus stated that the root causes of accident occurrence are related to lack of management involvement and lack of safety knowledge. It also can be seen from justification of the Multiple Causation Model that this model provides a new approach in accident causation research that behind every accident there lie many contributing factors, causes, and sub-causes. These factors combine in random fashion causing accidents. The two root causes indicated from the Multiple Causation Model approach will be carried forward in this research.

2.2.3. A Summary of Studies on Accident Causation

Sections 2.2.2.a, 2.2.2.b, and 2.2.2.c concern accident causation based on the management approach. Firstly, there was the fundamental work of Heinrich: the Domino Theory (section 2.2.2.a). Followed by attempts to update the domino sequence (section 2.2.2.b), and thirdly, the Multiple Causation Model proposed by Petersen (section 2.2.2.c).

It is obvious that there is nothing wrong with the Domino Theory and the Updated Domino Sequence as both give a good approach to preventing accident by removing factors that cause them. However, it is clear from the example of a person falling off a stepladder by Petersen (1978) that in compare accident causation approach between the Domino Theory and the Multiple Causation Model, the accident causation models based on the Domino Theory approach has proved ineffective in investigating accident causes. The example shows that the theory only works at symptomatic level, not with the root causes. Removing the symptoms means that the root causes may still remain and allow another accident to occur.

On the other hand, the Multiple Causation Model proposed an approach to accident causation that can trace the root causes or underlying causes. All underlying causes that relate to the combined factors of human attitudes, surrounding conditions, and management processes both at company level and site organisation must be considered if safety programs are to be effective.

Linked to the explanation above, this research will carry forward factors that can prevent accidents identified from the Domino Theory (people are the fundamental reason behind accidents and management has the ability to control is responsible for the prevention of accidents) and factors of underlying causes identified from Multiple Causation Model (lack of management involvement and lack of safety knowledge). These four factors are similar to the definition of accident prevention by Heinrich et al. (1980), “an integrated program, a series of coordinated activities, directed to the control of unsafe personal performance and unsafe mechanical conditions, and based on certain knowledge, attitudes, and abilities”.

2.3. Safety in Construction Project

All over the world, people know about the pyramids, great mosques and cathedrals, the Great Wall of China, and other wonders of the world. Today, the human landings on the moon, new roads or bridges, high-rise buildings, new computer systems are all impressive project, but behind the success, lies a basic question “how were these endeavours attained and what safety quote were enforce?”

Safety in the context of civil engineering is the discipline of preserving the health of those who build, operate, maintain, and demolish engineering works and of others affected by those works (Davies and Tomasin, 1990). Discussion about construction safety should be linked with accidents because safety is the mechanism to prevent their occurrence (see section 2.2.1).

The following section will give a brief overview of construction projects. Linked to safety, it starts with a review of studies that have been done on accident causation then reviews of studies that have been done to improve safety. It concludes with a summary of safety in construction projects.

2.3.1. An Overview of A Construction Project

This section will briefly explain the definition of a project to clarify the term "project" used in this thesis. According to Denise Bower (Smith, 2002), a project is an investment of resources to produce goods or services; it costs money. A project can be any new structure, plant, process, system or software, large or small, or the replacement, refurbishing, renewal or removal of an existing one. One project may be much the same as a previous one, and differ from it only in detail to suit change in the market or a new site. Projects thus vary in scale and complexity from small improvements of existing products to large capital investments. A number of definitions of the term "project" have been proposed e.g.

- The Project Management Institute (PMI), USA, defines a project as "a temporary endeavour undertaken to create a unique product or service".
- The UK Association for Project Management defines a project as "a discrete undertaking with defined objectives often including time, cost and quality (performance) goals".
- THE British Standards Institute (BS6070) defines a project as "a unique set of coordinated activities, with definite starting and finishing points, undertaken by an individual or organisation to meet specific objectives with defined schedule, cost and performance parameters".

From the above definitions, it may be concluded that a project has the following characteristics:

- It is temporary, having a start and a finish
- It is unique in some way
- It has specific objectives
- It is the cause and means of change
- It involves risk and uncertainty

- It involves the commitment of human, material and financial resources

According to these definitions, a construction project can be defined as a project because it is temporary or starts on an exact date and finishes on exact date too. It also unique, as every construction site has its own characteristics, such as one type of house is to be built on a rock; another may be built on soft soil. Construction project has a specific objective; primary objectives are usually measured in terms of time, cost, and quality. Because of the construction time, it involves risk and uncertainty, and also involves the commitment of human, material, and financial resources. Based on these explanations, it is clear that a construction project is a project and in this research, the term “construction” and “project” are used interchangeably.

2.3.2. Safety and Accident Causation in Construction Projects

Construction accidents are defined as those that occur during construction and demolition activities resulting in injury, mostly to employees on site. Accidents occur before works begin, during construction phases and even after works have been completed because of faulty design or construction.

Why do accidents occur in construction? In this industry, the working environment is constantly changing. Sites exist for a relatively short time and the activities and inherent risks change daily. Within a short time of a hazard being identified and dealt with, the work scene has changed, bringing new hazards. There is also a high turnover in the workforce which means safety awareness is not always as good as it should be.

There are several other causes. For small construction firms, the financial resources are generally insufficient to provide the necessary high standard of safety, such as safety training. Moreover, the managerial knowledge of many small contractors is based on experience and is often lacking in theoretical background. Many small contractors do not employ professional safety advisers and have neither the time nor the tendency to keep abreast of legal requirements and technical developments in safety matters.

Some contractors too are prepared to ignore safety legislation and safe working practice in order to bid competitively and unfortunately, there are also clients who are willing to employ these contractors regardless of their competence in safety management. However, dedicated safety management and a disciplined approach to ensure compliance with safety rules and procedures by all involved in construction operations can prevent the majority of accidents.

In recent years, people concerned about safety have accepted the new approach given by the Multiple Causation Model. They agree that behind every accident there lie many contributing factors, causes, and sub-causes. The following sections review studies that have been done regarding accident causation in construction safety that consider the approach given by the Multiple Causation Model.

a. The Study of Tariq S. Abdelhamid and John G. Everett

In 2000, Abdelhamid and Everett carried out research focusing on identifying root causes of construction accidents. They presented a model of accident causation, called Accident Root Causes Tracing Model (ARCTM). It was based on the theories of accident causation and human error. The main concept proposed in ARCTM was that an occupational accident will occur due one or more of the following three root causes: (1) Failing to identify an unsafe condition that existed before an activity was started or that developed after an activity was started; (2) Deciding to proceed with a work activity after the worker identifies an existing unsafe condition; (3) Deciding to act in an unsafe manner regardless of the initial conditions of the work environment.

It can be concluded from the report that ARCTM presented that unsafe conditions are due to four causes: (1) Management action/inaction; (2) Unsafe acts of workers or co-workers; (3) Non-human related event(s); and (4) An unsafe condition that is natural part of an initial construction site condition.

b. The Study of Akhmad Suraji, A. Roy Duff, and Stephen J. Peckitt

Suraji et al. reported on their research in 2001 focusing on the development of a more extensive behaviour modeling approach to construction accident causation and analysis of past accidents to identify principal causes. It was conducted in the United Kingdom, in collaborative work between University of Manchester Institute of Science and Technology (UMIST) and Loughborough University, supported and financed by the United Kingdom Health and Safety Executive (HSE), using an investigation of 500 recent accident records.

This research proposed a conceptual but practical model of accident causation for the construction industry, highlighting the underlying and complex interaction of factors in the causation process. A model called the Constraint-Response Model, is needed to represent ways in which the behaviour of all participants in construction projects, from clients to site operatives, could lead to accidents. The fundamental assumption in this model is that all participants operate within a variety of constraints arising from features of the project environment or produced by the behaviour of other participants. Their response to these conditions can generate inappropriate situations or conditions which directly increase the risk of an accident.

From the report, of 500 accident records studied, it can be noted that accident causes in projects were: 1) inappropriate construction planning (28.8%), 2) inappropriate construction control (16.6%), 3) inappropriate construction operation (88.0%), 4) inappropriate site condition (6.0%), and 5) inappropriate operative action (29.9%). The total percentage is more than 100, as many accidents had multiple causes.

c. The Study of Panagiotis Mitropoulos, Tariq S. Abdelhamid, and Gregory A. Howell

Mitropoulos et al. reported their research in 2005 focusing on accident causation, human error, and construction safety. They proposed an accident causation model that would give a new direction for accident prevention. Different from the current approach of safety research, which focuses on prescribing, enforcing, and defences (physical and procedural barriers that reduce workers' exposure to hazards), this research presented a new accident causation model of the factors affecting the likelihood of accidents during construction activity.

The conceptual framework successfully identifies variables influencing likelihood of accidents during the construction phase, such as hazardous work situations, efficient work behaviours, production, and exposure to hazards, error and changes in conditions, and incidents and consequences. The model also proposed two important directions for accident prevention: (1) reduce task unpredictability and (2) increase error management capability. Reduce task unpredictability will reduce unexpected tasks and hazardous situations, interruptions and 'short-term' production pressures and the likelihood of errors, whereas increased error management capability will enable workers to successfully recognise, cope with, and recover from hazardous situation and errors. The practical benefit of the model is that it provides practitioners with strategies to reduce the likelihood of accidents.

d. A Summary of Studies on Accident Causation in Construction Projects

Abdelhamid and Everett (2000) proposed a practical model for tracing accident root causes called ARCTM which asserted that unsafe conditions are due to four causes: (1) Management actions/inactions; (2) Unsafe acts of worker or co-worker; (3) non-human related event(s); and (4) An unsafe condition that is a natural part of initial construction site conditions. Suraji et al. (2001) proposed a conceptual but practical model of accident causation for the construction industry, highlighting the underlying and complex interaction of factors in the causation process. A model called the Constraint-Response Model. This model represents ways in which the behaviour of all participants in construction projects, from clients to site operatives which could lead to accidents. Mitropoulos et al. (2005) proposed a new model of the factors likely to cause accident during construction activity. This model also gives a new direction for accident prevention by providing practical strategies to reduce the likelihood of accidents.

2.3.3. Study on Improving Safety in Construction Projects

Safety has always been a major issue all over the world, especially in the construction industry (see section 1.1). The number of accidents and their victims those killed and injured, and loss of properties, are significant. Failure in managing construction safety results in worker injuries and impacts on financial losses, human conflicts, and civil penalties (Hadikusumo and Rowlinson, 2004).

In recent years, attempts have been made to improve construction safety. It is found that there is a need for research to deal with the "how" question which is concerned with an accident and circumstances preceding it (section 2.2.1). Therefore, this section will only review recent studies that fill that need.

There are four causes influencing safety in the construction industry as identified from the studies reviewed: (1) Construction safety management, (2) Human factor in construction safety, (3) Occupational safety in construction, and (4) Construction safety program, each of which is described below:

2.3.3.1.The Studies Related to Construction Safety Management

The Occupational Safety and Health Act has been enforcing for many years to provide a safe working environment in many industries including the construction industry. With the rapid increase of construction activities, safety has become a big concern because worker injuries cause tremendous losses (Fang et al., 2004a). The key for site safety is safety management which provides guidance to improve safety on construction sites. There are three areas of safety management recognised from the studies reviewed, design for construction safety, construction safety management effectiveness, and safety performance. Each area will be briefly explained as follows:

a. Design for Construction Safety

The respective roles of the various parties involved in construction site safety are far from settled, although some safety regulations have been agreed on years. A survey of design engineers, general contactors, and subcontractors indicates there is no uniform agreement on site safety responsibilities. This is particularly true for architects and engineers (A/Es), i.e., design professionals. It was recognised in Toole (2002) that one of the outstanding texts on construction site safety does not even mention the role of the A/Es. Toole suggested that all future construction projects should have detailed practical expectations on respective safety roles clearly articulated before the site work begins.

Supporting this suggestion, Becker (2003) wrote that construction designers often mention that they lack training to address worker safety but construction worker safety from the design side is becoming more common. Behm (2005) also supported this finding. He believed that “by addressing safety during the design process, hazards will be eliminated or reduced during construction, thus improving the safety performance of the constructor”. From research conducted by Behm (2005), 42% of fatalities reviewed in construction accident records were linked to the construction concept. Another finding was that the associated risk that contributed to accidents would have been reduced or eliminated had the design for construction safety concept been utilized. In the early stage of the project, a safety-in-design task force was formed. The charge of the task force included the three main parties to the design process: the owner, the design firm, and the contractor, along with an outside safety consultant who facilitated the process (Becker, 2003). Gambatese et al. (2006) also recognize the importance of implementing the safety of construction workers in the design of a project. Designing to eliminate or avoid hazards prior to exposure on the job site is listed as the top priority in the hierarchy of controls common to the safety and health professions.

To fill the gap indicated by Becker (2003), a lack of training to address construction worker safety, Hadikusumo and Rowlinson (2004) proposed the idea of capturing construction safety knowledge as a Design-For-Safety-Process (DFSP) tool. Unlike Toole (2002) who stated that safety expectation should be in writing, Hadikusumo and Rowlinson (2004) said that capturing safety knowledge by using engineering drawings and method statements represented as texts and two-dimensional drawings may be difficult to understand. To produce safe construction design, a visualization tool needs to be implemented so that a safe design can be developed from the beginning of the project. The idea to capture safety knowledge for a DFSP tool was supported by the research findings conducted by Gambatese et al. (2006). They have mentioned that some factors need to be implemented in practice for construction worker safety, such as a change in designer mindset toward safety, utilizing designers' knowledge about design-for-safety modifications and designing safety tools.

b. Construction Safety Performance

To evaluate the implementation of safety in a construction project, further safety performance should be measured. Koesmargono et al. (1997a, 1997b, 1998) proposed a conceptual framework for studying the relationship between the attitudes of workers toward safety and safety performance. In these studies safety performance was measured in terms of workers' injury frequency, directly influenced by workers' attitudes toward safety. This would depend on job satisfaction, their perception of manager behaviour, management system, and project environment. Case studies from twenty-one high-rise building projects revealed that injury frequencies were lower on projects where workers were most satisfied with their job. Therefore, it can be concluded from that a better understanding of workers' attitudes toward safety will improve safety performance.

Siu et al. (2004) proposed a model to examine the relations among safety climate (safety attitude and communication), psychological strains (psychological distress and job satisfaction), and safety performance (self-reported accident rates and occupational injuries). The research revealed that psychological distress was found to be a mediator of the relationship between safety attitudes and accident rates. In this research, safety performance was only indicated by self-reported accident rates and occupational injuries.

Unlike Siu, but similar to Koesmargono, Fang et al. (2004a) were concerned with management factors that influence site safety to assess safety performance. In this research, there are three factors in the safety management assessment method, the organisational and managerial factors, safety economic factors, and management-labor relation factors that have a significant relation with safety performance on construction sites. They established Safety Management Assessment Index (SMAI) and Safety Performance Index (SPI).

Besides establishing SMAI and SPI, Fang et al. (2004b) also focused on other research into evaluating overall onsite safety management performance. In this research, to evaluate onsite safety performance, management intensities of the routine safety management elements, they noted that there are five important common key factors in evaluating safety performance, foreman related, worker related, crew related, manager related factors, and safety training. Fang et al. (2004b) research findings were related to organisational and managerial factors in Fang et al. (2004a).

Other research conducted by Tam et al. (2006) used a rough set theory to distil the rules that determine safety performance of construction firms. They used six management philosophies and attitudes towards safety management as condition attributes and safety performance level based on accident rates as decision attributes. Basically construction firms need to adopt all safety measures to achieve the top level of safety performance. However, for firms with resource constraints, it hard to follow all these safety measures and would rather implement only some of these measures to obtain optimal results. The proposed model proved to be useful for distilling the best mix of combinations to achieve optimal performance. It can be seen that research conducted by Tam et al. combined the management approach of Fang et al. and safety performance indication similar with Siu et al.

c. Construction Safety Management Effectiveness

Besides a strong suggesting implementing safety in construction design, analysis of the effectiveness of construction safety management should be made. This can be done based on factors related to costs of safety control, as well as management's most crucial factors and attributes affecting safety.

A background to evaluate the effectiveness based on costs of safety control was derived from the fact that the cost of injuries and accidents to an organisation is very important in establishing how much it should spend on safety control in order to determine the most appropriate level of safety management investment. The study must be subject to review and clarification to ascertain its cost effectiveness. The idea of measuring a safety management system was based on the need to improve its effectiveness by safety management auditor.

Son et al. (2000) proposed a model for estimating safety control costs. Total costs are property damage, costs of injuries and taking care of the dead; indirect costs, which are difficult to determine are primarily relate to loss of individual productivity, loss of system productivity and unpredictable costs of insurance and litigation. Using empirical data and modeling with reference to practical observations suggests that an optimal level of safety control investment and hence safety management might be in range of 1.2 – 1.3% of total project costs.

Teo and Ling (2006) undertook research to develop a model to measure the effectiveness of safety management systems of construction sites. Their aim was to propose a method to develop and test tools that safety auditors may use to assess the effectiveness of a construction firm's Safety Management System (SMS). In this research, in order to identify most crucial factors and attributes that affecting safety, two methods were used: the Analytical Hierarchy Process (AHP) and the Factor

Analysis. The factors were collected from safety experts using interviews or workshop methods. The model itself was developed using the multi-attributes value model approach and validated via site audits. Using the model, a Construction Safety Index (CSI) can be calculated. Ineffective SMS can be identified through low CSI scores.

d. A Summary of Studies Related to Construction Safety Management

From the studies referred, it is clear there is a need to implement safety management in construction projects. Some researchers have even stated that construction safety, including worker safety, should be addressed from the design phase (Becker, 2003; Gambatese et al., 2006). Research findings from Behm (2005) revealed that associated risks that contributed to accidents would be eliminated if the design for construction safety concept were utilized. It also stated that the role among the various parties involved in construction site safety was not clearly declared (Toole, 2002). Yet construction designers mention that they lack training to address worker safety (Becker, 2003). To fill that need, Hadikusumo and Rowlinson (2004) proposed the idea of capturing construction safety knowledge by using a Design-For-Safety-Process tool. Which would allow safe construction design to be developed from the beginning of the project.

Besides suggesting implementing safety in construction design, it should also be noted that it is crucial to evaluate the implementation of safety through measuring safety performance. Three approaches can be used to measure safety performance (Fang et al., 2004a), organisational and managerial factors, safety economic factors, and management-labor relation factors. Fang et al. (2004b) measured safety performance based on organisational and managerial factors, Koesmargono et al. (1997a; 1997b; 1998) and Siu et al. (2004) based on the management-labor relation factor. Tam et al. (2006) combined two approaches, the organisational-managerial factor and the management-labor relation factor and produced a model to achieve optimal safety performance for construction firms with resource constraints.

After implementation, the effectiveness of safety management should be analysed. Researchers reported there are two ways to measure the effectiveness of construction safety, first by using safety control costs (Son et al., 2000), and second using management's most crucial factors and attributes that affect safety (Teo and Ling, 2006). Son et al. (2000) stated that the optimal level of safety control investment might be in the range of 1.2-1.3% of the total project cost, whereas Teo and Ling (2006) produced a Construction Safety Index (CSI) and confirmed that an ineffective Safety Management System can be identified through low CSI scores.

In summary, the key for site safety is safety management. Safety should be implemented from the design phase and all future projects should have detailed practical expectations on respective safety roles clearly articulated before site work begins. The implementation of safety in construction projects through measuring safety performance is also crucial to be evaluated. Another important factor is to measure the effectiveness of the safety management system implemented which must contain a high construction safety index, good safety performance, and clear safety roles among construction stakeholders.

2.3.3.2.The Studies Related to Human Factor in Construction Safety

The scale of construction safety problems have been of considerable concern to the industry and calls for improvement have been heard from trade unions, employers' association and the Safety and Health Organisation. This concern has been translated into a search for a better understanding of safety problems. Several studies have been undertaken related to human factors in construction safety, human attitudes towards construction safety and the construction safety climate. Both areas will be discussed in the following section:

a. Human Attitudes Towards Construction Safety

Langford et al. (2000) conducted a study to identify the critical factors that influence the attitudes of construction workers toward safe behaviour on construction sites. It revealed that five factors influence operatives' attitudes to safety management: organisational policy, supervision and equipment management, industry norms, risk taking, and management behaviour. These factors have been identified as aspects of company safety management that lead to positive attitudes to safety by workers and are classified as a 'cultural issue'.

Tam et al. (2004) conducted exploratory work on risk-prone activities on sites to identify factors affecting site safety. The findings show that contractors' attitudes toward safety are of grave concern because of most contractors does not have proper documented safety management system only safety manuals. Only a small percentage of contractors provide adequate Personal Protective Equipment (PPE) for workers. Furthermore, top management has a perfunctory attitude toward safety as revealed from infrequent attendance at safety meetings and only a few contractors offer systematic safety training.

This finding strongly supported by Lin and Wen (2005) produced similar evidence, noting that contractors understand the importance of safety culture, but do not have the right attitude towards implementing it. Based on their research, Lin and Wen (2005) proposed a model for enhancing safety culture, it is believed will a reinforcement loop with new rules and regulations focusing on cultivating safety culture by organizing safety training, which serve to modify attitudes.

b. The Construction Safety Climate

Previous studies mention the attitude towards safety is classified as a 'cultural issue'. A positive safety culture means the safety attitudes and values of the company are totally accepted by its employees (Fang et al., 2006). They maintain that the indicator of the overall safety culture of an organisation is a safety climate which can be measured quantitatively.

Mohammed (2002) identified five independent sets of factors in a safety climate: management, safety, risk, work pressure, and competence, and mentioned safe work behaviours as consequences of the existing safety climate. His result demonstrated that achievement of a positive safety climate depends on the role of management commitment, communication, workers' involvement, attitudes, competence, as well as supportive and supervisory environments.

Fang et al. (2006) emphasized the roles and influences of fellow workers and safety resources on the safety climate. When compared with Mohammed's work, very strong similarities were found. The main difference between these two pieces of research is safety resources, such as human resource and equipment, factors needed in constructing a good safety climate.

c. A Summary of Studies Related to Human Factor in Construction Safety

Langford et al. (2000) stated that human factors including human attitudes and behaviour, are crucial factors in ensuring that strategies within management are devised, adopted, and maintained, as well as construction safety management. Several studies have been made related to human factors in construction safety.

Langford et al. (2000) revealed five factors identified as aspects of company safety management, classified as a cultural issue that can lead to positive worker safety attitudes. Unfortunately, Tam et al. (2004) found contractors' attitudes toward safety cause grave concern because they do not have a proper documented safety management system and only a small percentage provide adequate Personal Protective Equipment (PPE). This means contractors understand the importance of safety culture but do not have the right attitude toward implementing it (Lin and Wen, 2005).

The indicator of the overall safety culture of an organisation is a safety climate. The result of study done by Mohammed (2002) indicates that achievement of a positive safety climate depends on the role of management commitment, communication, workers' involvement, attitudes, competence, as well as supportive and supervisory environments. Fang et al. (2006) emphasized the roles and influences of fellow workers and safety resources, such as human resources and equipment on the safety climate.

In summary, human factors including attitudes and behaviour are crucial factors to ensure that strategies within management are devised, adopted, and maintained. Thus, to achieve a positive safety climate the management commitment, communication, workers' involvement, attitudes, competence, and supportive environment are strongly needed. Good implementation of company safety management, classified as a cultural issue, can lead to positive safety climate within construction project management.

2.3.3.3.The Studies Related to Occupational Safety in Construction

The construction industry accounted for 19.4% of workplace fatalities and 12.3% of occupational injuries and illness. The fatality rate is also the second highest in the United States (Abudayyeh et al., 2003). Many different occupations are typically involved in a construction project, electricians, plumbers, painters, equipment operators, and carpenters. Different trades have occupational hazards that are more frequent in their respective lines of work. The review below explains the studies related to occupational safety on construction sites.

a. The Occupational Injuries and Fatalities Among Electrical Contractor

It is difficult to describe exactly the varied activities an "electrical" contractor undertakes but he is the person primarily concerned with the installation and maintenance of the electrical system of a structure (Abudayyeh et al., 2003). Abudayyeh et al. (2003) had their objectives to determine jobs/tasks associated with current injury, illness, and fatality trends in electrical installation contracting; and to identify current safety practices associated with the prevention and of these injuries, illnesses, and fatalities. The jobs associated with the injuries current safety practice associated with these tasks are as follows:

- Eye injuries: cutting, drilling, and fastening. The current safety practice when there is a risk of getting foreign matter in the eyes is wearing safety glasses.
- Hand/finger injuries: cuts were the most frequent type of hand injuries; drills, hammers, saws, pliers, and knives were the tools most frequently involved. The safety practices mentioned only using gloves when drilling or hauling tasks were performed.
- Shoulder/arm injury: fastening tasks by using screwdrivers associated with the stress on the arm and shoulder. To reduce the stress, the use of a powered screwdriver or TORX head screws was suggested.
- Back problems due to heavy equipment and materials lifting. Working in a cramped or an awkward position was associated with back injuries. It also revealed that experienced back and shoulder discomfort is when the arms are elevated above the head for extended periods of time. Jobs that involved this type of positioning are drilling joints, installing conduits, making connections, and installing light fixtures. Another job related to back discomfort is pulling wire through a conduit.
- Electrical shocks were experienced in remodeling jobs requiring maintenance and troubleshooting of existing electrical systems, the incorrect use of handling of electric tools and test equipment. To prevent these hazards, it is important to follow state and national electric codes.

b. The Occupational Injuries and Fatalities in Trenching Operations

Study conducted by Arboleda and Abraham (2004) revealed that cave-ins have been identified as the major cause of fatalities in trenching operations. Other hazards associated were working at heights, working with heavy machinery, manually handling materials, and working near sources of existing utilities such as overhead power lines or gas pipelines. Their research had the main purpose to analyse fatalities in trenching operations based on accident causation models. Basically, the model needs to deal with both the event area, or the "how" of accident causation and the circumstances preceding the event, or the "why" of an accident. Two models were represented to analyse the fatality reports and to find the major relationships between the "how" and the "why" of trenching fatalities. The *Type of Accident Model*, the first model, considers the causes related to physical processes, and the *Behavioral Causes Model*, the second model, evaluates causes that can be linked to human behaviour.

The second model revealed that major accident causes are: lack of safety equipment, practice of unsafe methods or sequencing, and lack of proper training. From the first model, the major causes of fatalities are: cave-ins, caught in or compressed by equipment or object, and struck by objects. Based on the relationship between the first and the second model, the causation of accident fatalities can be explained. In cases where cave-ins occurred, safety equipment was not provided. When the victim was struck by material or equipment, a critical combination of lack of training and unsafe methods or sequencing caused the fatality. These findings could be used to formulate viable strategies to prevent trenching accidents.

c. The Occupational Injuries and Fatalities in Fall Accidents

Falls were the cause of the highest number of injuries and fatalities in the United States construction industry, accounting for 33% of all worker fatalities from 1985 to 1989 (Huang and Hinze, 2003). Falls from heights are the leading causes of death for workers, whereas scaffold-related falls, by collapse or fall from scaffolds, were the second leading causes of falls (Halperin and McCann, 2004).

It was revealed from research conducted by Huang and Hinze (2003) that the most frequent types of tasks being performed when accidents occurred were roofing, erecting steel structures, and exterior carpentry, while operations conducted at point of elevation or on temporary structures were the tasks where fall hazards were often present. It also reveals that fall accident generally related to certain human errors, such as misjudgment of a hazardous situation due to lower elevation, inadequate or inappropriate use of fall protection PPE, remove and inoperative safety equipment; and more than half the falls were related to environmental factors involving the working surfaces or facility layout conditions, such as slipping on sloped roofs, falling through floor openings, and slipping on the walking surfaces of scaffolds. The recommendation made in this research was that many topics related to falls need to be investigated in greater detail.

Supporting this recommendation, Halperin and McCann (2004) focused on the evaluation of scaffold safety at construction sites. This research was undertaken to measure the degree of safety in the use of scaffolds and to correlate safe scaffold practice to other variables present on sites. The finding assumed that more than two thirds of scaffolds were acceptable and almost one third were unacceptable. The unacceptable scaffolds had errors that could result in immediate tragedy, such as structural flaws. The four structural flaw factors were incompletely planked platforms, insufficient access, incomplete guardrails, and a lack of ties to the building where required. Another finding was the correlation between the presence of a competent person who has safe scaffold training and the safe scaffold practice was crucial. Unfortunately, the result shows that most scaffold competent persons do not have adequate training. It is clear that the findings indicate the need to specify what training is required for competent persons to perform safe scaffold practice.

d. The Occupational Safety Performance of Specialty Contractors

The focus of many studies involving the construction industry has been on general contractors, construction management firms, and design/build firms, but the reality is that specialty contractors, often working as subcontractors, perform most construction operations (Hinze and Gambatese, 2003). This is why it is necessary to evaluate factors that influence the safety performance of specialty contractors as their safety practices contribute most significantly to the health and welfare of construction workers.

The research concluded that specialty contractor safety performance was consistently influenced by a number of factors; include minimizing worker turnover, implementing employee drug testing, and training with the assistance of contractor associations. Safety incentive programs were not associated with better safety performance. Growth in company size was found, however, to be associated with improved safety performance. The researchers, however, acknowledged that the findings were not sufficiently compelling to be universally applied to all specialty contractors. A research study involving a larger sample was suggested.

e. A Summary of Studies Related to Occupational Safety in Construction

A construction project remains a hazardous project environment. Since many different occupations are involved each contractor has frequent occupational hazards in their respective line of work.

An electrical contractor identified injuries and illness associated with their jobs, including eye injury, hand/finger injury, shoulder/arm injury, back problems, and electrical shock hazards (Abudayyeh et al., 2003). For a contractor performing trenching operations, the major fatalities are: cave-ins, caught in, compressed by equipment, and struck by objects (Arboleda and Abraham, 2004). Falls are identified as the most prevalent accidents in construction projects and cause the highest number of injuries and fatalities. There are two main causes of falls: falls from heights and scaffold-related falls by collapse or falls from scaffolds (Huang and Hinze, 2003; Halperin and McCann, 2004). These studies show that all accidents leading to injuries and fatalities were caused by inadequate or inappropriate use of safety equipment, lack of safety training, and improper or unsafe acts or conditions. To improve safety performance among specialty contractors, it was stressed that they should minimize worker turnover, implement employee drug testing, and conduct training with assistance from contractor associations (Hinze and Gambatese, 2003).

Those who perform most construction operations are the specialty contractor. It is therefore necessary to evaluate their ability to provide safe conditions on sites. Several types of accident were identified in construction projects and the major causes of injuries and fatalities accidents were recognised, to safety equipment, safety training, and construction practice and conditions.

2.3.3.4.The Studies Related to Construction Safety Programs

From Teo and Ling's (2006) paper, it is clear that to reduce the number of accidents there must be a proper framework to enhance site safety. All stakeholders must assume responsibility for identifying risks and take steps to prevent or mitigate them. Therefore, hazard identification is fundamental to construction safety management. Unidentified hazards present the most unmanageable risks (Carter and Smith, 2006). Studies to enhance construction sites safety, including hazard identification, construction hazard identification and control, and construction safety control will now be described:

a. Construction Hazard Identification

Safety in the construction industry is a complex issue and is influenced by many factors, such as the technology being used, worker behaviour, actual site conditions, and the design being constructed (Hadikusumo and Rowlinson, 2002). Given these conditions, safety hazard identification and accident precautions are important elements in any site safety management system. Attempts have been made by several researchers to assist in hazard identification.

Hadikusumo and Rowlinson (2002) published an account of construction hazard identification based on their research. They produced a model to help identify safety hazards inherited during the building construction phase. The model is called the design-for-safety-process (DFSP) tool. The idea was based on actual reality that hazard identification could not be effectively undertaken using two-dimensional design drawings. Their research led to a model that provides a mechanism to allow users to do a walk-through of the virtually real project and to identify safety hazards inherited within construction components and processes, as well as to select accident precautions needed to prevent their occurrence.

Chantawit et al. (2005) supported the idea that hazard identification was not easy to recognize using two-dimensional drawings. Their work indicated there were two root problems in implementing safety planning in construction project management. Firstly, safety planning is usually separated from other planning function, such as scheduling. It is difficult for safety engineers to analyse what, when, why, and where safety measure are needed for preventing accidents. Secondly, as design drawings usually use two-dimensional presentations, it is difficult to combine 2D drawings with safety plans and engineers have to convert 2D drawings into 3D mental pictures. Regarding this problem, Chantawit et al. (2005) propose 4DCAD-Safety as a tool for visualizing project scheduling and safety planning.

The ideas of Hadikusumo and Rowlinson (2002) and Chantawit et al. (2005) are similar that is using three-dimensional mental models of construction objects. 3D objects provide the benefit that “what you see is what you get” visualization. It makes it easier to imagine the real picture of construction processes or in other words, the user of 3D software can visualize the processes, as they would be carried out in reality. The 4DCAD allows 3D objects to be integrated into the fourth dimension, such as safety planning.

There are two specific benefits related to 4DCAD-Safety application. First the safety planning function, the application can display safety measures that are required to carry out specific works. Second, since the safety plan is displayed in the 3D model, safety engineers can visualize spatial and physical information of construction activities and their products. This assist them to know and analyse what safety measure are needed to be installed and prepared for current activities.

Whitaker et al. (2003) focused on temporary access systems, particularly temporary scaffolds. Their objective was to develop a prototype decision aid, called Scaffold Planning Aid for System Safety (SCAFPASS), to promote access scaffold safety. It was developed based on two databases: (a) access-related incident files, and (b) incident appearing files. The Health and Safety Executive (HSE) in the United Kingdom held those two databases which were computerized. That safety model showed: (1) the more frequent root-causes in temporary scaffolds, include the fitting of defective components, unauthorized modification of the structure, omission of barriers, and structural faults; (2) common managerial deficiencies, including failure to control risk, unsafe methods and procedures, and inadequate training and supervision.

Lee and Halpin (2003) developed a predictive tool that uses safety factors to estimate accident risk for processes commonly employed on construction sites. The analysis uses fuzzy mathematical techniques and input from safety experts to assess factors that impact field operations and influence accident potential. The tool was employed in the utility trenching process and research found that it could be used to identify factors affecting safety performance in utility trenching operations and predict the risk level of accidents by estimating the probability of accident due to the fuzzy-based effect of safety factors.

Carter and Smith (2006) undertook recent research in construction hazard identification. They investigate the current levels of hazard identification on three U.K. construction projects. The method they used was “method statements”, documents that provide details of safe systems of work. The result was the maximum level of identification hazard was only 6.7% out of 89.9% for construction projects within the nuclear industry, 72.8% for projects within the railway industry, and 66.5% for projects within both the railway and general construction industries. The results indicated that hazard identification levels are far from ideal, their research then proposed an Information Technology (IT) tool for construction project safety management (Total-Safety), the Total-Safety exists as a data-driven website, consisting of a three-tiered structure: user interface, CF server, and a central safety database. The use of Total-Safety tool is helping construction personnel to develop method statements with improved levels of hazard identification.

b. Construction Hazard Identification and Control

It is obvious that planning and control failures related both to safety and production itself are major contributing factors to accidents on sites (Suraji et al., cited by Saurin et al., 2004). Although safety planning often appears as a core requirement in safety regulations and standards, most companies produce a health and safety plan only to avoid fines from governmental inspectors and do not effectively use it as a mechanism for managing construction site safety (Saurin et al., 2004; Wang et al., 2005). Thus, it is necessary to improve the implementation of safety planning and control beyond what is required by regulation and standards.

Following this requirement, Saurin et al. (2004) proposed a model of safety and production on integrated planning and control, called Safety Planning and Control (SPC). In this research, the proposed planning model using the Preliminary Hazard Analysis (PHA) technique was based on three hierarchical levels: long-term planning, look-ahead planning, and short-term planning. The long-term planning was developed before construction began, and updated and detailed at both look-ahead planning and short-term planning.

The SPC involved a set of proactive and reactive safety performance measures by using Percentage of Safe Work packages (PSW). The implementation of SPC was as follows: the safety plan stage was conducted during construction planning during which hazards were identified and analysed. The results were then written in a safety plans in a certain form. In the control stage, safety data must be collected on a daily basis by an observer walking around a site and identifying work being carried out and watching how each activity is being performed, checking whether the safety measures listed in the respective safety plan are being followed.

The model proved it could be implemented during the whole project. However it was found to be time-consuming and there is need to collect and process data more productively, for instance, by using information technology.

Wang et al. (2005) proposed a safety evaluation model integrated into a network schedule. Their research proposed a simulation-based model, namely, SimSAFE that incorporates safety management into schedule control. Specifically, the degree of hazard, measured by expected accident costs, of each activity in a construction project is evaluated and this information is attached to the project network schedule. Simulation algorithms are used to consider uncertainties that are often ignored in safety management. SimSAFE evaluates the degree of hazard of each activity according to the following four steps: (1) evaluating the likelihood of each accident cause (simply termed "causes" herein) occurring; (2) assessing accident costs (additional costs may be required to deal with the accident) associated with each cause; (3) applying computer simulations for dealing with uncertainties; and (4) integrating safety information with the network schedule. The findings of this research revealed the advantages and disadvantage of the proposed model (SimSAFE).

As to advantages, SimSAFE has two sources of theoretical strength, using qualitative model inputs is more practical because practitioners are more familiar with qualitative estimates and the uncertainty of an accident cause is systematically disaggregated by safety factors and factor conditions which eases the assessment of the individual factors on accident occurrence.

However, the disadvantage of SimSAFE is it is time-consuming. A user-friendly computer interface must be devised to simplify the use of SimSAFE in future. If compared with the research of Saurin et al. (2004) the difference between the two researches are: the Saurin et al. model combines safety control functions with existing production planning and the control process, which regards safety planning and control as a broad managerial process, but it did not formally evaluate the uncertainty in the occurrence of causes of accidents and safety planning and control were not integrated with schedule control.

c. Construction Safety Control

Besides strong encouragement for hazard identification in construction activities, there is also a need to monitor or control safety. Both actions are meant to prevent accidents from happening. The ability to identify safety and hazards as early as possible is vital to a project of any size and scale because “prevention is always better than cure” (Nikander and Eloranta, 1997 cited by Cheung et al., 2004). From this explanation, it can be seen that safety and hazards need to be detected as soon as possible to be able to take immediately right and corrective action. According by Cheung et al. (2004) carried out research that aimed to design and develop a prototype web-based safety and health monitoring system. It is called Construction Safety and Health Monitoring (CSHM).

CSHM can be used as a detector of potential risks and hazards and, more importantly, as a warning sign to areas of construction activities that require immediate action. All the functions of CSHM were designed to be web-based, thus enabling remote access, speedy data collection, retrieval, and documentation. In this system, data are safety and health performance parameters, including statistical type: number of accidents reported and the number of man days lost, and functional type: safe work practice, personal protective equipment (PPE), fire protection, electrical safety, housekeeping, hygiene, first aid facilities, and bamboo scaffolding. For assessment system of safety and health management, Knowledge Base was chosen which contains a summary of expert advice and guidelines. Upon completion of data entry, the program will automatically highlight those parameters that are underperformed and indicated by a warning sign next to the underperformed parameter. By clicking on the warning sign, practical suggestions will be given on the monitor screen.

These are, in fact collected from and based on expert experience and professional practices. As a result, the developed CSHM streamlines safety and health performance measurement and assessment process through its web-based interface, database, and expert systems. The final product is its Executive Report that contains instructions, advice, and graphical presentations of important data all in one sheet. However, CSHM is not intended to replace management involvement in making decisions, particularly those involving human factors, but to improve efficiency and accuracy and serve as a complement to managerial and leadership competence.

d. A Summary of Studies Related to Construction Safety Programs

The ability to identify safety and health hazards as early as possible is vital to a project as “prevention is always better than cure”. Hence, there is a need to detect potential risks and hazards and more importantly to give warning signs to areas of construction activities that require immediate corrective action.

In order to detect potential risks and hazards, several studies have identified hazards in construction projects. Two employed three-dimensional mental model that provides the benefit of visualization (Hadikusumo and Rowlinson, 2002; Chantawit et al., 2005). Both programs allow users to visualize the construction process, as it would be actually carried out in reality. Whitaker et al. (2003) focused on developing a prototype decision aid to promote safe construction practice and in this study the temporary access system was chosen as a sample activity. The aid was built based on two paper-based databases.

Another research developed a predictive tool that uses safety factors and fuzzy mathematical techniques to estimate accident risk for processes commonly employed on construction sites (Lee and Halpin, 2003). The recent research of Carter and Smith

(2006) investigated the current level of hazard identification on construction projects. As the results were far from ideal, they then proposed an IT tool for construction project safety management to improve the level of hazard identification.

Besides the need for hazard identification, it is also evident from these studies that it is necessary to control identified hazards (Saurin et al., 2004; Wang et al., 2005). Saurin et al. (2004) proposed a model of integrated safety planning and control. In the planning stage, the construction hazards were identified and analysed using a preliminary hazards analysis technique and the results written down in a certain form as a safety plan. In the control stage, the implementation of the safety plan is checked. Wang et al. (2005) suggested a safety evaluation model integrated into a network schedule. In this study, the degree of hazard was evaluated using simulation algorithms to consider uncertainties, measured by expected accident cost. The result was attached to the project network schedule. The two models could be implemented, however, both were found to be time-consuming.

Saurin et al. (2004) recommended the need to collect and process data more productively by using information technology, whereas Wang et al. (2005) suggested a user-friendly computer interface to simplify the safety program. To meet the need of information technology, Cheung et al. (2004) carried out a study to design and develop a prototype web-based safety and health monitoring system. Their program streamlined the measurement and assessment process through its web-based interface, database, and expert system, but it was not intended to replace safety management decision-making.

In summary, in order to prevent accidents, hazards should be identified and analysed as early as possible and safety planning and scheduling be implemented to control safety during construction, to eliminate time-consuming activities, the use of information technology, in particular a Web-based program was proposed, however, it is not intended to replace management decision-making regarding safety.

2.3.4. Critique of Studies on Safety in Construction Projects

From a review of recent studies on construction safety, it can be seen that a great deal of research has been done on four causes influencing safety in the construction industry (sections 2.3.3.1 to 2.3.3.4). The four causes are: (1) Construction safety management, (2) Human factors in construction safety, (3) Occupational safety in construction, and (4) Construction safety program. From summaries of these studies, it is clear that providing safe work environments in construction is necessary from the early stage of construction project.

The main framework included construction safety management, human factors in construction safety, occupational safety, and a safety program. The reviewed studies state that for practical reasons, the most important thing to do to prevent accident is to provide a good safety program. As stated in section 2.3.3.4, the ability to identify safety and health hazards as early as possible is vital to a project as "prevention is always better than cure". Hence, there is a need to detect potential risks and hazards and more importantly, to indicate warning signs in areas of construction activities that require immediate corrective action.

The reviewed studies on construction safety program (section 2.3.3.4) contain two main ideas: identifying hazards in projects and controlling identified hazards. Study on identifying hazards including the use of three-dimensional mental model was carried on by Hadikusumo and Rowlinson (2002) and Chantawit et al. (2005), promoting safe practice using a decision aid prototype by Whitaker et al. (2003), estimating accident risk using mathematical techniques by Lee and Halpin (2003), and investigating identified hazard levels by Carter and Smith (2006).

Study on controlling identified hazard was undertaken by Saurin et al. (2004) by proposing a model of integrated safety planning and control and Wang et al. (2005) by proposed a safety evaluation model integrated into a network schedule. All the models were implemented but found to be time-consuming. As a result, it was recommended developing system to collect and process data more productively by using information technology and using a user-friendly computer interface to simplify the safety program.

Cheung et al. (2004) therefore carried out a study to design and develop a prototype web-based safety and health monitoring system to streamline the measurement and assessment process through its Web-based interface, database, and expert system. However, as the program was based on a paper-based database, Hadikusumo and Rowlinson (2002) and Chantawit et al. (2005) were not support it, as they maintained that it is easier to imagine the real picture or real conditions of construction processes rather than use two-dimensional drawings and/or written reports. Hence, there is still a need to develop a web-based safety program using pictures or images of construction processes.

From studies which utilized pictures or images, it can be seen that Virtual Reality (VR) technologies have verified their use as a useful method to help predict problems that can occur during the construction phase. Although information after the construction is indispensable for proper control, no single study has developed a safety control program based on it.

2.3.5. A Summary of Safety in Construction Projects

Research in accident causation and prevention has to answer two vital questions in explaining accident causation: how do accidents happen? and why do accidents happen? The answers to the "how" question concern the accident and circumstances preceding it and the answers to the "why" question deal with identifying the root causes of accidents (see section 2.2.1).

From the explanations in sections 2.3.2.a, 2.3.2.b, and 2.3.2.c, it is clear that the studies of Abdelhamid and Everett (2000), Suraji et al. (2001), and Mitropoulos et al. (2005) were concerned with practical investigation, however they only deal with the "why" question, leaving research to deal with the "how" question. This supports

DeReamer (1958) who stated that some safety programs have become accident observation programs rather than true accident prevention programs. In order to answer the “how” question, a review of recent study to improve safety in construction projects has been given in section 2.3.3.

The factors of the immediate causes and underlying causes discussed in section 2.2.3 are: people and management (immediate causes) and lack of management involvement and lack of safety knowledge (underlying causes). A critique of recent research on improving construction safety reveals there is a lack of safety control programs that provide data to plan safe construction methods and to control those methods during construction. The data that have ability to capture the exact situation on construction sites for safety control programs are the focus of this research.

2.4. Construction Project Safety Management and Safety Management Information Systems

The management process is a necessary feature of all organised activity, including construction projects and safety. Although the purposes of organisations may differ, the process remains constant assuming that what managers do can be divided into a set of interrelated basic functions:

- Henry H. Albers (1972) divided basic functions of management into planning, organising, directing, controlling, and
- Garry Dessler (1985) considered the basic functions of management as: planning, organising, staffing, leading, controlling.

Although these functions have been formulated in different lists, their differences are generally not as great as they appear. In this thesis the basic functions of management are defined as follows: planning, organising, leading, and controlling, as stated below:

Planning is concerned with the determination of organisational objectives and the procedures and methods that will be necessary to achieved them.

Organising involves the development of a structure of interrelated managerial positions, according to the requirements of planning. This includes staffing which is allocating persons to positions. An important aspect of the organising function is management development, which is concerned with the education, training, recruitment, and promotion of managerial personnel.

Leading is concerned with carrying out the policies that result from planning. Important aspects in this function are the authority relationship, the communication process, and the problem of motivation.

Controlling determines whether everything is going in accordance with the policies developed through the planning process. The purpose of control is to find mistakes, correct them, and to prevent them from occurring in future.

Of these basic functions this thesis is only concerned with the fourth: control. If a manager could be sure that every task would be perfectly executed, there would not be a need to control, but things rarely go this smoothly. People execute most plans vary in their abilities, motivation, and honesty. Furthermore, plans themselves become out-dated and require revision. For these reasons control is an important management function. A mechanism to effect control is monitoring and the terms “monitor” and “control” is synonymous.

It is widely recognised that Cost-Quality-Time is a major constraint in any construction project. However, as an awareness of safety increases, now become the forth constraint and is the major concern of this thesis.

2.4.1. Monitor and Control as A Function of Construction Project Safety Management

Monitor and control is a comprehensive process to determine whether everything is going in accordance with the policies developed through the planning process (see section 2.4). It involves setting a target, measuring performance, and taking corrective action. All monitor and control systems collect, store, and transmit information on various factors. In construction projects, the system is used throughout construction phases for constraints: cost, quality, time, and safety. Monitor and control also requires targets, standards, or goals to be set. In this research, only the fourth constraint, safety will be discussed. Dessler (1985) describes three steps in this process:

- **Step 1. Establish Standards**. Monitor and control begins by setting standards. The standards could be expressed in quantitative terms, such as safety scores, or qualitatively, such as levels of safety performance.
- **Step 2. Measure Actual Performance against Standards**. The second step involves measuring actual performance against standards. The simplest and most popular way of doing this is by personal observation (monitoring). At this point a formal written report becomes important and may be in the form of statistical reports, charts, or narratives; they all report actual versus planned performance.
- **Step 3. Identify Deviations (from Standard) and Take Corrective Action**. After comparison of the actual with planned performance, if the actual one does not match the planned performance, the next step is to identify important deviations, and take corrective action. Inadequate performance is usually just a symptom, and so it is important to clearly identify the central problem.

Hence by establishing standards, measuring actual performance against standards (monitoring) and identifying deviations a control decision of corrective action can be taken. All the information about the decision taken should be stored in a construction safety management information system.

2.4.2. The Construction Safety Management Information System

Management information systems are designed instantly to provide the information that management needs for effective decision-making (Dessler, 1985). While systems for managing are not new, the term management information system is relatively new, and is usually reserved for a special type of information that has two distinguished characteristics. Firstly, it is always computer based, which allows large amounts of information to be processed quickly. Secondly, it typically refers to an information system whose objective is to integrate all or most of the organisation's subsidiary information systems, and to monitor activities throughout the company.

According to Dessler (1985) designing a management information system involves the following steps:

- **Determine information needs**: This is a step to determine the manager's needs to make decisions. In practice, the information required by management differs according to the level. Top management requires summarised information for policymaking and strategic planning. Middle management needs summarised reports of the day-to-day operations for management control. Lower management needs relatively more detailed daily reports to make sure specific operational tasks are performed efficiently.
- **Determine information source**: The next step is to find sources for information identified in step one. In most cases, this involves analysing the organisation's existing records.
- **Collect and summarise information**: This step involves developing the necessary computer programs and procedures for collecting information and for compiling and summarising it within the computer.
- **Transmit the information**: The information can be transmitted to managers in many ways, paper-based such as printouts, and computer-based such as computer files.

- **Use the information**: The final step is to use the information to make decisions.

One method to link information to support decision-making is a knowledge-based system (Al-Jibouri and Mawdesley, 2002). In order to be able to make good decisions, a manager should understand his/her tasks and the necessary information for these tasks. Al-Jibouri and Mawdesley (2002) proposed a model to utilise the benefit of information and its links using an expert system. Their results revealed that it is feasible to benefit from the field of Artificial Intelligence (AI) to develop a computer program that can assist a project manager to understand his/her tasks and the information necessary to undertake these tasks.

One of the industries interested in applying a management information system to facilitate their projects is construction. Construction projects consist of several phases, in which a large number of resources interact and cooperate to perform various tasks. The construction professionals need to collect data/information for their activities, thus data should be usable, reliable, accessible, and immediately available (Scott et al., 2000). The use of Information Technology (IT) improves coordination and collaboration between stakeholders participating in a project, leading to better communication practices (Chassiakos and Sakellaropoulos, 2008; Nitithamyong and Skibniewski, 2004).

There are information technologies that have the potential to be used in all integration aspects in construction. One such area is Electronic Networking Technology (ENT), which includes the Internet, Intranet, and Extranet technologies (Abduh and Skibniewski, 2002). Scott et al. (2000) reported study on developing the Construction and Real Estate – Information Service (CARE–IS). This study was developing an information system based on the Internet to meet the specific needs of professional users who require dependable and wide-ranging data.

Abduh and Skibniewski (2002) developed an assessment model to measure the utility of ENT services in supporting construction project activities. The Design-Build project was chosen as an example to apply the developed model. The results revealed the potential use of the model to determine the optimal configuration of ENT services for supporting Design-Build activities.

Among IT applications, the Internet, more specifically the World Wide Web (WWW), is the technology that best facilitates a collaborative working environment in a construction project. A Web-based system including Web-based project management system (Nitithamyong and Skibniewski, 2004), a Web-based system for managing construction information (Chassiakos and Sakellaropoulos, 2008), a Web-based integrated system for international project risk management (Han et al., 2008), developing construction assistant experience management system using people-based maps (Lin, 2008), and Web-based Case-Based Reasoning system applied to early cost budgeting for pavement maintenance project (Chou, 2008) have been recently undertaken.

The development of information management systems that combine database and web technologies in those studies revealed that a Web-based system is considered significantly beneficial for the coordination and collaborative process, in particular in construction projects.

Unfortunately, not much research has been done on the use of Information Technology (IT) concerning project safety. Only Carter and Smith (2006), Cheung et al. (2004) have used IT and its use in safety control programs was strongly supported by Saurin et al. (2004) and Cheung et al. (2005), as discussed in section 2.3.3.4. This research will benefit from this technology in monitoring and controlling the project safety system.

With reference to the need for alternative sources of information that can reveal exact situations on construction sites mentioned in section 2.3.4, this research considers the use of images.

2.4.3. The Image as A Source of Construction Related Information

For effective construction management, the manager needs up-to-dated information (see section 2.4.2). The following paragraphs will discuss information and its relationship with data and knowledge.

Firstly, this section will discuss knowledge. What is knowledge? Knowledge is one of those words that everyone knows the meaning of, yet finds it hard to define. It has many meanings and words such as data, facts and information are often used synonymously with knowledge. Knowledge can be further classified into: procedural, declarative, and tacit knowledge (Giarrarano and Riley, 1994). Procedural knowledge is often referred to as knowing how to do something, declarative knowledge refers to knowing that something is true or false, and tacit knowledge is sometimes called unconscious knowledge because it cannot be expressed by language.

Although knowledge is often used synonymously with data and information, they are not the same. To better understand knowledge, data, and information and their relationships, Giarratano and Riley (1994) considered it is part of a hierarchy as illustrated in Figure 2.1.

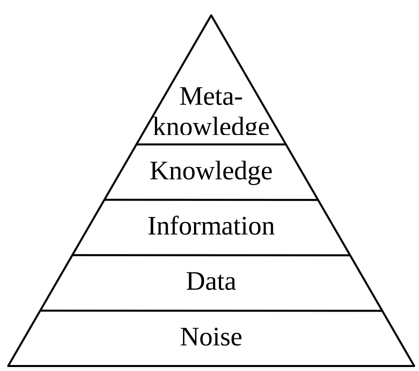

Figure 2.1. The Hierarchy of Knowledge

It can be seen from Figure 2.1 at the bottom of hierarchy of knowledge is noise, items that are of no interest and which obscure data. The next higher level is data, items of potential interest. Processed data is information that is of interest. Next is knowledge, which represents much specialised information. The highest level is meta-knowledge which means knowledge about knowledge and expertise.

Knowledge in rule-based expert systems has been defined as rules activated by facts to produce new facts or conclusions, and this process is called inference. The term facts can mean data or information. Expert systems may draw inferences using data or information and may also separate data from noise, then transform it into information or transform data into knowledge.

From this explanation, it is clear that noise is everything in common. Noise turns into something meaningful, data, if someone observes that it is based on one point of view or interest. In that case, if someone wants to represent data based on a special interest that is information.

In the construction industry, paper-based reports and it drawings have been used as a source of construction-related information for many years. For someone who does not have a background of construction knowledge, these documents have no meaning and refer to the previous paragraph, called noise. But, for someone who possesses of construction knowledge background as his or her interest, it has a meaning therefore called data.

Refer to previous paragraph, the data can reveal some information after processed based on certain knowledge. A designer, such as an architect, a construction designer, a construction engineer, should have certain knowledge to understand information revealed from construction data, that reports or drawings. The knowledge often only stored in the heads of individuals and called tacit knowledge. Throughout the lifecycle of a project, AEC (Architecture, Engineering, and

Construction) firms rely on tacit knowledge to perform satisfactory work. However, such sources are not always available when most needed during the early stages.

Beside construction reports and drawings, the project sites themselves are likely to be the original sources of construction-related information. The natural capability of an image to capture an event at any point of time suggests that it can be used to represent another source of information. A photograph always portrays an image of objects as they are, without any alteration, so that it is recognised as highly accurate information (Kim and Kano, 2008).

As the term “image” means it a two-dimensional photograph, the term “image” and “photograph” can be used interchangeably. Thus, in this research the term “construction images” are defined as two-dimensional photographs taken on sites. Nowadays, besides a conventional photograph from a manual camera, a digital camera produces a digital photograph/image. Digital photography technology enables images to be taken and readily available for review at virtually the same time. They can then be stored as image files in a computer file system.

Brilakis and Soibelman (2005) consider three possible reasons for using an image in construction projects: knowledge retrieval, construction progress monitoring, and litigation. Mursadin (2008) has done recent study on utilising construction images for information retrieval. He states that an image offers a number of advantages as a source of information. First, it can capture and immortalise events of any point of time and is as objective as the site itself. Second, the unstructured nature of an image enables them to store a huge amount of information. For example one construction image may show several parts of a facility, may demonstrate construction activities being carried out such as the methods being used and the practice of safety, or may focus on construction resources, i.e. construction workers, columns, beams, scaffoldings, concrete, timber, etc.

Yet, as the information content in digital form is unstructured, it is difficult to obtain information representing the construction concept. An approach proposed by Mursadin (2008) to retrieve these images in a structured way is using content descriptions of images and the extraction of construction terms from such descriptions. The results revealed that it is possible to use this approach to retrieve construction images and the information can be stored to for future uses such as for image retrieval and knowledge discovery.

2.4.4. A Summary of Construction Project Safety Management and Safety Management Information Systems

Monitoring and controlling safety in a construction project as a part of management, is very important as a result of increasing awareness of safety. The three steps of monitoring and controlling safety recognised in this research are: establishing safety standards, measuring safety actual performance, and taking corrective action if deviations between plan and actual performance are revealed.

To corrective action quickly, a manager needs reliable, accessible, and immediately available information. Hence, information about construction safety needs to be stored. However, not much research has been written on managing safety in construction projects by using Information Technology.

Besides a fast, reliable, and accessible system, a construction information system needs an alternative source of information that can provide data of "exact situations" of construction sites. Referring to section 1.2, the term "exact situations" means present the actual situation on a site. An image in the form of a photograph has been recognised as having this ability, therefore its use as a source of construction related information increased.

In addition with a construction project management information system, it is assumed that by storing images from previous projects into a database, they can be used as a source of information in future construction projects. Furthermore, parallel with the fast growing use of IT in the management system, digital images stored in computer files become a part of IT based construction management systems. This enables everyone to access the images and their content information. Moreover, this makes information more useful because related information is available from the early stage of a project.

From the studies previously mentioned, it is clear that an image has been accepted as a source of construction information and its ability to be stored in digital files has enhanced its use for IT based construction management systems. Another ability of image to capture and immortalise events of any point of time, as objective as the site itself, may demonstrate construction activities being carried out such as the methods being used and the practice of safety. Therefore it can be concluded that construction image has a potential benefit as sources of safety information. However, no single study has used an image in this way. Its potential benefits regarding safety need to be considered further (see also section 2.3.5).

2.5. An Overview of Literature Related to Construction Images as Sources of Information in Construction Project Safety

The Domino Theory and the Multiple Causation Model led to a fundamental concept in industry accident causation. The four factors of which are: people, management, lack of management involvement, and lack of safety knowledge (see section 2.2.3).

Construction sites are recognised worldwide as hazardous environments. Several studies have suggested practical ways of tracing construction accidents (see section 2.3.2) and endeavor to answer the “why” question mentioned in section 2.2.1 and others answered the “how” question (see section 2.3.3.) However, many construction managers have neglected the importance of safety in the criteria of project success although from the previous discussion, it is obvious that they have both a moral and legal duty to consider the criterion of maximum safety in managing construction processes (see section 2.3.4). This fact is evident.

Regarding the four factors of accident causes, it can be noted that root causes of accidents are related to human attitudes, work conditions, and the management process. To manage safety, basic management functions, in particular monitoring and controlling, should be undertaken (see section 2.4.1). It is widely recognised that most plans are not perfectly executed and people vary in their abilities, motivation, and honestly. The plans themselves also become out-dated and require revision. For these reasons, monitor and control becomes an important management function.

This involves setting a target, measuring performance, and taking corrective action. In order to be able to take fast and effective corrective action, the manager needs information which management information systems is designed to provide.

For many years, paper-based reports and construction drawings have been used as sources of information but people recognise that the project site itself is likely to supply the original source of information and to obtain valuable data, the two-dimensional photo or an image is being used. This has a number of advantages (see section 2.4.3).

An image can capture and immortalise events of any point of time, it is as objective as itself and can store a huge amount of information because of its unstructured nature. An image has become a powerful source of information for when taken from a digital camera it is readily available to review at virtually the same time. A digital image can be stored, transferred, copied, even published on the Internet and be accessed by anyone and anywhere. Storing images from the previous construction projects can provide source of information for future projects from the early stage of construction (see section 2.4.4).

Finally, it can be concluded that to create a safe construction site, a project manager should take into account safety programs along with the time-cost-quality constraints as a part of project management. Several researchers have developed a safety program with a computer as the basic component as a tool for accident prevention using information from a database as an input. Their information basically was paper-based. Nowadays image as sources of information has becomes very popular. However, the use of images as sources of safety-related information in the construction industry has not yet been attempted.

This research will study the potential use of images as a source of safety-related information in construction projects. The research objectives will be described in the next section.

2.6. Research Objectives

From a review of the literature on construction safety, apparently there is a lack of safety monitor and control programs that provide exact information data that can be used to plan, monitor and control safe construction methods. On the other side, construction images are considered data of exact information of sites and practices, consequently, there is a need to develop an image construction database to use as a tool for safety assessment during construction. This research will endeavor the potential use of construction images as a source of safety-related information for safety monitor and control program. As construction images are considered data suiting the needs of exact information, the objectives of this research are:

1. Construction images have been considered as data that suit with the needs of "exact information" and assumed has a potential benefit as safety-related sources of information (see sections 2.4.3 and 2.4.4). The first objective therefore was investigated the possibility of using construction images and the "exact information" in them as data to assess safety.

   Objective 1: To investigate the potential use of construction images as data to assess safety.

2. Leading from objective 1, after investigating how construction images can be used as safety-related sources of information the second objective was set to develop a safety assessment system using construction images as the data or sources of information.

   Objective 2: To develop a safety assessment system using construction images as sources of information.

3. To support good construction project management practice, especially construction safety, the construction manager should make use of an effective decision making in management system. In addition, for the monitor and control process, the manager needs the up-to-date information which can provide by Information Technology-based (IT-based) database. To address this need, the third objective was to develop a Web-based safety assessment system for automated safety assessment system.

   Objective 3: To develop a Web-based safety assessment system for automated safety assessment system.

4. The Web-based safety assessment system had to be demonstrated, assessed, reviewed, and refined to provide a useful and practical safety assessment system. The use of the safety assessment system result had to be presented as well to demonstrate the benefits and practically use of the developed safety assessment system. To achieve this, the fourth objective of this research was to demonstrate an application of the Web-based safety assessment system and the use of the results.

   Objective 4: To demonstrate an application and use of the developed safety assessment system.

2.7. Conclusions of Review of Construction Images as Sources of Information in Construction Project Safety

This chapter has presented a literature review on the concept of safety, construction project management, the use of images as alternative sources of information and discussed study that has done on safety research. No research, however, has been undertaken using a Web-based database of images as a safety assessment tool. Leading on that, four objectives have been developed. The following chapters will present the work that has been done to satisfy and achieve these four objectives.

Chapter 3

RESEARCH METHODOLOGY

3.1. An Introduction of Research Methodology

Chapter 2 discussed history of safety, safety in construction and research related with construction safety. The suggestion to use construction images as sources of safety-related information is mentioned and methods for an effective project management are reviewed.

This chapter will present the methodology to achieve the aim and objectives of the research. It will begin with a compilation of relevant knowledge in section 3.2.1, preliminary investigation will be explained in section 3.2.2, the development of a safety assessment system will be described in section 3.2.3 and the development of Web-based safety assessment system will be explained in section 3.2.4. Data collection will be described in section 3.2.5 its analysis and results will be discussed in sections 3.2.6 and 3.2.7. The results of the refined safety assessment system will be presented in section 3.2.8 and section 3.3 will present conclusions. A schematic representation of the research methodology is depicted in Figure 3.1.

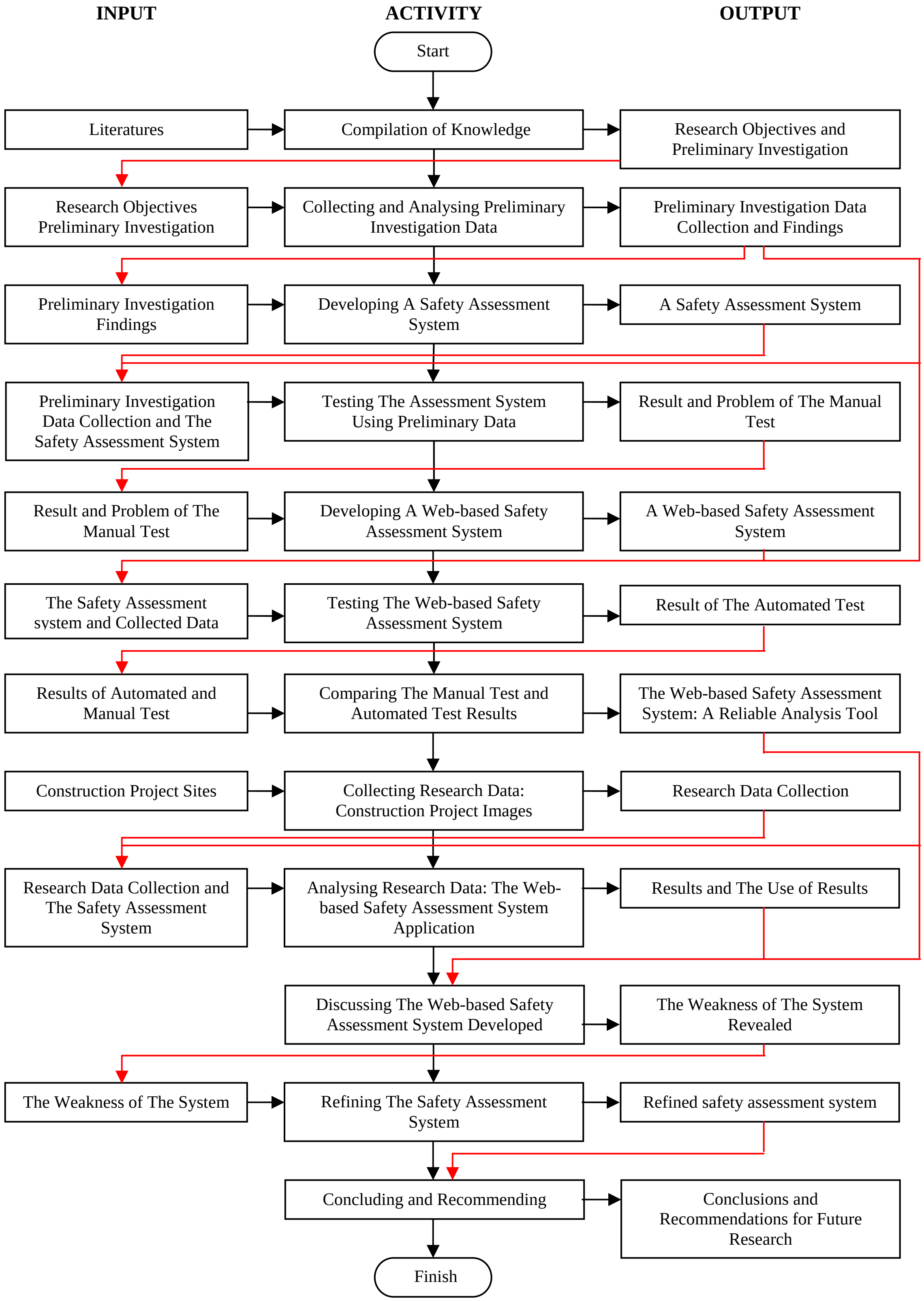

Figure 3.1. Research Activities and Expected Output

3.2. Methodology

The research methodology in Figure 3.1 is described below:

3.2.1. A Compilation of Relevant Knowledge

3.2.2. The Preliminary Investigation of Using Images to Assess Safety

3.2.2.a. Data Collection

3.2.2.b. Data Analysis

3.2.2.c. Preliminary Investigation Findings

3.2.3. The Proposed Methods of Analysis

3.2.3.a. Bayes' Theorem

3.2.3.b. Fuzzy Logic Theory

3.2.3.c. Case-Based Reasoning

3.2.4. The Development of A Safety Assessment System

3.2.5. The Development of a Web-based Safety Assessment System

3.2.6. The Research Data Collection

3.2.6.a. Selection of Samples, Sites and Kinds of Images

3.2.6.b. Data Collection Process

3.2.6.c. Data Storage

3.2.7. The Research Data Analysis (An Application of A Safety Assessment System)

3.2.8. The Discussion of The Data Analysis Result

3.2.9. The Safety Assessment System Refining

The explanation of each step is given in following sections:

3.2.1. A Compilation of Relevant Knowledge

The literature review in Chapter 2 covered industrial safety management, in particular construction safety and related topics, including construction safety management, human factors in safety, occupational safety, safety programs and management information systems. From a review of the literature on construction safety, apparently there is a lack of safety monitor and control programs that provide "exact information" data that can be used to plan, monitor and control safe construction methods (see section 2.5).

Besides, a review of construction safety management information reveals that construction images are considered data of "exact information" of sites and practices. The benefits of images are they can capture and immortalize events of any point of time, objective, can store a huge amount of information and become more powerful when taken from digital a camera as they are readily available to review at virtually the same time. Storing images from the previous construction projects can provide source of information for future projects consequently, there is a need to develop an image construction database (see section 2.5).

Attempts have been made to improve safety in construction project, especially safety program. Studies have developed a safety program as a tool for accident prevention using information from paper-based database as an input. Although images as sources of information has become very popular, the use of information collected from images and stored into image database as sources of safety-related information has not yet been attempted (see section 2.5). This research will endeavor the potential use of construction images as sources of safety-related information for safety monitor and control program.

3.2.2. The Preliminary Investigation of Using Images to Assess Safety

Following the literature review, preliminary investigation was conducted to investigate the possibility of utilizing construction images as sources of information for safety assessment purposes, the first objective (see section 2.6).

To investigate the use of images as sources of information, one has to understand an image and reveal information from it. In order to do that, first stage images have to be collected as preliminary investigation data and will be explained in section 3.2.2.a. Second stage, the preliminary investigation data have to be analysed and will be described in section 3.2.2.b. Third stage, the use of preliminary investigation findings obtained from data analysis will be explained in section 3.2.2.c. To make these three stages clear, a flowchart of the preliminary investigation will be illustrated in Figure 3.2 (adapted from Figure 3.1).

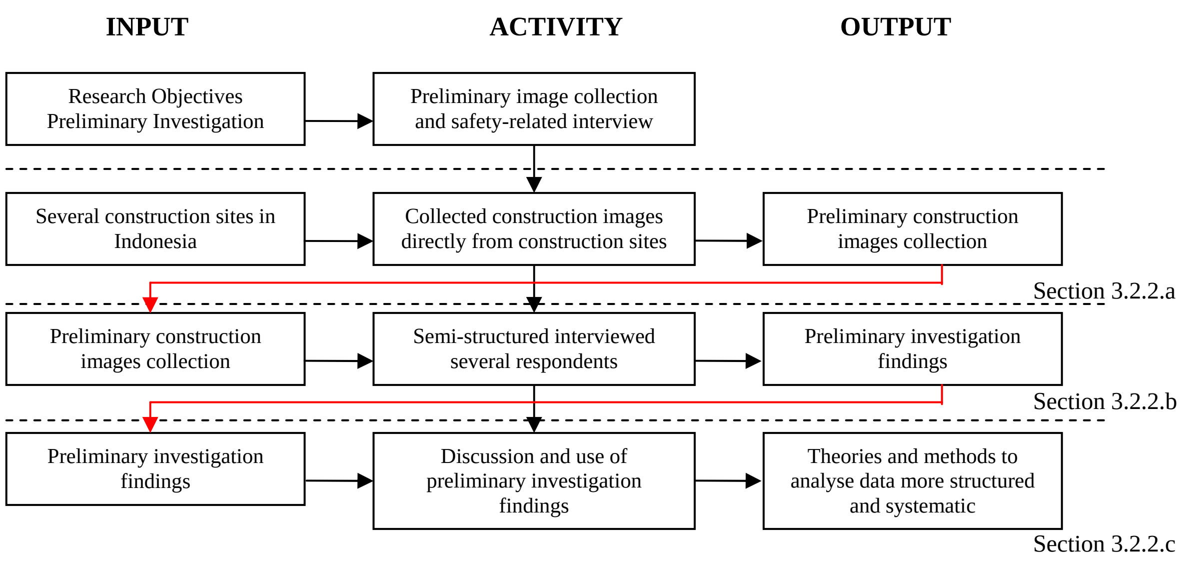

Figure 3.2. Preliminary Investigation Flowchart

3.2.2.a. Data Collection

The construction images are needed as data for observation purposes. The natural capability of an image to capture event at any point of time suggests that it can be used to represent a construction site and provide “exact information” of the construction site as well (see section 2.5).

According to Adler and Adler (1998), observational research starts by select a setting. Researchers may choose to focus on a group to observe behaviour or observe behaviour naturally around them. In this research construction images would be obtained directly from sites without any involvement in construction activities and would be observed in a natural environment. Images for preliminary investigation were obtained directly from two towns in Indonesia to record several construction practices that are often used.

Developing countries are recognized has having poor construction safety records, Indonesia was therefore, chosen as representative of a developing country to observe the state of practices in the hope that a safety assessment system could be applied that would result in safer construction practices and reduce accidents. The images were taken on a variety of single-storey residential and multi-storey building projects. Problem did not arise for the preliminary data collection. This stage will be discussed later in Chapter 4.

3.2.2.b. Data Analysis

The second stage in the preliminary investigation is data analysis which image interpretation. Information needs to be collected from respondents to know kinds of information as a result of data interpretation. To obtain such information interviews are conducted. An interview is a conversation or verbal interchange between two or more people where questions are asked by an interviewer who tries to obtain or elicit information, beliefs, or opinions from another person or an interviewee (Burns, 2000). It has three forms: Structured (or questionnaire), semi-structured and unstructured interviews.

Information for preliminary investigation in this research was obtained through semi-structured interviews with respondents who have knowledge and experience of construction projects. It has been chosen as a data analysis method because of the nature of the information required. A semi-structured interview is the choice where the direction of the questions focuses on crucial issues of a study without fixed wording or fixed ordering of question (Burns, 2000). In this research, it is important to obtain as much information as possible by viewing construction images for safety purposes.

20 construction practitioners from small construction firm to big construction firm in Indonesia were asked questions about the safety of construction practice being undertaken observed from construction images. Example of questions used for semi-

structured interviews such as “What can you see from this image?”; “What is/are construction activity/activities being performed?”; “What do you think about construction practice safety being performed?”; “What is/are the reason/reasons of your answer/answers?”. The answers collected from respondents were then recorded and used as preliminary investigation findings.

The research findings which results and problems related to utilizing construction images as safety-related information were obtained in this stage. There were problems related to image interpretation and dissimilar safety judgment. It was assumed those problems were arising from respondent’s safety knowledge and safety experience in construction projects and no safety assessment method existed that could be used when using images as sources of information. To overcome those problems, it suggests developing a structured and systematic approach as an assessment system for analyzing data. This stage will be explained more details in Chapter 4.

3.2.2.c. The Preliminary Investigation Findings

The preliminary investigation findings suggest developing a structured and systematic approach as an assessment system for analyzing images as data. The problem related to image interpretation was assumed caused by uncertainty. Because of lack of safety knowledge and experience, respondents give a wrong safety judgment. A non-existence of safety assessment method to analyse information observed from images also give contribution of wrong safety judgment.

3.2.3. The Proposed Methods of Analysis

It was assumed that a similar judgment would arise from a same guideline therefore a safety guideline has to be established and decided to derive safety guideline from safety regulation provided by Occupational Safety and Health Administration. In this research, a safety guideline is called safety checklist. To be able to give similar judgment of safety practice, safety scores were provided. The scores were based on degree of confidence to judging safety practice observed from images.

To give meaning of sets of safety scores, two methods of conditional probability approach from Artificial Intelligence that quantitatively deal with uncertainty, the Bayes' Theorem and the fuzzy logic theory, were employed

3.2.3.a. The Bayes' Theorem

The Bayes' Theorem formula was adopted calculating a likelihood of a hypothesis (H) being true based on evidence (E). A hypothesis in this research is a safe construction practice is being used, whereas evidence in this research is information observed from an image. This method will allow construction practices to be defined into two definitions. More details of the Bayes' Theorem and an example of its application will be given in Chapter 4.

3.2.3.b. The Fuzzy Logic Theory

The fuzzy sets formula was adopted from the fuzzy logic theory mapping the likelihood scores into three classifications. This method will allow high-level of safety of construction practice to be classified into three classifications. More details of the fuzzy logic theory and an example of its application will be given in Chapter 4.

3.2.3.c. The Case-Based Reasoning

To overcome problem of dissimilar safety judgment related to lack of safety knowledge and safety experience, one method of reasoning based on reuse past experience was employed, called the Case-Based Reasoning (CBR). It suggests the CBR method will allow safety information stored in database to be reused for reasoning process to give safety scores. More details of the Case-Based Reasoning and an example of its application will be given in Chapter 4.

3.2.4. The Development of Safety Assessment System (SAFE AS)

Preliminary investigations, the first research objective were completed and achieved their purpose. Results, problems, theories, and methods that could potentially be used to overcome the problems during this stage were noted and the next activity was the development of a safety assessment system (refer to Figure 3.1), the second objective (see section 2.6). A flowchart of the safety assessment system is shown in Figure 3.3, adapted from Figure 3.1.

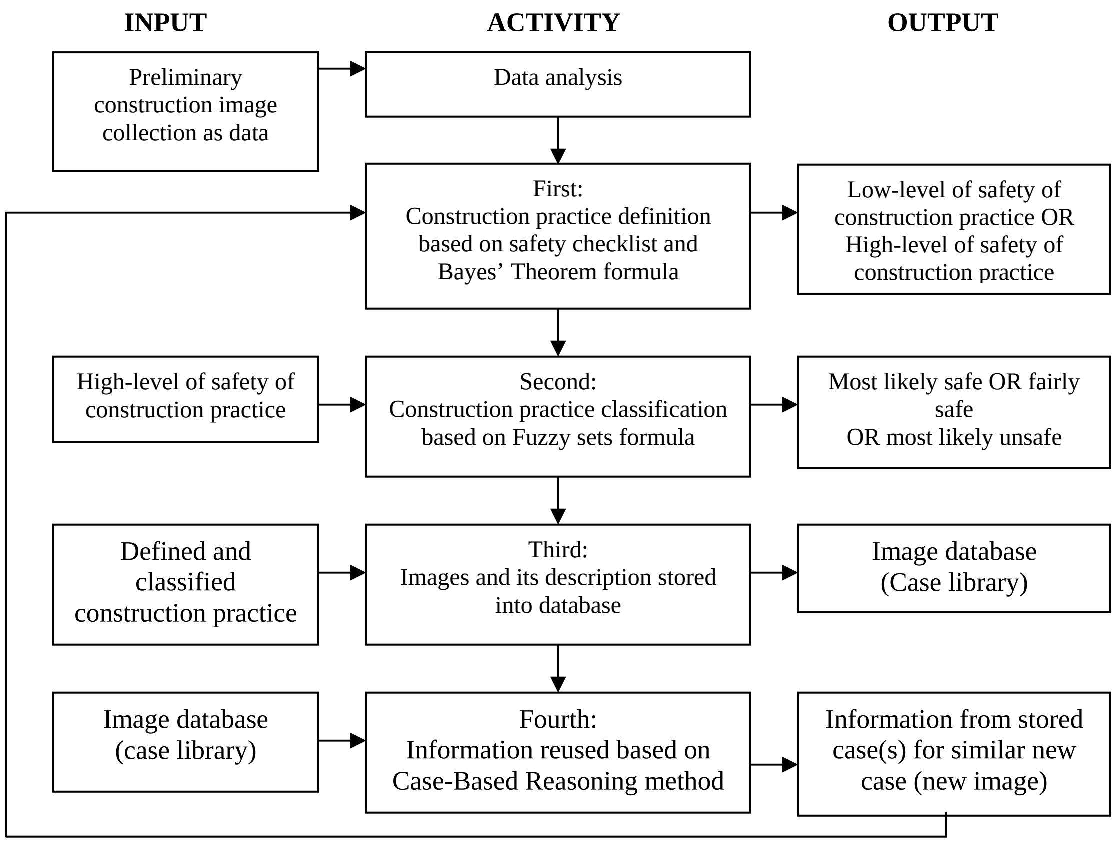

Figure 3.3. The Flowchart of The Safety Assessment System

The safety assessment system was developed using theories and methods described in the preliminary investigation section and were tested using images collected in the preliminary investigation as data. The development of the safety assessment system is briefly described as follows.

With reference to Figure 3.3, firstly construction practices observed from images were defined using the Bayes' Theorem formula and safety checklist (see section 3.2.2.c).

Secondly, construction images defined as high-level of safety of construction practice then had to be classified into one of three classifications. A fuzzy sets formula derived from the fuzzy logic theory has been proposed to map a high-level of safety of construction practice classification (see section 3.2.2.c).

Thirdly, after construction images had been defined and classified, hazards were identified from image observation and solutions found. All images and their descriptions then were stored in a database. The storage system was based on construction activity called a case. The database is known as a case library.

Fourth, all cases stored in the case library can provide information for reasoning purpose based on past information called the Case-Based Reasoning (CBR) (see section 3.2.2.c). More details of the development of the safety assessment system will be given in Chapter 5.

3.2.5. The Development of The Web-based System

The test results revealed that the system could be used to assess safety. However, there was a problem with the manual assessment process as it was time-consuming especially if the assessment process was separate from the process of retrieving past experience information from a database. To solve this problem, a Web-based safety assessment system enabling automated safety assessment and storing information from images into a database was required. The development of this Web-based safety assessment system is the third objective of this research (see section 2.6). A flowchart of the Web-based safety assessment system development can be seen in Figure 3.4, adapted from Figure 3.1.

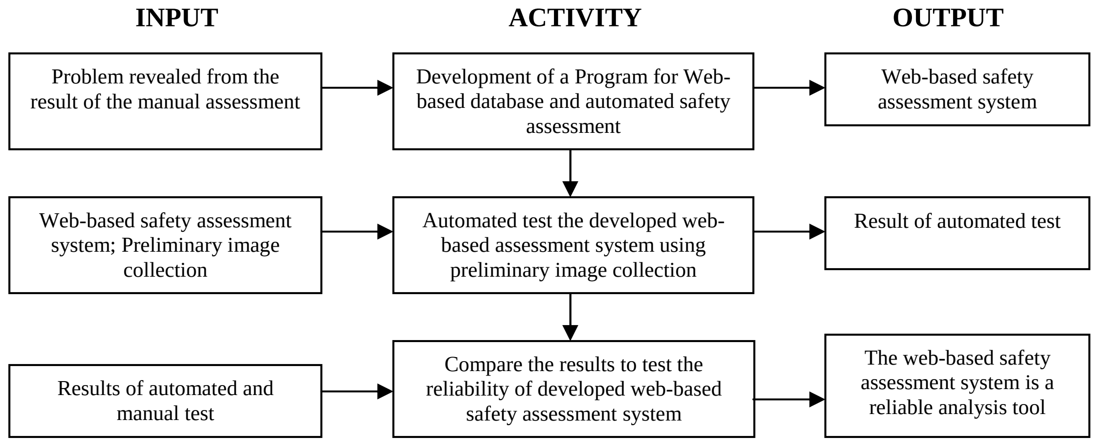

Figure 3.4. The Flowchart of The Web-based Safety Assessment System

The Web-based system was developed using an Active Server Pages (ASP) application, one available framework for Web-based system application. ASP was chosen, as it is compatible with Microsoft software thus easily available to use by everyone. A brief explanation of the computer program for developing the Web-based database will be given in Chapter 6.

A series of automated tests of the Web-based safety assessment system was also conducted using data images collected during the preliminary investigation. These images were exactly the same images as were manually tested.

The results from the manual and the automated tests were compared to test the reliability of the Web-based system before larger amount of data were used. The comparison revealed that the manual and the automated tests produced the same results thus confirming the reliability of the Web-based safety assessment system. More details of the development of the Web-based safety assessment system, the comparison test, and its result will be dealt with in Chapter 6.

3.2.6. The Research Data Collection

The development of Web-based safety assessment system and its tests were confirmed its reliability as a tool to analyse larger amount of data. Therefore, the next step is to decided kinds of data, data collection process and data storage. The following sections 3.2.5.a, 3.2.5.b and 3.2.5.c will explain it briefly.

3.2.6.a. Selection of Data Collection Places, Samples and Kinds of Image

Firstly, as construction practices in developed countries, such as Australia, are recognized as having a high standard of safety images as data for the research were taken from sites in the Perth metropolitan area. These were to serve as good examples of safe construction practices. If the safety assessment system can be used to assess safe construction practices, it may be assumed that it would be easy to assess unsafe construction practices.

Secondly, samples of construction activity and project type were selected, access scaffolding, lifting, and concreting practices at a bridge over a highway, a train station, a multi-level residential/apartment and a single level educational building projects.

Thirdly, what kind of image should be taken? As a researcher can only take images from outside a site, those used as data in this research were not detailed images.

3.2.6.b. The Data Collection Process

Data were taken from each project of each activity on a weekly basis. In each day, several photographs were taken from a particular project and each photograph recording at least one activity. Photographs were taken from anywhere surrounding the construction site as long as the focus of photographs remained inside the site. The period of data collection data was 10 weeks on average.

3.2.6.c. Data Storage

Every photograph collected as a datum was stored in a computer with identification, location and the date taken as the basis data for the development of an image database.

3.2.7. The Research Data Analysis (The Application of The Safety Assessment System)

Data analysis is a process analysing collected data using a specific method to achieve an objective. This research had as its objective to assess safe construction practices based on information from images collected from four construction sites in Perth (see section 3.2.6.a). The method used was the safety assessment system (see sections 3.2.5). The application of the data analysis process is described in Chapter 7. The flowchart of the data analysis process can be seen in Figure 3.5 adapted from Figure 3.1

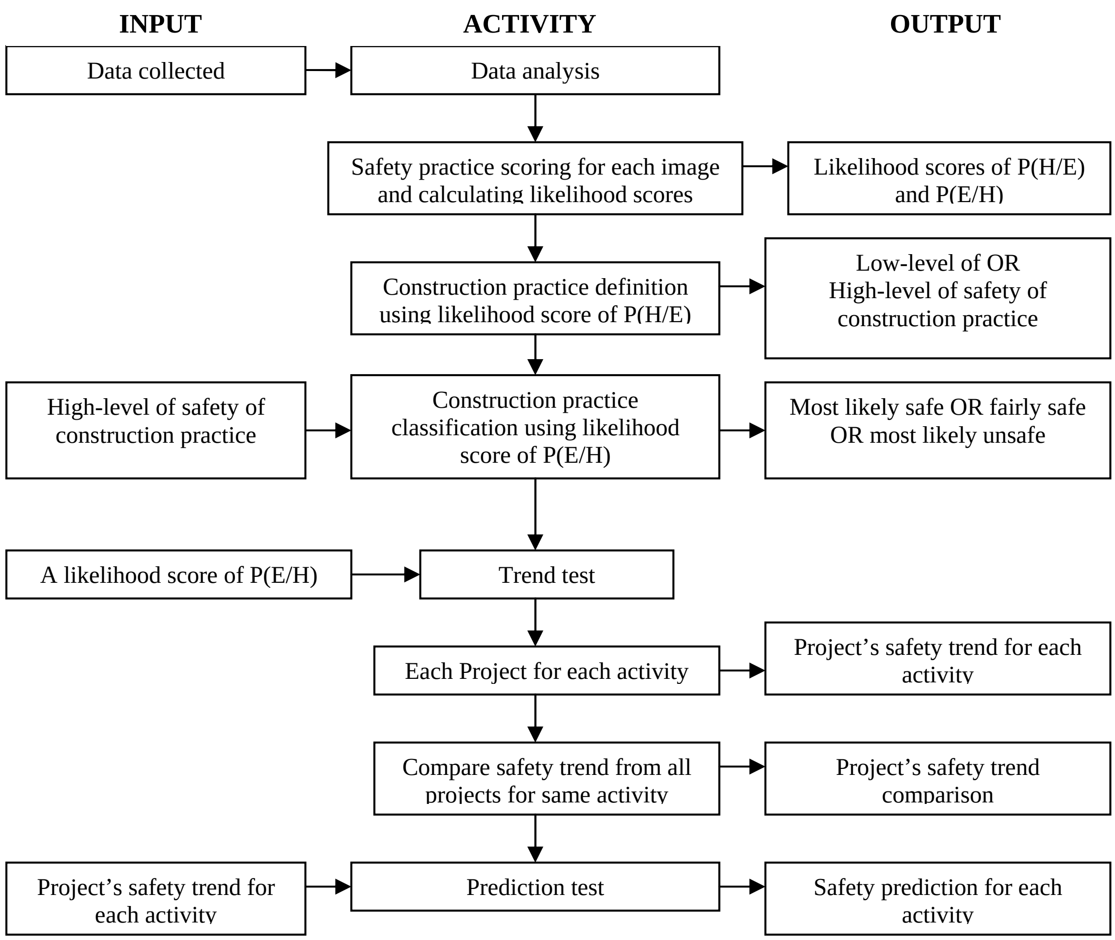

Figure 3.5. The Data Analysis Flowchart

The data analysis process starts by obtaining a score of construction practice safety for each activity observed from each image from which each activity can be defined as high level or low level of safety. All construction practice activities with "high level of safety" definition were classified into one of three classifications: most likely safe, fairly safe, and most likely unsafe. This was achieved in two steps using the Web-based safety assessment system as explained in Chapter 6.The results of this process are likelihood scores and can be used for a safety trend tests. Later a prediction test was conducted based on the safety trend test results. These two tests will be described in Chapter 7.

3.2.8. The Safety Assessment System Refining

The application of the system revealed its weaknesses and needs to be refined (see Figure 3.6). A method to refine the system will be proposed and set out in Chapter 7. A series of four cases using one activity from one construction site as data to demonstrated ways of refining the safety assessment system will be explained respectively.

3.2.9. The Discussion of The Safety Assessment System (SAFE AS)

Research data, images collected from four construction sites on a weekly basis, became data for the application of the safety assessment system. This also tested its reliability to analyse and store larger amounts of data. About 95 cases were analysed and stored using the developed safety assessment system (see Appendix 3). The use of results obtained from the application has been demonstrated. Utilizing construction images as sources of safety-related information and the use of the safety assessment system as a tool of safety control were then discussed (see section 3.1 and Figure 3.6 adapted from Figure 3.1). The discussion in Chapter 7 will reveal system limitation and offer suggestions for its enhancement.

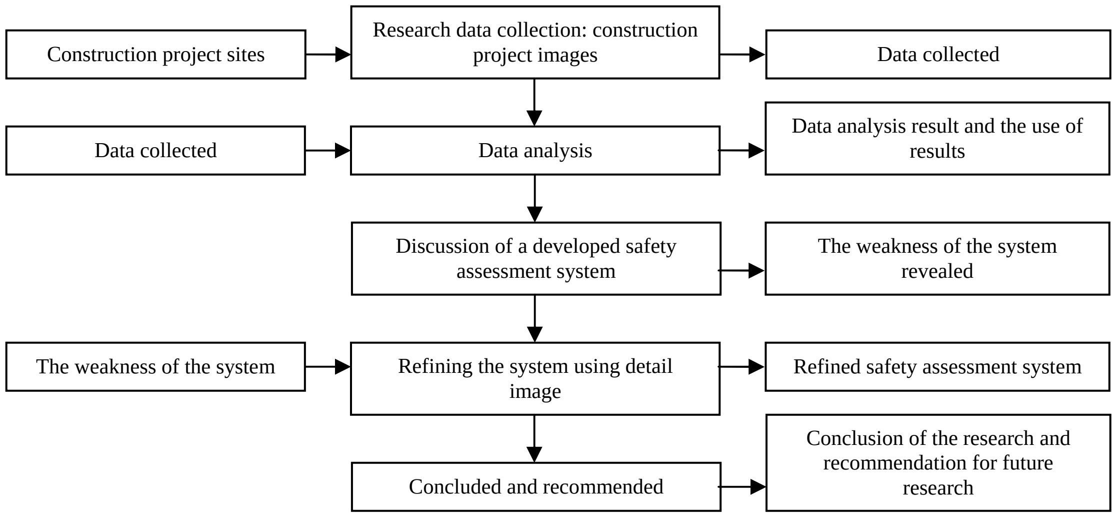

Figure 3.6. The Flowchart of Research Activities After The Application of The Safety Assessment System

3.3. Conclusion of Research Methodology

This chapter has given an appraisal of the research methodology used to achieve the objectives stated in Chapter 1 and explained in Chapter 2. From a compilation of relevant knowledge in section 3.2.1, explained in detail in Chapter 2, the idea of utilizing construction images as sources of safety-related information was proposed and a brief explanation of preliminary investigation on the possibility of the idea is given in section 3.2.2. Details of preliminary investigation activity will be given in Chapter 4.

Problems from preliminary investigation needed to be solved. Three methods were chosen to develop the safety assessment system, are described briefly in section 3.2.3. The development of safety assessment system using three proposed methods is explained briefly in section 3.2.4 and will be set out in detail in Chapter 5.

Developing a Web-based safety assessment system was the next step for an automated process. This has been briefly mentioned in section 3.2.5 and will be clarified in detail in Chapter 6. The Web-based safety assessment system was used to analyse research data collected from four sites in the Perth Metropolitan Area. Three different project activities were chosen as sources of image data. These processes have been mentioned in section 3.2.6.

The application of the safety assessment system using research data has been explained briefly in section 3.2.7. Brief explanation of method to refining safety assessment system has been given in section 3.2.8. After analyzing the data and obtaining the results, trend tests and prediction test were conducted then a short discussion of the system has been described in section 3.2.9. All processes mentioned in sections 3.2.7, 3.2.8 and 3.2.9 would be covered in detail in Chapter 7.

Finally, conclusions and recommendations for future research will be presented in Chapter 8. The following chapters will explain step-by-step the research process.

Chapter 4

UTILISING CONSTRUCTION IMAGES AS SOURCES OF SAFETY RELATED INFORMATION

4.1. Introduction to The Utilising of Construction Images as Sources of Safety Related Information

Information in the form of photographic images is increasingly being used in the study and control of construction practices. In particular, they have been used for sometime to provide details of the methods used, progress, damage, and the condition of a site. A discussion of an image as a source of construction-related information presents in Chapter 2 (see section 2.4.3) and the methodology used describes in Chapter 3.

This chapter will describe the preliminary investigation into the potential use of images as sources of safety-related information and the results and problems will be discussed (section 4.2). To solve the problems, two theories related with uncertainty will be employed, and the explanations and examples of which will be given in sections 4.3 and 4.4. Finally, a method of using past experience case-based reasoning will be proposed and examples given (section 4.5).

4.2. Understanding an Image – A Preliminary Investigation

Based on the idea to use images in a form of photographs as sources of information for safety assessment (section 2.5) there was a need to conduct a preliminary investigation to study their potential uses as data for a safety assessment system. The preliminary investigation then became the first objective of the research (section 2.6).

The methodology explained in Chapter 3, in particular the preliminary investigation (section 3.2.2) is shown in Figure 4.1 (adapted from Figure 3.2) and is explained as follows:

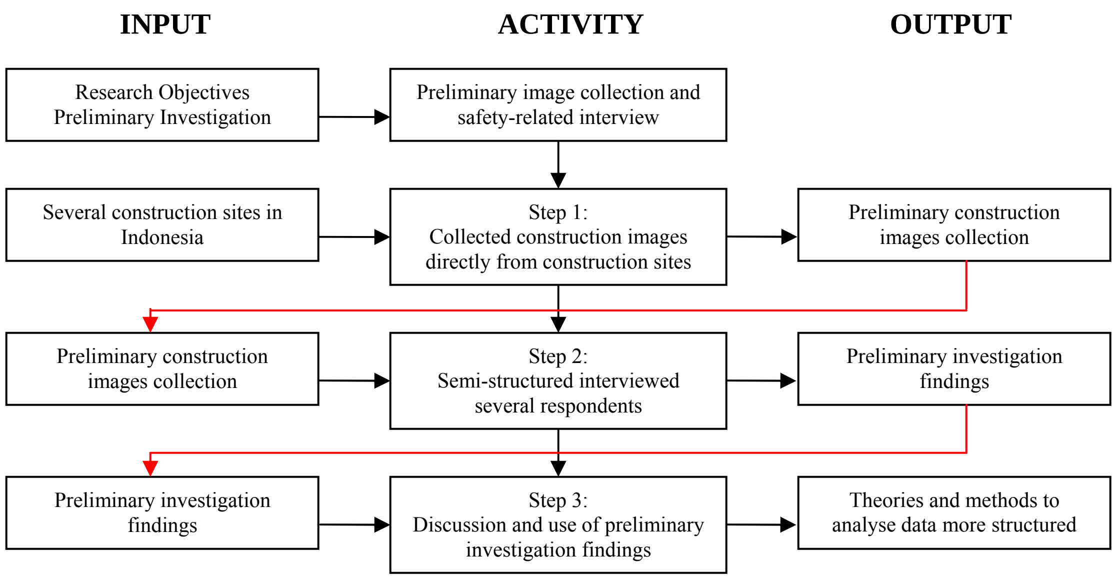

Figure 4.1. The Flowchart of Preliminary Investigation

Step 1: Images were taken directly from construction sites.

The first step was taking images from several construction sites, and neither the images nor the sites were specific. As a result of an early survey in several towns, the most common construction projects were a building projects and the distance between the object (building) and the photographer varied between 20-30 meters. In this step, 41 images were collected from two towns in Indonesia. Figure 4.2 shows two examples of construction images at this step.

(a) (b)

Figure 4.2. A Multi-level Building Project

Step 2: The images were show to experienced construction practitioners (respondents) who were given semi-structured interviews.

In the second step, the collected images were shown to 20 experienced construction practitioners who had been involved in at least one project and a minimum of one year's experience in a similar project. They were interviewed about construction practice safety and are hereinafter called "respondents".

All 41 images were shown to respondents and semi-structured interviews were conducted to collect the information required (section 3.2.2). In this research, it is important to capture as much information as possible by viewing construction images for safety purposes. Respondents were asked about the safety of the practice being undertaken observed from the images. Example of questions has been described in section 3.2.2.b. The information collected from the preliminary investigation would be used as factual data.

Firstly, they were asked about what they learned by observing the images and then what safety construction practices they noticed. For example, in Figure 4.2 (a) when asked what it revealed respondents stated it was a are multi-level building project with bamboo scaffolding was being used, walls were being plastered and electric cables had been installed, there were trees, two white round lamps, visible blue sky, and the top corner of a sign. From Figure 4.2 (b) respondents said it was a multi-level building project with steel system scaffolding, timber formwork, a crane, concrete plates, concrete columns, concrete beams and two construction workers at the top level of the building, there was blue sky, and the top of a tree could be seen. The information revealed from the images was relatively the same so it can be concluded that respondents were in agreement about the common information observed from the images.

When asked about the safety of the access scaffold method being used in Figure 4.2 (a) answers were varied. Some said the method was likely safe, some said likely not safe, some said partly safe with expression such as a little bit safe, quite safe, etc. and some said they did not know. In this point, the safety information revealed from the same image was different showing there was some disagreement about safety information observed from the image.

Respondents were then asked the reasons for their answers. The reasons for the first question "the safety of the access scaffold method being used" can be summarised as follows:

1. Respondents who said that the method was likely safe made their justification based on experience. In past projects, they had used the same method and no accidents had happened thus using bamboo scaffolding in such a way is safe.
2. Respondents who said that the method was likely not safe justified their answers also based on experience. There had been accidents using bamboo scaffolding.
3. Respondents who had said that the method was partly safe justified themselves based on experience as well, saying that the method was safe as they had used it in past projects without accident, however if they used the method, they had to make sure about connections between the bamboos. They felt the method was only partly safe because they were not sure about how the connections were made

whether they were correct or not. It seems that the project was using black rope to tie up bamboo's connection, but they were not sure what kind of rope it was.

4. Respondents said they did not know because they had never used bamboo scaffolding in past projects.

From their answers it can be noted that some respondents did not have experience of using bamboo scaffolding and others did with two different sequences: accidents did not occur and accidents did occur.

Some answered based on their interpretation of the information provided by the image. The finding related to image interpretation was interested, further questions were asked. In common they said that the images did not show the activity in detail thus their answers were based on interpretation of the uncertain information observed from the images.

With regard to their answer, it seems there were two main reasons of the answers, based on experience and based on information interpretation. From the first two steps, the results and problems revealed as the preliminary investigation findings were as follows.

a. Results:

1. Respondents could answer questions about information by observing the images thus it can be concluded that a construction image can be used as sources of information,

2. Respondents gave a relatively similar answers about common information thus it can be concluded that there was an agreement of that kind information provided by the images, and

3. Respondents gave several different answers about safe construction practice information thus it can be concluded that there was some disagreement about safety justification using information provided by the images. There were

basically two main reasons for disagreement: Experience and Interpretation of uncertain information.

b. Problems:

Based on respondents' answers regarding safety judgment, it was assumed the results of preliminary investigation to study the potential use of construction images as sources of safety related information were influenced by respondents' knowledge of construction practices, in particular safe practice knowledge. From these results, it was clear new problems for utilizing images were revealed and need to be addressed:

1. How to use past experience, either personal or from other persons for particular construction methods?
2. How to make a relatively similar judgment about safe construction practices being performed based on the interpretation of the information from construction images?

Besides the results and problems revealed, at this point, it can be stated that the purpose of preliminary investigation to study the potential use of images as sources of safety related information was achieved, however there was the third step to find methods that can be used to overcome these problems (see figure 4.1).

Step 3: A discussion and the use of preliminary investigation findings

Based on the assumption that respondents' safety knowledge was a major factor that influenced the preliminary investigation findings, to solve the problems a knowledge-based approach was employed with the use of Artificial Intelligence. A feasible benefit of Artificial Intelligence as an analytical method for the knowledge-based approach has been discussed in section 2.4.2.

Two problems were revealed from the second step. First it was related to the reuse of past experience. When respondents were asked about construction practice safety, they followed a path of reasoning obviously relying on their personal experience. Therefore, respondents with no experience of one particular activity could not answer questions. To overcome problems related to the reuse of past experience, one method of Artificial Intelligence related with reasoning based on past experience, Case-Based Reasoning was proposed.

Regarding the second problem revealed in the preliminary investigation, dissimilar safety judgments, no safety assessment system and method exist to assess safe construction practice using information from construction images. There was, therefore, a need to develop a system using images which furthermore could be potentially used to overcome problem related to disagreement. The development of the safety assessment system based on the preliminary investigation findings was as follows:

1. Step 1: It was found that respondents did not give their safety judgment based on the same basis such as a safety checklist, but past experience and interpretation of uncertain information from images. Therefore, the first step had to be making safety checklists with basic questions on safety judgment.

2. Step 2: Respondents expressed their safety judgment in a qualitative way. It was assumed that the same qualitative expression did not always have the same meanings; it depended on a respondent’s preference. Therefore, the second step was to establish safety scores to express judgments in a quantitative way based on a respondent’s safety knowledge and degree of confidence.

3. Step 3: All safety scores based on the safety checklist needed to give meaning in a comprehensive way. Artificial Intelligence was to deal with the uncertainty problems stated in step one. One tool of Artificial Intelligence is probability, a quantitative way of dealing with it. A number of theories have been devised to deal with uncertainty. These include classical probability, Bayesian probability, Hartley’s theory based on classical sets, Shannon’s

theory based on probability, Dempster-Shafer's theory, and Zadeh's fuzzy theory.

To utilize information from images for safety assessment purpose, a relationship needs to be understood between the information provided by the image and its interpretation based on the safety knowledge of the safety officer or respondent. That relationship is as follows:

> An observer who has safety knowledge about the construction method depicted by the image such as the access scaffold was not connected properly can predict the consequences of that method that it will probably collapse and cause workers to be injured. Hence, it can be stated that one event that has occurred may cause another. This term matches conditional probability, which says "The probability of an event A, given that event B occurred, is called a conditional probability". P $(A|B)$ indicates this conditional probability.

From the above explanation, to make a relatively similar safety justification of construction practice based on interpretation of uncertain information collected from an image, the conditional probability approach was chosen. To overcome problems revealed in the preliminary investigation, two theories of Artificial Intelligence, case-based reasoning and conditional probability were used to develop the safety assessment system, the second objective of the research (section 2.6). Explanations of the theories used are given in following sections: section 4.3 for Bayes' Theorem, section 4.4 for fuzzy logic theory, and section 4.5 for Case-Based Reasoning.

4.3. Bayes' Theorem

In section 4.2, all safety scores of construction activity observed from images based on a safety checklist need to be clearly defined. The use of conditional probability was considered using Bayes' Theorem formula. This will allow construction practice to be defined at two levels of safety. The Bayes' Theorem and its example are as follows.

4.3.1. The Bayes' Theorem

Bayes' Theorem is a theory commonly used for decision three analyses in business and the social sciences (Gravetter and Wallnau, 1992; Giarratano and Riley, 1994; Bouchon-Meunier, B et al., 2000). A decision tree analysis provides the answer to a problem from a predetermined set of possible answers and derives a solution by reducing a set of possibilities with a series of questions that prune the search. Because the answer set must be predetermined, decision trees do not work well for scheduling, planning, or synthesis problems (Giarratano and Riley, 1994). In his book, *Expert Systems: Principles and Programming*, 2^{nd} ed. Giarratano and Riley stated that two successful Bayes' Theorem applications are MYCIN and PROSPECTOR. MYCIN is a system of medical diagnosis for bacteremia and meningitis infections and PROSPECTOR for mineral oil exploration.

Giarratano and Riley (1994) quote an example of Bayesian decision-making used to decide favorable sites for mineral exploration in PROSPECTOR. Initially, the prospector must decide what the chances are of finding oil based on the evidence to assign the subjective prior probabilities for oil. The basis of Bayes' Theorem is a conditional probability, that is the probability of proposition A given an event B. Related to PROSPECTOR, as an example, an event B is the evidence to assign the prior probabilities for oil whereas proposition A is a hypothesis of the availability of oil in an certain area.

Given that A is the proposition, the conditional probability $P(A/B)$ can be interpreted as the ***degree of belief*** that A is true, given B. For the purposes of this research, the term "degree of belief" can be better expressed as "degree of confidence". If $P(A/B) = 1$, then A is belief to be certainly true. If $P(A/B) = 0$, then A is belief to be certainly false while other values, $0 < P(A/B) < 1$, mean that A is not entirely sure to be true or false.

This type of ***hypothesis*** is used for some propositions whose truth or falseness is not known for sure on the basis of ***evidence***. The conditional probability is then referred to as the ***likelihood*** or ***degree of confidence***, as in *P(H/E)*, which expresses the likelihood of a hypothesis, H, being true based on evidence, E.

$$P(H/E) = \frac{P(E/H)P(H)}{P(E)} \qquad \text{(Equation 4.1)}$$

The Equation 4.1 is known as Bayes' Theorem formula.

Where:

P(H/E) is a degree of confidence of hypothesis (H) is true given evidence (E) occurred.

P(E/H) is a degree of confidence of evidence (E) is occurred given assumed (prior) hypothesis (H) is true.

P(H) is a probability of hypothesis (H).

P(E) is a probability of evidence (E).

For example, given an image in Figure 4.3:

Figure 4.3. A Construction Accident Image

An event may be

“The concrete columns that supported the slab were inadequate to support the load”

And the proposition is

“The concrete slabs collapsed”

Refer to Equation 4.1 and Figure 4.3 all the meanings of expressions are as follows:

P(H/E) is a degree of confidence that the concrete columns were inadequate to support the load given that the concrete slabs collapsed (refer to Figure 4.3).

P(E/H) is a degree of confidence that the concrete slabs collapsed based on hypothesis the concrete columns was inadequate to support the load (refer to Figure 4.3).

P(H) is a probability of hypothesis (H) that that the concrete slabs collapsed (refer to Figure 4.3).

P(E) is a probability of evidence (E) that the concrete columns were inadequate to support the load (refer to Figure 4.3).

In the real world, the more general and realistic situations are based on uncertain hypotheses and uncertain evidence. For general cases, assume that the degree of confidence in the complete evidence, E, is dependent on the partial evidence, e, by $P(E/e)$. The score of E is an average of the scores of e. Referring to Figure 4.3, it can be stated that evidence (E) is the concrete columns were inadequate to support the load, and the partial evidence (e) is the support scaffolds were removed earlier than planned. Complete evidence is the total evidence which represents all possible evidence, and hypotheses, which comprise E. The partial evidence, e, is the portion of E that is known. Partial evidence is known, then E = e and $P(E/e) = P(E)$.

A more complex situation arises if there is compound evidence, i.e. multiple pieces of evidence and expressed formally:

IF $E_1, E_2, \ldots$ AND E_N THEN H

For the example, using Figure 4.3, the statement can be expressed:

E_1 is the support scaffold was removed

E_2 is concrete columns were inadequate to support the load

H is the concrete slabs collapsed

Then the logic statement can be expressed formally:

"IF the support scaffolds were removed AND the concrete columns were inadequate to support the load THEN the concrete slabs collapsed."

So Equation 4.1 becomes Equation 4.2 as follows:

$$P(H / E_1 \cap E_2 \cap ...E_N) = \frac{P(E_1 \cap E_2 \cap ....E_N / H)P(H)}{P(E_1 \cap E_2 \cap ...E_N / H)P(H) + P(E_1 \cap E_2 \cap ...E_N / H')P(H')}$$

(Equation 4.2)

Where the symbols are as before and the meaning of symbol using statement for Figure 4.3 as an example is:

$P(H/E_1 \cap E_2 \cap ...E_N) = P(H/E_{comb})$ is a degree of confidence of hypothesis (H) is true, given compound evidences $E_1, E_2, ...E_N$ are occurred.

In this example, $P(H/E_{comb})$ means a degree of confidence of the concrete slabs collapsed because of the support scaffold was removed and the concrete columns were inadequate to support the load.

$P(E_1 \cap E_2 \cap ...E_N/H) = P(E_{comb}/H)$ is a prior probability which is degree of confidence of evidences $E_1, E_2, ...E_N$ are true given hypothesis (H) occurred.

In this example, $P(E_{comb}/H)$ means a prior probability that the support scaffold was removed and the concrete columns were inadequate to support the load then caused the concrete slabs collapsed.

$P(E_1 \cap E_2 \cap ...E_N/H') = P(E_{comb}/H')$ is a prior probability which is degree of confidence of evidences $E_1, E_2, ...E_N$ are true given hypothesis complement (H') occurred.

In this example, $P(E_{comb}/H')$ means a prior probability that the support scaffold was removed and the concrete columns were inadequate to support the load then caused the concrete slabs not collapsed.

P(H) is a prior probability of hypothesis (H). In this example, *P(H)* means a prior probability of the concrete slabs collapsed.

P(H') is a prior probability of hypothesis complement (H'). In this example, *P(H')* means a prior probability of the concrete slabs not collapsed.

The Equation 4.2 can be expressed as: The degree of confidence or likelihood of hypothesis because of the occurrences of the evidences $P(H/E_{comb})$, that comes from the calculation of the degree of confidence an occurrence of evidences that caused the hypothesis $P(E_{comb}/H)$ multiply by the probability of hypothesis $P(H)$, divided by the sum of the degree of confidence an occurrence of evidences that caused the hypothesis $P(E_{comb}/H)$ multiply by the probability of hypothesis $P(H)$ and the degree of confidence an occurrence of evidences that caused the hypothesis complement $P(E_{comb}/H')$ multiply by the probability of hypothesis complement $P(H')$.

In summary, the Bayes' Theorem formula has three basic relations in probability, union ($\cup$), intersection ($\cap$) and complement. An explanation of the first two is as follows. The meaning of union is a summation, while intersection is a multiplication. For example, there are two variables A and B. Probability of A union B means probability of all possible events as member of variables A and B therefore, probability A union B equals summation of probability A and probability B.

$$P(A \cup B) = P(A) + P(B) \quad \text{(Equation 4.3)}$$

Meanwhile, probability of A intersection B means only events that become a member of A that also a member of B are considered therefore, probability A intersection B equals multiplication of probability A and probability B.

$$P(A \cap B) = P(A) * P(B) \quad \text{(Equation 4.4)}$$

An explanation of complement is as follows. Different with union and intersection which events are affecting each other, a thing and its complement is mutually exclusive, that all events are not affecting each other. Mutually exclusive means that a thing and its complement cannot be both at the same time. For example, a safe construction practice cannot exist at the same time with an unsafe construction practice. Because of the highest value of probability is 100% or 1.00 therefore the sum of all possible events of a thing and its complement is equal 1.

$$P(A) + P(A') = 1 \text{ or } P(A') = 1 - P(A) \quad \text{(Equation 4.5)}$$

4.3.2. An Example of Bayes' Theorem

To demonstrate the Bayes' Theorem, a simple example of a floor tile crack using a Brand A floor tile within one year is given. Employ the Bayes' Theorem formula there should be a prior probability, that is a probability from an assumption based on a hypothesis.

Example:

Using data given by an administrator from his record there is a prior probability of 0.5 of floor tile crack using a Brand A floor tile within one year. This means that 50% of tiles were cracked using a Brand A floor tile within one year. This value of 50% can be obtained from every single record of a Brand A floor tile that was cracked within one year using Equation 4.4. Table 4.1 shows the hypothetical probabilities of a tile crack using a Brand A floor tile within one year. This data were come from an administrator record.

Table 4.1. Hypothetical Probabilities of a Floor Tile Crack Within One Year

	Brand A	Not Brand A	Total of Rows (Brand A + Not Brand A)
Crack (C)	0.5	0.1	0.6
Not crack (C')	0.3	0.1	0.4
Total of Columns (Crack + Not Crack)	0.8	0.2	1.0

Using Table 4.1, the probabilities of all events can be calculated. Some probabilities are:

1) The probability of a tile crack (C) for both Brand A and not Brand A, or the sample space, is $P(C) = 0.6$
2) The probability of not crack (C') for the sample space is $P(C') = 0.4$
3) The probability of using Brand A is $P(A) = 0.8$
4) The probability of not using Brand A is $P(A') = 0.2$
5) The probability of a floor tile crack using Brand A is $P(C \cap A) = 0.5$

6) The probability of the floor tile will crack, given that Brand A is used, is

$$P(C/A) = \frac{P(C \cap A)}{P(A)} = \frac{0.5}{0.8} = 0.625$$

7) The probability of the tile will crack, given that Brand A is not used, is

$$P(C/A') = \frac{P(C \cap A')}{P(A')} = \frac{0.1}{0.2} = 0.50$$

Probabilities (5) and (6) seem to have similar meanings from their description. However, probability (5) is only the intersection of two events, while probability (6) is called a conditional probability. The conditional probability states the probability of event C given that event A occurred P (C $|$A). The meaning of the intersection (5) is:

> "If a floor tile is picked randomly, then 0.5 of the time it will be Brand A and have cracked"

In contrast, the meaning of the conditional probability (6) is:

> "If a Brand A floor tile is picked, then 0.625 of the time it will have cracked"

Suppose an administrator has a floor tile and does not know its brand, what is the probability that if it cracks, it is Brand A? Not Brand A? This question called inverse probability states the probability of an earlier event given that a later one occurred. According to Table 4.1 and some probabilities stated above, from the conditional probability (6), there is a 0.625 or 62.5% probability of a Brand A floor tile crack within one year, while based on (7), the probability of a non-Brand A floor tile crack within one year is 0.50 or 50%. Given that a tile cracked, the probability of it being a Brand A can be stated using conditional probability and the results (1), (5).

$$P(A/C) = \frac{P(C \cap A)}{P(C)} = \frac{0.5}{0.6} = 0.833$$

The meaning of this result is:

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“The tile cracked, then the probability of the brand is a
Brand A is 0.833 or 83.3%”
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Using the example above, it can be seen that Bayes’ Theorem is the right method to calculate the probability of an event based on another event. Suppose Brand A has 0.3 or 30% probability of cracking (see Table 4.1), what is the meaning of 0.3? Is Brand A good? Or is it quite good? Or is it bad? Or is it a little bit bad? How if the probability of Brand A not cracking change by 0.37, does still have the same meaning as 0.3? The problem associated with given the meaning of a number cannot be solved using Bayes’ Theorem, therefore a fuzzy logic theory was chosen. More details about the fuzzy logic theory will be given in following section (section 4.4).

4.4. Fuzzy Logic Theory

The explanation in section 4.3 states the Bayes’ Theorem approach has been used to calculate the probability of an event given another event occurs. The example in section 4.3.2 demonstrates how it possible to calculate the probability of event given another event. However, another problem was revealed from a result, as explained in section 4.3. The Bayes’ Theorem cannot deal with the need of giving a meaning of a number. The theory that can deal with the problem is fuzzy logic. This will be explained briefly in section 4.4.1 and an example given in section 4.4.2.

4.4.1. The Fuzzy Logic Theory

In everyday life, the real world is not just yes or no, right or wrong, black or white. The meaning of something is perhaps best indicated by a shade of gray, rather than by the black or white of a simple dichotomy. Just as there are many shades of gray, so too there are many different gradations of meaning in the real world. For example, a proposition “John is *tall*” is may be true to some degrees: *A Little True, Somewhat True, Fairly True*, and so on, in contrast to a proposition “John is *exactly 150 centimeters tall*” that represents a proposition which is either true or false. Terms such as “*A Little”, “Somewhat”, “Fairly*” are called fuzzy terms of natural language.

The proposition “John is tall” has degrees of truth called fuzzy proposition, whereas the proposition “John is exactly 150 centimeters tall” is called a classic proposition.

The traditional way of representing which objects are elements of a set is in term of a *characteristic function*. If an object is an element of a set, then its characteristic function is 1. If it is not an element of a set, then its characteristic function is 0. Sets to which this applies are called *crisp sets*. This type of thinking is called two-valued or *bivalent logic*, in which true or false are the only possibilities. The problem with this bivalent logic is that the real world lives in an analog. Real world things are generally not in one state or another, but belong partially to a set. This is a basic concept of *fuzzy sets*. The degree of membership in a fuzzy set is measured by a generalization of the characteristic function called the *membership function*. This membership function is defined as: μ_A (x): X → [0,1] states that it maps all elements of X into the codomain of real numbers defined in the interval from 0 to 1 and symbolized by [0,1]. It is a real number $0 \leq \mu_A \leq 1$, where 0 means no membership and 1 means full membership in the set.

While it is difficult to think of an object as being only partially in a set, another way is to consider membership functions as representing the degree to which an object has some attribute. This concept of degree of attribute means how well one object conforms to some attribute and this degree is represented by a particular value such as 0.5, called a *grade of membership*.

Depending on application, a membership function may be constructed from one person’s opinions or from a group of people. Intuitively, the membership function for a group may be thought of in terms of an opinion poll. It is important to realize that it is really not a frequency distribution. The opinions are likelihood or degree of confidence because it expresses a personal belief. The S-curve of a membership function is a mathematical function that is often used in fuzzy sets as a membership function. In this definition α, β, and γ are parameters that may be adjusted to fit the desired membership data. Depending on the given membership data, it may be possible to give an exact fit for some values of α, β, and γ, or the fit may only be approximate. The S-curve is flat at a value of 0 for $x \leq \alpha$ and at 1 for $x \geq \gamma$. In between α and γ the S-curve is a quadratic function of *x*. As shown in Figure 4.4, the β parameter corresponds to the crossover point of 0.5 and is (α + γ)/2. The mathematical function for the S-curve is defined as follows:

$$S(x; \alpha; \beta; \gamma) = \begin{cases} 0 & \text{for } x \leq \alpha \\ 2\left(\dfrac{x-\alpha}{\gamma-\alpha}\right)^2 & \text{for } \alpha \leq x \leq \beta \\ 1 - 2\left(\dfrac{x-\gamma}{\gamma-\alpha}\right)^2 & \text{for } \beta \leq x \leq \gamma \\ 1 & \text{for } x \geq \gamma \end{cases}$$

(Equation 4.6)

Where:

α is a minimum value of the parameter,

β is a value of the crossover point of membership function, and

γ is a maximum value of the parameter.

A plot of the S-curve for membership function is shown in Figure 4.4.

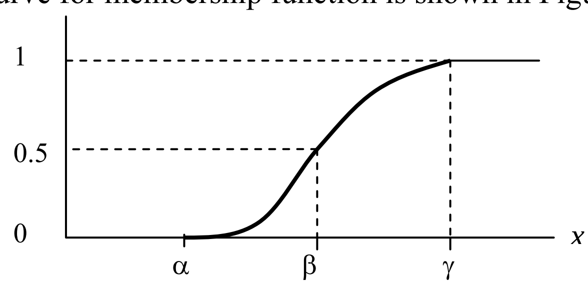


Figure 4.4. The S-Curve of The Membership Function in Fuzzy Logic

4.4.2. An Example of The Fuzzy Logic Theory

Referring to the previous example of the fuzzy propositions "John is tall" and additional information states he is an eight years old boy. Suppose a group of people were asked to specify a minimum value for the word *tall* for the eight years old boy. Probably no one would say someone less than 130 centimeters is tall. Likewise everyone would probably say someone of 150 centimeters and over is tall. In between 130 centimeters and 150 centimeters, the percentage of people agreeing as to what constitutes tall is analogous to the membership function curve shown in Figure 4.4. For this particular function, the crossover point of tall is 140 centimeters where μ = 0.5. For the "tall" membership function, the S-function using equation 4.6 is the following:

$$S(x; 130; 140; 150) = \begin{cases} 0 & \text{for } x \le 130 \\ 2\left(\dfrac{x-130}{150-130}\right)^2 = \dfrac{(x-130)^2}{200} & \text{for } 130 \le x \le 140 \\ 1 - 2\left(\dfrac{x-150}{150-130}\right)^2 = 1 - \dfrac{(x-150)^2}{200} & \text{for } 140 \le x \le 150 \\ 1 & \text{for } x \ge 150 \end{cases}$$

Example:

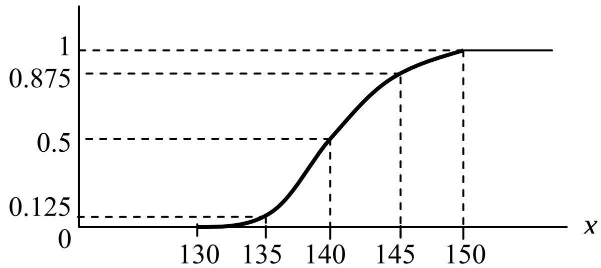
1. Paul is 145 centimeters tall. What percentage of people would agree that Paul is tall? The value 145 is in between 140 and 150, and so given x = 145 then the percentage is:

$$1 - \frac{(145-150)^2}{200} = 1 - \frac{(-5)^2}{200} = 0.875 = 87.5\%$$

2. Simon is 135 centimeters tall. What percentage of people would agree that Simon is tall? The value 135 is the value in between 130 and 140, and so given x = 135 then the percentage is:

$$\frac{(135-130)^2}{200} = \frac{(5)^2}{200} = 0.125 = 12.5\%$$

The S-Curve for the example above is as follows:



The result showed that 87.5% would agree that someone of 145 centimeters is classified as "tall" and 12.5% would agree that someone of 135 centimeters is classified as "tall". To give meanings of the value of 87.5% and 12.5%, then fuzzy terms of natural language are used. The value of 87.5% is close to 100% so it can be classified as "*most likely* tall". The value of 12.5% is far from 100% so it can be classified as "*a little bit* tall". The terms "most likely" and "a little bit" can be replaced with other natural language terms, such as "very', "not', "sort of", so on.

The explanations and examples of the Bayes' Theorem and the fuzzy logic theory in sections 4.3 and 4.4 have shown that these theories can be used to solve a problem associated with uncertainty revealed from preliminary investigation. However, problem associated with reusing past experience for reasoning has not yet been solved. To deal with this problem a method called case-based reasoning was employed, a brief explanation of which follows.

4.5. Case-Based Reasoning

A construction project is a process to build a construction product. For similar projects there are similar problems or cases are repeated. Previous project(s) have problems and their solutions, but they are hardly ever used to solve similar problems for subsequent project(s). For example, in a particular building project, there is the problem of the scaffold. What material should be used? How should the material be tied? Is that method safe construction practice? Answers to these questions give a chance to learn from previous project(s) about successes and failures to ensure better performance in future project(s). Currently, there is an approach that uses information (problems and their solutions) from previous events for future events called Case-Based Reasoning (CBR). Case-Based Reasoning and its use will be briefly reviewed in the following sections.

4.5.1. The Theory of Case-Based Reasoning

The following example will be briefly described an application of Case-Based Reasoning (CBR).

Example:

It is planned to erect a building with foundations 1.5 meters deep with on a sandy area. The plan-engineer remembers he did this and the sand was dug on a 35^o slope. On 45^o slope and more, the sand collapsed so it was decided. Thus, the plan-engineer decides to dig the sand on a 35^o slope to avoid collapsed.

Here he is using his experience to decide which method to use to build the foundation. The engineer is employing case-based reasoning (CBR) by remembering previous similar situations to the current one to help solve the new problem.

In case-based reasoning, there are two main terms, Reasoning and a Case. What is reasoning? Reasoning means thinking to form conclusions, make inferences or judgments and to be an evidence or argument used in thinking or argumentation. Another definition suggests reasoning is a process using a logical, rational, and analytic thought to arrive at conclusion of an event or a case. Reasoning in the traditional view of both artificial intelligence and cognitive psychology, is a process of remembering abstracts and composing them with each other (Kolodner, 1993).

What is a case? A case is a record of a previous experience or problem (Pal and Shiu, 2004). It is a contextualized piece of knowledge representing an experience (Kolodner and Leake, 1996). Cases, which represent specific knowledge tied to specific situations, represent knowledge at an operational level; that is, they make explicit how a task was carried out or how a piece of knowledge was applied or what particular strategies for accomplishing a goal were used (Kolodner, 1993).

Cases come in many shapes and sizes. They may cover a situation that evolves over time (as in designing a building), they may represent a snapshot (as in choosing a particular type of window for a building), or they may cover any time slice in between those extremes. They may represent a problem-solving episode (as do architectural cases); associate a situation description with an outcome (as in legal cases), or some combination.

What is common to all cases is that they represent an experienced situation which remembered later, forms the context in which the knowledge embedded in the case are presumed applicable. The nature of cases is summarised below (Kolodner, 1993):

1. A case represents specific knowledge tied to a context. It records knowledge at an operational level.
2. Cases can come in many different shapes and sizes, covering large or small time slices, associating solutions with problems, outcomes with situation, or both.
3. A case records experiences that teach a useful lesson: that have the potential to help people achieve a goal or a set of goal more easily in the future. That warns about the possibility of a failure, or a point out an unforeseen problem.

There are two major functional parts to a case: the lesson(s) it teaches or it content, and the context in which it can teach its lesson(s). Described by its indexes; a case designates the circumstances in which it would be appropriately retrieved. There are three major parts to the content of any case: problem/situation description, solution, and outcome. The problem/situation description is the state of the world when the episode in the case occurred, and if appropriate, what problems needed solving at that time. Solution means the stated or answered to the problem specified in the problem description. Outcome is the resulting state of the world when the solution was carried out.

Reasoning is often modeled as a process that draws conclusions by chaining together generalized rules starting from scratch. Case-based reasoning (CBR) takes a very different view as it means reasoning based on previous cases or experiences. The primary knowledge source is not generalized rules but a memory of stored cases. New solutions are generated not by chaining, but by retrieving the most relevant cases from memory and adapting them to fit the new situations (Leake, 1996). CBR emphasizes manipulation of cases over composition, decomposition, and re-composition processes (Kolodner, 1993). The approach is based on two tenets about the nature of the world. The first is that *the world is regular*: similar problems have similar solutions. Consequently, solutions for similar prior problems are a useful starting point for new problem solving. The second is that *types of problems an agent encounters tend to recur*. Consequently, future problems are likely to be similar to current problems. If the two tenets are holding together, it is worthwhile to remember and reuse prior reasoning: case-based reasoning is an effective strategy.

Regardless of whether the problem-solving outcome is a success or a failure, the case-based reasoners learns from their experience and their knowledge are constantly changing as new experiences give rise to new cases that are stored for future use. They learn from experience to exploit prior successes and to avoid repeating failures. CBR tasks are often divided into two classes, *interpretation* and *problem solving*. Interpretive case-based reasoning uses prior cases as reference points for classifying or characterizing new situations whereas problem-solving case-based reasoning uses prior cases to suggest solutions that might apply to new circumstances. These two classes will be described as follows.

a. Interpretive Case-Based Reasoning

In interpretive case-based reasoning, the reasoner's goal is to form a judgment about or classification of a new situation by comparing and contrasting it with case(s) that have already been classified. In its simplest form, it involves four steps. First, the reasoner must perform a current situation assessment to determine which features are really relevant: *Proposed*. Second, based on this assessment, by comparing and contrasting, the reasoner retrieves a relevant prior case(s): *Justification*. Third, the reasoner then compares these cases to the new situation to determine which interpretation apply: *Criticism and Evaluate*. Fourth, the current situation and the interpretation are the saved as a new case on which to base future reasoning: *Store*. Interpretive case-based reasoning is used for tasks such as classifying a new situation in context, showing cause or the demonstration of the rightness of an argument, position, or solution, or predicting the effect of a solution.

b. Problem Solving Case-Based Reasoning

The goal of problem-solving case-based reasoning is to apply a prior solution to generate a solution for a new problem. Unlike interpretive one, problem-solving CBR involves three steps: *Proposed*: case(s) retrieval by extracting the solution from some retrieved cases, *Adaptation*: the process of fixing an old solution to fit a new situation, and *Criticism*: the process of critiquing the new solution before trying it out. In the adaptation stage, the similarities and differences between new and prior cases are used to determine how the solution of the previous case can be adapted to fit the new situation. When presented with a new problem, the CBR system uses a situation assessment to generate a problem description and searches for a prior problem with a relevant problem description. The solution of the most relevant problem is used as the starting point for generating a solution to the new problem. Case-based problem solving reasoning has been applied to a wide variety of problem solving tasks, including planning, diagnosis, and design. In each of these tasks, cases are useful in both suggesting solutions and in warning of possible problems that might arise. After a solution has been generated, the final step is to apply it, repair it if problems arise and to learn from the experience.

The process of both classes of CBR can be simplified as illustrated in Figure 4.5 which indicates the primary processes required. First and foremost, partially matching cases must be retrieved to facilitate reasoning. Thus, case retrieval is of prime importance. In the research, because of time limitations, the system adapted only one class of CBR, interpretive case-based reasoning.

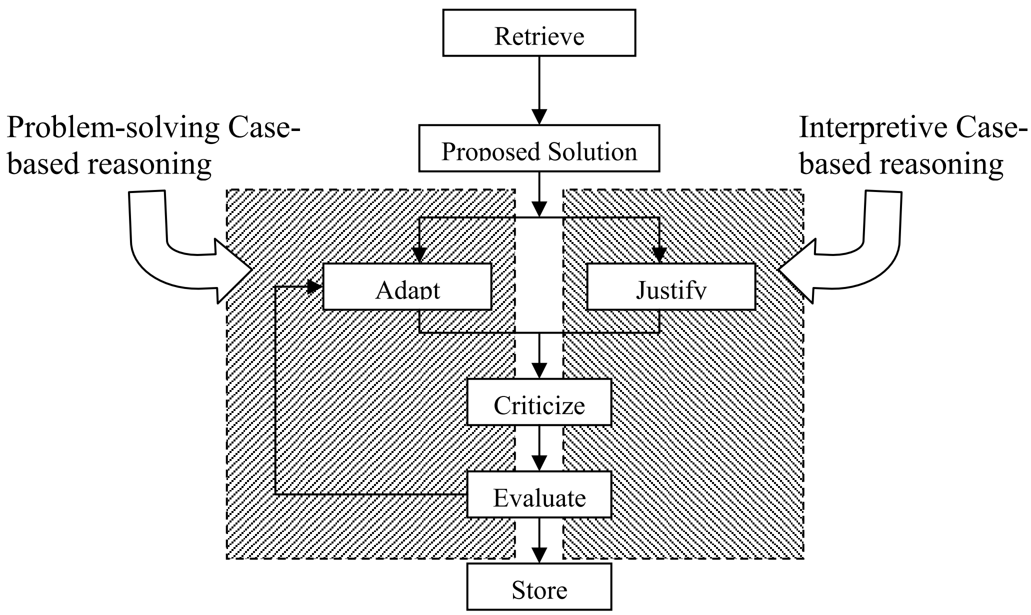


Figure 4.5. The Case-Based Reasoning Process

Source: Case-based Reasoning, AAAI Press/The MIT Press, page 36, with modification

4.5.2. An Example of Interpretive Case-Based Reasoning

Interpretive case-based reasoning involves four steps: proposed, justification, criticism and evaluate, and stored (see section 4.5.1). In Kolodner (1993), one example of interpretive case-based reasoning is HYPO, works in the domain of law. It takes as input a legal situation and as output it creates an argument for its client. HYPO's reasoning process has several steps (Kolodner, 1993) and if this process is joined together with the basic steps of interpretive case-based reasoning, then the process is as follows:

a. Proposed

Analyse the case for relevant factors and retrieve cases that share those factors.

b. Justification

Position the retrieved cases and separate them into those that support the point the arguer wants to make and those that support an opposing point then select the most on-point cases from each set.

c. Criticism and evaluate

Argue approach method: 1. the most on-point case that supports its point is chosen to make the point, 2. the strongest case that makes the opposing point is chosen to counter it and 3. the differences between the two cases are examined and cases that can address the differences and support the arguer's point are chosen to rebut the counterarguments.

Followed by the analysis which is done while arguing the issue is used to explain and justify the arguer's point. Then, hypothetical cases are created and used to test the analysis that has been created.

d. Stored

Stored all relevant information in a database for future use.

The described process can be illustrated using a simple and more commonsensical domain as follows:

Example:

> George, a two-years experienced contractor, got a new project which is a two storey residential house. Now, he is arguing with his new project owner. The case is George wants to provide Personal Protective Equipment (PPE) in his project but the owner objected to provide them. The first things George has to do in arguing his case is to analyse the relevant factors. Accidents can happen in project site, so accident is a factor. Related to accident is safety and so safety is a factor. The availability of PPE in project site is also a relevant factor here.

George recalls cases in which accident, safety, and PPE were factors. First case, his colleagues as contractor have experiencing accidents in their project similar with George's project. Common accidents that happen in two-storey building such as: struck or fallen by objects, hand/finger injuries, and electrical shock. Second, his other colleagues have no accident records in their projects when the projects providing PPE. Their cases supported his point, both share the same factors: accident, safety, and Personal Protective Equipment (PPE). Thus, George could appropriately create an argument based on either.

George creates a three-ply argument based on these cases. First, he argues that his project should be able to provide PPE because project site is dangerous environment. Second, he anticipates that the owner will focus on the occurrence of accidents, pointing out that the two-storey building is just a small project therefore accidents more rarely. Third, he will use his colleagues' cases to show that PPE is necessarily needed because there was accidents happen even in a small project similar with his project.

Discussion of example:

In this example, George has used CBR to attain his goal, that provide PPE in his two-storey building project. He develops arguments based on stored cases, either project with accidents or project without accidents, in his memory. He **proposed** by analyse factors that relevant with his case: accidents, safety, and PPE, then retrieve past cases that have similar factors. He **justifies** by choose cases that support him and select the most on-point factor from each case. Then, he uses the most on-point factor to **criticism and evaluate** in arguing process. When he finish argues with his project's owner, whatever the result is, he then **stored** the result in his memory.

4.6. A Summary of Bayes' Theorem, Fuzzy Logic Theory and Case-Based Reasoning

Preliminary investigation revealed three findings: a construction image could be used as sources of information, there was agreement about common information observed from images and disagreement about construction practice safety. Disagreement occurred on account of lack of experience and interpretation of uncertain information observed from images. Methods need be found to remedy these shortcomings.

A relatively similar judgment was reached concerning construction practice safety which required a safety assessment system employing tools from Artificial Intelligence (see section 2.4.2). Firstly, to understand images from a safety point of view, a checklist needed to be constructed and safety scores needed to be established using personal degree of confidence. To give meanings to overall safety scores, a Bayes' Theorem formula was employed based on the conditional probability that calculate a likelihood of an event based on occurrence of another event (see Equation 4.1).

An example in section 4.3.2 showed how to use Bayes' Theorem formula on which construction practice observed from images could be defined based on a likelihood score of $P(H/E)$. The example also showed that there was another likelihood score which is $P(E/H)$. Problem associated with given a meaning of a number using natural language such as a little bit, most likely, etc cannot be solved using Bayes' Theorem formula. Another tool from Artificial Intelligence could be used to deal with this problem that is fuzzy logic theory where thing partially belong to sets. The fuzzy logic membership function formula has been chosen to deal with problem related to given meanings (see Equation 4.6).

By using these two methods, problems related to uncertain interpretation were potentially overcome, however, they could not deal with problem related to reuse past experience. A tool from Artificial Intelligence was, therefore, used, case-based reasoning. These three Artificial Intelligence methods were employed to develop a safety assessment system.

4.7. Conclusion of Utilising Construction Image as Sources of Safety-related Information

The results of the preliminary investigation showed that it was possible to utilize images as sources of information for construction safety assessment purposes. It revealed:

1. Construction images can be used as sources of information,
2. There was agreement about common information provided by the images,
3. There was disagreement about safety justification using the information provided by the images.

The disagreement basically has two main reasons: (1) Lack of experience and (2) Uncertain interpretation, both relating to respondents' safety knowledge. In addition, problem arose regarding the utilization of construction images e.g.

1. How to use past experience, either personal or from another person for particular construction method?
2. How to make the relatively same judgment about a safe construction method being used based on the interpretation of information from construction images?

To overcome those problems, methods from the Artificial Intelligence field were considered. As regards disagreement based on the uncertain interpretation, two theories were chosen. Firstly, the Bayes' Theorem was used initially to define construction practice based on the degree of confidence. Secondly, because the real world is an analog, then in the real world things are generally not in one state or another, but partially belong to a set and so the construction practice, which was defined using Bayes' Theorem, should be classified into three categories of safety. The fuzzy logic theory was chosen to deal with this classification.

To deal with the problem of using past experience, case-based reasoning was selected. Information from past experience can be re-use for current or future projects in similar situations. Unfortunately, the information obtained from past experience as knowledge often become a tacit knowledge stored in the heads of individuals. No one else can reuse it. To make the knowledge more useful, thus the knowledge needs to be stored in database, and someone else can have benefit by using the stored knowledge. Regarding this need, a safety assessment system will be developed. Detailed explanation of the development of a safety assessment system will be given in Chapter 5.

Chapter 5

THE DEVELOPMENT OF A SAFETY ASSESSMENT SYSTEM (SAFE AS)

5.1. Introduction to The Development of A Safety Assessment System (SAFE AS)

The preliminary investigation postulated that construction images can be used as sources of safety-related information but problems related to utilizing them are their uncertain interpretation and lack of past experience. Chapter 4 is described results and problems of preliminary investigation and proposed theories to deal with these challenges.

This chapter will explain the development of the safety assessment system using the theories explained in Chapter 4. Firstly, the system will be outlined in section 5.2 and secondly the explanation and application of Bayes' Theorem to define construction practice will be presented in section 5.3. Thirdly, the application of Fuzzy Logic Theory to classify of a high-level of safety practice images will be demonstrated in section 5.4. Fourth, images storing process into a database will be explained in section 5.5 and fifth, a brief explanation of the use of case-based reasoning in this research will be given in section 5.6. Section 5.7 will discuss the developed safety assessment system. At the end, the development of a safety assessment system will be concluded.

The safety assessment system flowchart is shown in Figure 3.2 and re-presented in Figure 5.1. The demonstration of the automated assessment system in this research, which is presented in this chapter, will only cover activities 1 (ACT 1) to 3 (ACT 3), whereas activity 4 (ACT 4) will briefly explain in section 5.6.

5.2. The Description of The Structure and Process Used in A Safety Assessment System (SAFE AS)

In previous chapters, the idea to utilize construction images as sources of safety-related information was explained and investigated. It also revealed problems and suggested methods of solving them (see Chapter 4). Methods for safety assessment using a systematic approach will be proposed and explained in this chapter. A flowchart of the proposed system is shown in Figure 5.1 and explained as follows:

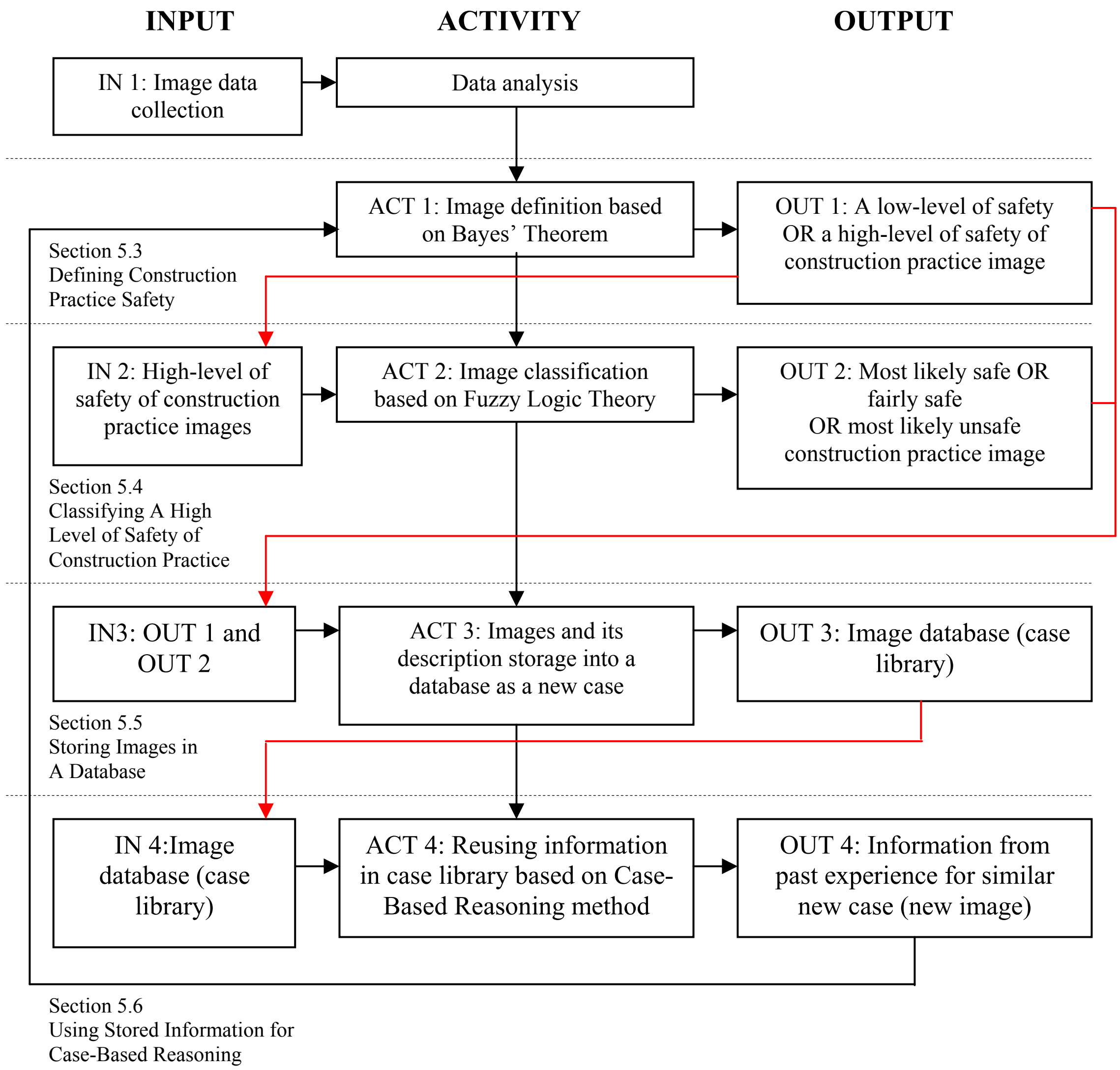


Figure 5.1. The Safety Assessment System Flowchart

An image consists of information about construction practices. To determine whether the practices shown are safe or not, they need to be assessed for safety purposes. First, they must be defined based on the Bayes' Theorem. Then, the high-level of safety construction practice needs to be classified into one of three classifications, based on the fuzzy logic theory.

After the safety assessment process, the results of the two steps are defined and classified construction practices shown in an image. Besides these factors, this step also provides indirect results, hazard identification and proposed solutions to minimize future occurrence of possible accidents. To ensure these results are available, the image and its information needs to be stored in a database as new case(s), called a case library. In future, this data can be used as a repository of safety-related information in assessing new case(s). Details of the steps in the safety assessment system and examples to demonstrate the methods used will be given in following sections 5.3, 5.4 and 5.5.

5.3. Defining Construction Practice Safety (ACT 1)

Semi-structured interviews conducted during preliminary investigation revealed that answers on construction practice safety from the same image were varied. Some respondents said the practice was safe, some said not safe, was partly safe, and some said they did not know (see section 4.2). This suggests that there is a need to develop a method to define construction practice as a part of a safety assessment system which will be given in section 5.3.1. Its application will be demonstrated in section 5.3.2. With reference in Figure 5.1 image definition is the first activity (code: ACT 1) and start with development of an assessment method, detail as follows.

5.3.1. Developing An Assessment Method to Define Construction Practice Safety

Information revealed from construction images comes solely from individual interpretations of things/evidence as discussed in section 4.2. To solve this problem, the Bayes' Theorem was chosen and an example has been quoted. Bayes' Theorem basically is a conditional probability meaning there is the probability of a hypothesis being true given the occurrence of the evidence. This theory commonly used to provides the answer to a problem from a predetermined set of possible answer (see section 4.3.1). Using this theorem, the hypothesis in this research is to assess safe construction practice, whether it being used or not, based on evidence that of information observed from an image. To show how to assess safe practice given information from an image, one particular activity was chosen, an access scaffolds.

With reference to the problem of disagreement explained in Chapter 4, judging whether construction practice was safe or not, it is assumed that it came about because of uncertain interpretation there being no guidelines. Guidelines regarding safe access scaffold needs to be provided so everyone will base a judgment following the suggested guidelines. The scaffolds practice in an image will then be defined as a high-level or a low-level of safety of construction practice.

The Occupational Safety and Health Administration guidelines available from their website: www.osha.gov, were adapted to construct a safety checklist to assess safe construction practice from an image. Since the safety checklist adapted from OSHA regulation that provide safety and health guidance, so the all sub attributes description in the checklist refers to safe practice. The safety checklist for safe access scaffold is shown in Table 5.1.

Table 5.1. The Attributes and Sub Attributes for Safe Access Scaffold

Attributes	Sub Attributes
Base section	1. The supported scaffold should be set on a stable object, such as base plates, mud sills, other adequate firm foundation 2. The supported scaffold should be plumbed and braced to prevent swaying and displacement
Support structure	1. The supported scaffold and scaffold components should be capable to support their own weight and at least four times maximum intended load without failure 2. Frames and panels are connected by cross, horisontal, or diagonal braces, to secure vertical members laterally 3. Cross braces is in such length as will automatically keep the scaffold plumb, level, and square 4. Brace connections are secure to prevent dislodging 5. Frames and panels are joined together vertically by coupling or stacking pins or equivalent means 6. Frames and panels are locked together to prevent uplift
Access and ladders	1. The hook-on and attachable ladder is specifically designed for use with the type of scaffold on which they are used 2. Stairway-ladders must have slip-resistant treads on all step and landings
Fall protection	1. Fall protections which are consists of either personal fall-arrest system or guardrail system should be provided on any scaffold ten feet or more above a lower level 2. Guardrail are installed along all open sides and ends of platforms 3. The top edge height of toprails on supported scaffold should be between 36 and 45 inches 4. If midrails are used, they should be installed at a height approximately midway between the top edge of the guardrail system and the platform surface
Platform and walkways	1. Each platform should be fully planked between the front uprights and the guardrail supports 2. The gaps between adjacent planks or between platforms and uprights are not greater than one inch 3. There is no more than a 14-inch gap between the scaffold platform and the structure being worked on 4. The toeboard should be installed along the edge of platform those more than ten feet above the lower level and have at least 3.5 inches high from the top edge 5. Ramps and walkways which is six feet and more above lower level should have guardrails
Electrical hazard	1. The scaffold and their conductive materials, such as building materials, paint roller extensions, scaffold components, that may be handled on them should not closer than ten feet to the power line, or scaffolds may be closer to overhead power lines than ten feet but they do has either de-energised the lines (grounded) or relocated the lines or installed protective coverings to prevent accidental contact with the lines

(Source: www.osha.gov)

The following example using Figure 5.2 shows the guidelines in practice.

a. **Interpretation of Information from An Image**

Figure 5.2. An Image of Scaffolds Activity

Information observed from the image in Figure 5.2 indicates scaffolds and concrete columns. Are the scaffolds in the image safe? To answer this question, reference must be made to the access scaffolds safety checklist in Table 5.1.

For the "Base section" (attribute 1) and sub attribute 1 it is stated that: "The supported scaffold should be set on a stable object, such as base plates, mud sills, other adequate firm foundation". The image in Figure 5.2 shows the scaffoldings seem to be set on a stable object as some bases can clearly be seen others are, however, not. Evidence suggests some bases are safe however, although some bases are not clearly visible, it is assumed they are also safe.

b. **Safety Judgment**

The example is an assumption made on individual beliefs so, on the safety checklist it is not possible to judge only "safe" or "not safe". There is a need to be a confidence judgment based on the degree of belief made based on information from observed evidence. A reason is because the all evidence can be clearly observed so it is easier to give judgment whether the practice is "safe" or "not safe". If the practice is safe, a given score is 1.0 which is refer to degree of confidence to say the practice is 100% safe and if unsafe a given score is 0.0 which is refer to degree of confidence to say the practice is 0% safe. Meanwhile, if some of the evidence cannot be clearly observed, the score of safety practice can be any number between 0% and 100%.

By translating the judgment statement for each sub attribute into a score, the overall judgment of construction practice based on the safety checklist can be mathematically calculated. Because the safety assessment method was developed based on the Bayes' Theorem so, the mathematical formula used in this method was adopted the Bayes' Theorem formula (see section 4.3.1).

c. Safety Score

The four scores established in the research for the assessment method are: 1.000 means it is confidence to say the practice is 100% safe, 0.667 means the practice is 66.7% safe, 0.333 means the practice is 33.3% safe, and 0.000 means the practice is 0% safe. There is another option available for information that cannot be observed from an image, N/A or Not Available and it will be excluded from calculations.

d. An Example of A Proposed Assessment Method Demonstration

To recap, a safety assessment method calculates the degree of confidence or likelihood of safe construction practice being used for the particular activity observed from an image. The formulas used for this calculation are Equations 4.2 to 4.5 in section 4.3.1. The following example will demonstrate the application of proposed method using the image in Figure 5.2, re-illustrated below.

Re-illustrated Figure 5.2

The example of the assessment method demonstration

Information revealed from construction images comes solely from individual interpretations of things/evidence. To avoid dissimilar safety judgment sections a, b and c is shown a systematic way to interpret information observed from an image. Further, to give meaning to overall safety scores, a Bayes' Theorem formula was employed (see section 4.6). The Bayes' Theorem formula used in this research is as follows.

$$P(H/E_1 \cap E_2 \cap ...E_N) = \frac{P(E_1 \cap E_2 \cap ....E_N / H)P(H)}{P(E_1 \cap E_2 \cap ...E_N / H)P(H) + P(E_1 \cap E_2 \cap ...E_N / H')P(H')}$$

(Equation 4.2)

It can be seen from Equation 4.2, there are prior probabilities, a probability from an assumption made based on a hypothesis, that have to calculate before calculating the likelihood of safe construction practice being used given information from an image (see section 4.3.2).

According to its explanation therefore the prior probabilities in this research were made based on assumption that safe construction practice being used. These prior probabilities are: a probability that a particular activity observed in an image is caused by safe construction practice *P(E/H)*, a probability that a particular activity observed in an image is caused by unsafe construction practice *P(E/H')*, a probability of safe construction practice based on a particular activity shown in an image *P(H)* and a probability of unsafe construction practice based on a particular activity shown in an image *P(H')*. The steps to calculate all probabilities in this stage will illustrate in Figure 5.3.

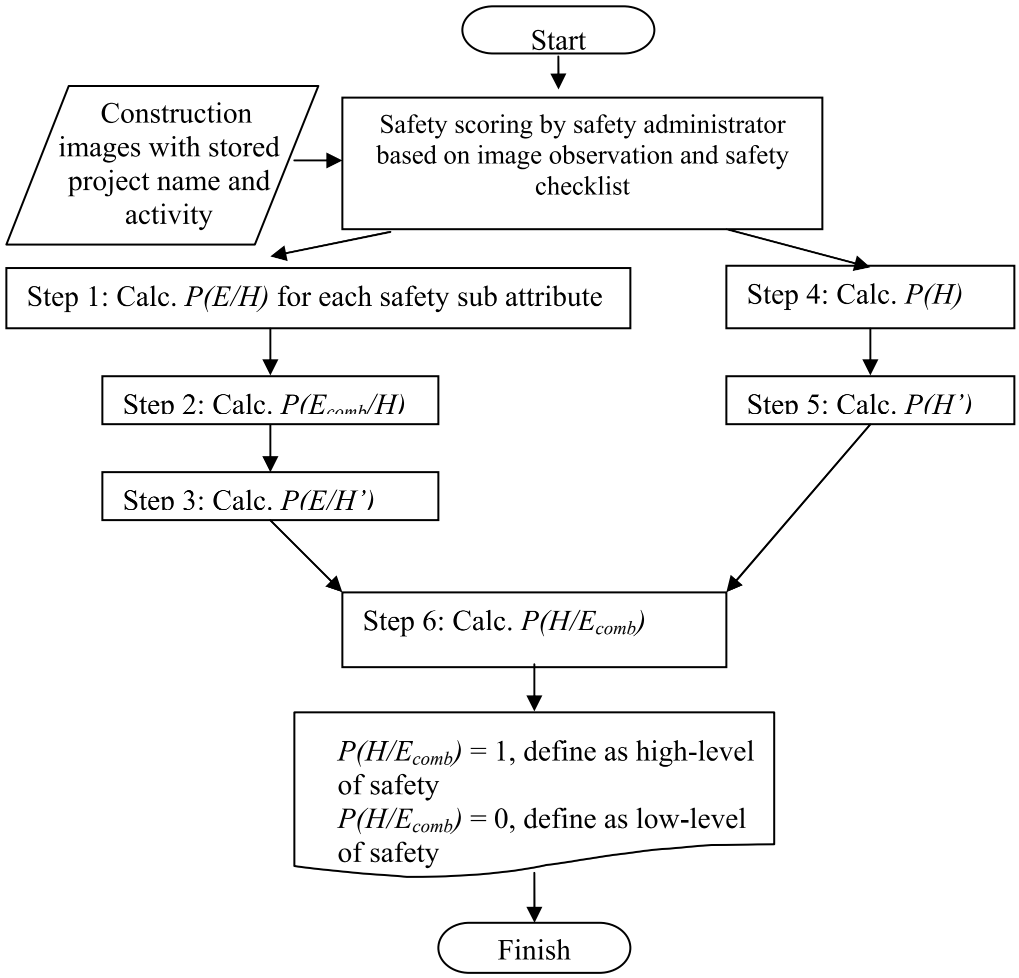


Figure 5.3. Flowchart of Safety Assessment Steps

With reference to Figure 5.3 the following example shows a step-by–step the assessment process.

Step 1: Use of image data to calculate the prior likelihood of safe construction practice being used for particular activity based on each observed sub attribute.

This step is to calculate prior probability of particular activity safety based on assumption that the activity shown in an image is resulted from safe construction practice being used. For example, the safety checklist in Table 5.1 states that: "The supported scaffolds set on a stable object (attribute 1= E_1, sub attribute 1 = e_1)".

Visual observation of Figure 5.2 suggests that the scaffolds were set on a stable object, as there are base plates on the ground. Therefore, the safety score of this sub attribute was 1.000. Likewise, for sub attribute 2 (e_2), visual observation suggests that the scaffolds were plumbed and braced. So the safety score of this sub attribute was 1.000. Consider the safety score is given based on assumption that safe construction practice being used.

From this, the degree of confidence of base section (E_1) is safe based on two sub attributes (e_1,e_2) safety is:

$P(E_1/e_1 \cup e_2) = (\Sigma e_1, e_2)/2 = (1.000 + 1.000)/2 = 1.000$.

Thus the prior likelihood of base section is safe based on assumption that safe construction practice being used or $P(E_1/H)$ is 1.000.

Calculations are then made for all the sub attributes observed. The results are:

For attribute 2 (E_2): e_1= 1.000, e_2= 0.667, e_3= 1.000, e_4= 0.667, e_5= 1.000, e_6= 1.000, and so $P(E_2/H) = (\Sigma e_1,..e_6)/6 = 0.890$

Step 2: Use the step 1 results to calculate the prior likelihood of safe construction practice being used for particular activity based on all observed sub attributes.

Step 1 is calculation for each attribute with its sub attribute. Considering all observed attributes with their sub attributes incorporate to obtain a likelihood score, step 2 has been conducted. From sample image in Figure 5.2 only two attributes can be observed, attributes 1 and 2. Each attribute has a $P(E/H)$ score obtained from step 1. The likelihood of safe construction practice being used for particular activity is as follows:

$P(E_1 \cap E_2/H) = P(E_1/H) * P(E_2/H) = 1.000 * 0.890 = 0.890$

Step 3: Use the step 2 results to calculate the prior likelihood of unsafe construction practice being used for particular activity.

Mutually exclusive is the sum of all events that do not affect each other, such as hypothesis and hypothesis complement, and equal 1 or $P(H) + P(H') = 1$. In this research, as the hypothesis is to assess safe construction practice being used, then the hypothesis complement is unsafe construction practice being used. The mutually exclusive means that the construction practice cannot be both safe and unsafe at the same time. So the likelihood of unsafe construction practice being used was determined by subtracting the likelihood score as result from step 1 from 1. The results of this step are as follows:

$P(E_1/H') = 1 - P(E_1/H) = 1 - 1.000 = 0.000$

$P(E_2/H') = 1 - P(E_2/H) = 1 - 0.890 = 0.110$

$P(E_1 \cap E_2/H') = 0.000 * 0.110 = 0.000$

Step 4: Use of image data to calculate the prior probability of safe construction practice being used.

The hypothesis and each attribute have four possible events which refer to four provided safety scores: 0.000, 0.333, 0.667, and 1.000. The possible event for a safe construction practice is only one (a safety score = 1.000). Sample space refers to all possible events from all observed evidences (attributes) and hypothesis. The probability of the safe construction practice being used was determined as the possible event of safe hypothesis divided by sample space.

The image in Figure 5.2 only showed the base section (attribute 1) and the support structure (attribute 2), so the total evidence was two. Each has four possible events; the hypothesis also has four possible events so the number of sample space was then $4^3 = 64$.

$P(H) = 1/64 = 0.0156$

Step 5: Use of step 4 result to calculate the prior probability of safe construction practice complement being used.

The possible event for a safe construction practice only one (refer to safety score of 1) therefore the possible events of an unsafe construction practice are three referred to three other safety scores. The number of sample space was 64 as stated in step 4. Thus, the probability of unsafe construction practice being used is:

P(H') = 3/64 = 0.0469

Step 6: Use the results from steps 1 to 5 to calculate the likelihood of a safe construction practice being used given information obtained from an image.

With reference to Equation 4.2 in section 4.3.1, after all the variables for Equation 4.2 have been determined, the degree of confidence or likelihood of a safe construction practice being used given information obtained from an image.

$$P(H / E_1 \cap E_2 \cap ...E_N) = \frac{P(E_1 \cap E_2 \cap ....E_N / H)P(H)}{P(E_1 \cap E_2 \cap ...E_N / H)P(H) + P(E_1 \cap E_2 \cap ...E_N / H')P(H')}$$

So simplifying $P(H/E_{comb})$ = (A*B)/(A*B+C*D)

Where:

A = $P(E_{comb}/H)$ = 0.89 (see step 2)

B = *P(H)* = 0.0156 (see step 4)

C = *P(E/H')* = 0.0000 (see step 3)

D = *P(H')* = 0.0469 (see step 5)

$P(H/E_{comb})$ = (0.89*0.0156)/(0.89*0.0156+0.000*0.0469) = 1.000.

This assessment method has two possible scores to arrive at the final step, is 1.000 or 0.000. If $P(H/E_{comb})$ = 1.000, the construction practice observed from an image is defined as a high-level of safety. If $P(H/E_{comb})$ = 0.000, the construction practice is defined as a low-level of safety.

5.3.2. The Application of The Safety Assessment Method to Define Construction Practice Safety

In order to “calibrate” the method to define construction practice safety, 20 construction images from preliminary investigation image collection are used (see Figure 5.4 image numbers 1 to 20).


Image 1


Image 2


Image 3


Image 4


Image 5


Image 6


Image 7


Image 8


Image 9


Image 10


Image 11

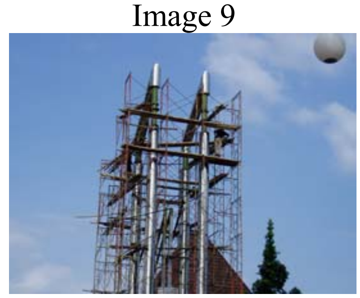


Image 12

Image 13

Image 14

Image 15

Image 16

Image 17

Image 18

Image 19

Image 20

Figure 5.4. Images Used to Test The Assessment Method

Calculations using developed safety assessment system were undertaken manually using MS Excel spreadsheets by a safety administrator and the results were presented in Tables 5.2 and 5.3. In those two Tables, the columns' name e.g. A.1.1, A 1.2 and A1 score represent the safety sub attributes and attribute from safe access scaffold safety checklist (see Table 5.1). A.1 is representing safety attribute number 1 in Table 5.1, A.1.1 and A.1.2 are representing safety attribute number 1 for sub attributes 1 and 2 in Table 5.1. Other columns' names in Tables 5.2 and 5.3 have the same explanation and all refer to Table 5.1

Table 5.2. Safety Scores Given by Safety Administrator Based on Safety Checklist for Every Image

Image #	A1.1	A1.2	**A1 score**	A2.1	A2.2	A2.3	A2.4	A2.5	A2.6	**A2 score**	A3.1	A3.2	**A3 score**	A4.1	A4.2	A4.3	A4.4	**A4 score**	A5.1	A5.2	A5.3	A5.4	A5.5	**A5 score**	**A6 score**
1	N/A	1.000	**1.000**	1.000	1.000	1.000	0.670	0.670	0.670	**0.835**	1.000	0.670	**0.835**	1.000	1.000	0.670	1.000	**0.918**	N/A	N/A	N/A	1.000	1.000	**1.000**	**1.000**
2	1.000	0.670	**0.835**	0.670	0.670	0.670	0.670	0.670	0.670	**0.670**	N/A	N/A	**N/A**	0.000	0.000	0.000	0.000	**0.000**	0.000	0.000	0.000	0.000	0.000	**0.000**	**1.000**
3	N/A	0.670	**0.670**	0.670	0.330	0.670	0.330	0.670	0.330	**0.500**	N/A	N/A	**N/A**	0.000	0.000	0.000	0.000	**0.000**	0.000	0.330	0.330	N/A	N/A	**0.220**	**1.000**
4	0.670	0.670	**0.670**	0.670	0.000	0.000	0.000	0.670	0.670	**0.335**	0.000	N/A	**0.000**	0.000	0.000	0.000	0.000	**0.000**	N/A	N/A	N/A	0.00	N/A	**0.000**	**0.000**
5	0.670	0.670	**0.670**	1.000	0.670	1.000	0.670	0.670	0.670	**0.780**	N/A	N/A	**N/A**	1.000	0.670	0.670	1.000	**0.835**	0.670	0.670	1.000	0.670	1.000	**0.802**	**1.000**
6	0.670	0.670	**0.670**	0.670	1.000	1.000	0.670	0.670	0.670	**0.780**	N/A	N/A	**N/A**	1.000	1.000	0.670	N/A	**0.890**	1.000	N/A	1.000	1.000	1.000	**1.000**	**1.000**
7	N/A	0.670	**0.670**	0.670	1.000	1.000	1.000	1.000	1.000	**0.945**	1.000	N/A	**1.000**	1.000	1.000	0.330	1.000	**0.833**	1.000	N/A	1.000	1.000	1.000	**1.000**	**1.000**
8	1.000	1.000	**1.000**	0.670	1.000	0.670	1.000	1.000	1.000	**0.890**	N/A	N/A	**N/A**	N/A	N/A	N/A	N/A	**N/A**	N/A	N/A	N/A	N/A	N/A	**N/A**	**N/A**
9	N/A	0.670	**0.670**	0.670	1.000	0.670	N/A	N/A	N/A	**0.780**	N/A	N/A	**N/A**	0.000	0.000	0.000	0.000	**0.000**	N/A	N/A	N/A	N/A	0.000	**0.00**	**1.000**
10	1.000	0.670	**0.835**	0.330	0.000	0.330	0.670	0.670	0.670	**0.445**	N/A	N/A	**N/A**	0.000	0.000	0.000	0.000	**0.000**	0.670	N/A	0.670	0.000	0.000	**0.335**	**1.000**
11	N/A	0.670	**0.670**	0.670	0.670	0.330	0.330	0.670	0.670	**0.557**	N/A	N/A	**N/A**	0.000	0.000	0.000	0.000	**0.000**	0.000	0.000	0.000	0.000	0.000	**0.000**	**1.000**
12	N/A	0.330	**0.330**	0.670	1.000	1.000	0.670	N/A	0.670	**0.802**	N/A	N/A	**N/A**	0.000	0.000	0.000	0.000	**0.000**	0.000	0.000	0.000	0.000	0.000	**0.000**	**1.000**
13	N/A	0.670	**0.670**	0.670	0.000	0.000	0.000	0.670	0.670	**0.335**	N/A	N/A	**N/A**	0.000	0.000	0.000	0.000	**0.000**	N/A	N/A	1.000	0.00	0.00	**0.333**	**0.330**
14	N/A	0.670	**0.670**	0.670	0.330	0.670	0.670	0.670	0.670	**0.613**	N/A	N/A	**N/A**	0.000	0.000	0.000	0.000	**0.000**	0.000	0.000	0.000	0.000	0.000	**0.000**	**1.000**
15	N/A	N/A	**N/A**	0.670	0.330	0.670	0.670	0.670	0.000	**0.502**	N/A	N/A	**N/A**	0.000	0.000	0.000	0.000	**0.000**	0.000	0.000	0.000	0.000	0.000	**0.000**	**1.000**
16	1.000	1.000	**1.000**	1.000	1.000	1.000	1.000	1.000	0.670	**0.945**	N/A	N/A	**N/A**	1.000	1.000	0.670	1.000	**0.918**	1.000	1.000	1.000	1.000	1.000	**1.000**	**1.000**
17	N/A	0.670	**0.670**	1.000	1.000	1.000	1.000	0.670	0.670	**0.890**	N/A	N/A	**N/A**	1.000	1.000	1.000	1.000	**1.000**	1.000	1.000	1.000	1.000	1.000	**1.000**	**1.000**
18	N/A	0.670	**0.670**	1.000	1.000	0.670	0.670	0.670	0.670	**0.780**	0.670	N/A	**0.670**	1.000	1.000	0.670	1.000	**0.918**	1.000	0.670	0.670	0.330	1.000	**0.734**	**1.000**
19	N/A	0.670	**0.670**	0.670	0.330	0.000	0.330	0.670	0.670	**0.445**	N/A	N/A	**N/A**	0.000	0.000	0.000	0.000	**0.000**	0.330	0.330	0.330	0.00	0.00	**0.198**	**1.000**
20	1.000	0.670	**0.835**	1.000	0.670	0.670	0.670	0.670	0.330	**0.668**	N/A	N/A	**N/A**	0.000	0.000	0.000	0.000	**0.000**	0.000	0.000	0.000	0.000	0.000	**0.000**	**1.000**

Table 5.3. The Result of Manual Calculation of Likelihood of Construction Practice Being Used Given Information of Particular Activity From An Image

Image #	A1 (score)	A2 (score)	A3 (score)	A4 (score)	A5 (score)	A6 (score)	B (score)	C (score)	D (score)	E (score)	Z (score)
1	1.000	0.835	0.835	0.918	1.000	1.000	0.640	0.00006	0.000	0.99994	1.000
2	0.835	0.670	N/A	0.000	0.00	1.000	0.000	0.00024	0.000	0.99976	0.000
3	0.670	0.500	N/A	0.000	0.220	1.000	0.000	0.00024	0.000	0.99976	0.000
4	0.670	0.335	0.000	0.000	0.000	0.000	0.000	0.00006	0.219	0.99994	0.000
5	0.670	0.780	N/A	0.835	0.802	1.000	0.350	0.00024	0.000	0.99976	1.000
6	0.670	0.780	N/A	0.890	1.000	1.000	0.465	0.00024	0.000	0.99976	1.000
7	0.670	0.945	1.000	0.833	1.000	1.000	0.527	0.00006	0.000	0.99994	1.000
8	1.000	0.890	N/A	N/A	N/A	N/A	0.890	0.01563	0.000	0.98437	1.000
9	0.670	0.780	N/A	0.000	0.000	1.000	0.000	0.00024	0.000	0.99976	0.000
10	0.835	0.445	N/A	0.000	0.335	1.000	0.000	0.00024	0.000	0.99976	0.000
11	0.670	0.557	N/A	0.000	0.000	1.000	0.000	0.00024	0.000	0.99976	0.000
12	0.330	0.802	N/A	0.000	0.000	1.000	0.000	0.00024	0.000	0.99976	0.000
13	0.670	0.335	N/A	0.000	0.333	0.330	0.000	0.00024	0.098	0.99976	0.000
14	0.670	0.613	N/A	0.000	0.000	1.000	0.000	0.00024	0.000	0.99976	0.000
15	N/A	0.502	N/A	0.000	0.000	1.000	0.000	0.00098	0.000	0.99902	0.000
16	1.000	0.945	N/A	0.918	1.000	1.000	0.867	0.00024	0.000	0.99976	1.000
17	0.670	0.890	N/A	1.000	1.000	1.000	0.596	0.00024	0.000	0.99976	1.000
18	0.670	0.780	0.670	0.918	0.734	1.000	0.236	0.00006	0.000	0.99994	1.000
19	0.670	0.445	N/A	0.000	0.198	1.000	0.000	0.00024	0.000	0.99976	0.000
20	0.835	0.668	N/A	0.000	0.000	1.000	0.000	0.00024	0.000	0.99976	0.000

Note:

A1 to A6 represent safety attribute number 1 to 6 in Table 5.1

Column B represents $P(E_{comb}/H)$ = the likelihood of safe construction practice being used for particular activity based on all observed sub attributes (section 5.3.1 step 2).

Column C represents $P(H)$ = the probability of safe construction practice being used (section 5.3.1 step 4)

Column D represents $P(E_{comb}/H')$ = the likelihood of unsafe construction practice being used for particular activity (section 5.3.1 step 3)

Column E represents $P(H')$ = the probability of unsafe construction practice being used (section 5.3.1 step 5)

Column Z represents $P(H/E_{comb})$ = Use the results from all steps to calculate the likelihood of a safe construction practice being used given information obtained from an image (section 5.3.1 step 6).

From Tables 5.2 and 5.3, it can be seen that from the 20 sample images in Figure 5.3, eight images can be defined as a high level of safety of construction practice (see Table 5.3 column Z, the Z score = 1.000), and 12 images defined as a low level of safety of construction practice (see Table 5.3 column Z, the Z score = 0.000). Tables such as these can be utilized to check the safety of construction practice on site when the database (table) is extended to cover all safety attributes that may be identified later.

Another result from Table 5.3 is that all images that defined as a high level of safety of construction practice (see Table 5.3 column Z, safety score = 1.000) have different score of $P(E_{comb}/H)$ (see Table 5.3 column B).

For example, image number 8 has a score of $P(E_{comb}/H)$ = 0.890 (see Table 5.3); its means the likelihood of safe construction practice being used that can cause the occurrence of construction practice shown in the image is 89%. Image number 18 has a score of 0.236 indicating that the likelihood of safe construction practice being used that can cause the occurrence of construction practice shown in the image is 23.6%.

The two images were defined as a high level of safety of construction practice (both with a $P(H/E_{comb})$ score of 1.000), so what does a score of 89% or 23.6% mean? Does the former indicate safe or partly safe or a little bit safe? How about 23.6%, has that score has a meaning of almost unsafe or most likely unsafe? Or do they indicate the same meaning?

It is assumed both have different meanings. Based on this assumption, the problems are: 1. How to classify the scores? 2. What is the meaning of each score classification? To deal with this problem, fuzzy logic theory has been chosen. The following section will explain the classifying method in the research.

5.4. Classifying A High-Level of Safety of Construction Practice (ACT 2)

Bayes' Theorem formula was chosen as the safety assessment method to define construction practice from images (see section 5.2). Table 5.3 indicates 12 images showed a low level of safety and eight images showed a high level of safety. The eight images of high level of safety have different scores of $P(E_{comb}/H)$. This assumes that different scores have different classifications and meanings.

To deal with this problem, a method was developed to classify construction practice based on fuzzy logic theory which deals with uncertainty reasoning, that is primarily concerned with quantifying and reasoning using natural language in which many words have ambiguous meanings e.g. *a little, very much*, and so on. Sections 5.4.1 and 5.4.2 will describe the method of classifying construction practice as a part of a safety assessment system and its application.

5.4.1. Developing A Method to Classify A High-Level of Safety of Construction Practice

The meaning of something is perhaps best indicated by a shade of gray, rather than by the black or white of a simple dichotomy (Giarratano and Riley, 1994). Just as there are many shades of gray, so too there are many different gradations of meaning in the real world. This is the concept of the term "fuzzy" (see section 4.4.1) which is often expressed using natural language such as "*A Little", "Somewhat", "Fairly.*"

The term "shade" mentioned earlier means in the real world, things are generally not in one state or another, but partially belong to a set. At some point a thing can become a member of particular co domain, but at the same time also become a member of another co domain. This is the basic concept of *fuzzy sets*.

The degree of membership in a fuzzy set is measured by a generalization of the characteristic function called the *membership function*, defined as: μ_A (x): X → [0,1] which states that it maps all elements of X into the co domain of real numbers defined in the interval from 0 to 1 inclusive symbolized by [0,1]. The membership function is a real number $0 \leq \mu_A \leq 1$, where 0 means no membership and 1 means full membership in the set.

a. The Development of The High Level of Safety of Construction Practice Classification

Depending on the application, a membership function may be constructed from one person's opinions or from a group of people. Its S-curve is a mathematical function that is often used in fuzzy sets. In this definition α, β, and γ are parameters that may be adjusted to fit the desired membership data. Depending on the given membership data, it may be possible to give an exact fit for some values of α, β, and γ, or the fit may only be approximate.

Based on this fuzzy logic theory, in this research the high-level of safety of construction practice have been classified as: most likely safe, fairly safe, and most likely unsafe. The term "most likely safe" refers to a practice that seems safe but a safety expert is not too sure. The term "fairly safe" refers to a practice that still has some unsafe practice but not too *much*. The term "most likely unsafe" refers to a practice that has more unsafe practice than safe practice.

b. The Determination of The Values of The Parameters α, β, and γ

In order to map these classifications into a S-curve membership function, the values of the parameters α, β, and γ (see section 4.4.1) should be determined. In Table 5.3, the results mention no image refers to being totally safe, shown by $P(E/H) \neq 1$ (see table 5.3 column B). This means all high level of safety images have some membership of both safe and unsafe construction practice. These specific functions have to be determined.

The value of α, β, and γ will be some value between 0% and 100% or between 0 and 1 and refer to the value of the likelihood. To determine a value for α of the likelihood of safe practice can be done by approximation. If 0 refers to unsafe, then 0.25 was chosen for the minimum value of safe practice. For a value of γ, of course, the maximum value is 1, as the highest value for the likelihood is 100% or 1. The β parameter corresponds to the crossover point of 0.5 and is (α + γ)/2, and so by determining the value of α = 0.25 and γ = 1 then the value of β = 0.625. Vice versa, for unsafe construction practice, the lowest value for the likelihood is 0% or 0. A value for γ of likelihood of unsafe construction practice was determined by approximation and 0.75 was chosen. Thus the membership function of unsafe construction practice has values of α = 0, β = 0.375, and γ = 0.75

c. The Development of The Membership Function and Classification Area Mapping

The mathematical calculations to develop the membership function for safe and unsafe construction practice is demonstrated below:

The membership function of safe construction practice has a value of α = 0.25, β = 0.625, and γ = 1. By using a mathematical formula for the S-curve (see section 4.4.1 Equation 4.6), the value of the axis *y* that refers to the grade of membership is calculate as follows:

S (*x*; 0.25; 0.625; 1)

- The membership is 0 for x ≤ α, which is 0 for x ≤ 0.25
- α = 0.25, β = 0.625, γ = 1, then:

  $$2\left(\frac{x-a}{\gamma-a}\right)^2 = 2\left(\frac{x-0.25}{1-0.25}\right)^2 = 3.556(x\text{-}0.25)^2 \text{ for } 0.25 \leq x \leq 0.625$$

  Example: for x = 0.5 then y = 0.222

$$1 - 2\left(\frac{x-\gamma}{\gamma-a}\right)^2 = 1 - 2\left(\frac{x-1}{1-0.25}\right)^2 = 1 - 3.556(x-1)^2 \quad \text{for } 0.625 \le x \le 1$$

Example: for x = 0.75 then y = 0.778

- The membership is 1 for x ≥ γ, which is 1 for x ≥ 1

Likewise, for the membership function of unsafe practice α = 0, β = 0.375, and γ = 0.75. To calculate the membership function for unsafe construction practice, the mathematical formula was changed. For α ≤ x ≤ β, the formula was $1 - 2\left(\frac{x-\gamma}{\gamma-a}\right)^2$ and for β ≤ x ≤ γ, the formula was $2\left(\frac{x-a}{\gamma-a}\right)^2$. The whole calculations are shown in Table 5.4, and the S-curve can be seen in Figure 5.5.

Table 5.4. Membership Function for Safe and Unsafe Construction Practice Likelihood

Value *x*	0.000	0.100	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.900	1.000
safe function	0.000	0.000	0.000	0.009	0.080	0.222	0.436	0.680	0.858	0.964	1.000
unsafe function	1.000	0.964	0.858	0.680	0.436	0.222	0.080	0.009	0.000	0.000	0.000

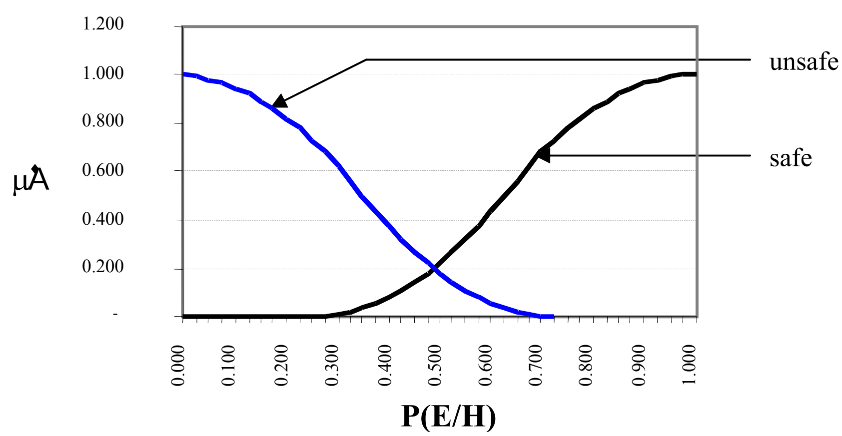


Figure 5.5. Membership Function Curves for Safe and Unsafe Construction Practice Likelihood

As stated earlier, the membership function means how well one object conforms to some attribute and representing it by a value that correspond to the grade of membership. From Figure 5.5, it can be seen that for the value x ≤ 0.25, the grade of membership for safe practice is 0% and for unsafe practice is between 82% and 100%. This area is a plot for the linguistic term “most likely unsafe”. For the value 0.25 ≤ x ≤ 0.75, the membership grade for safe is between 0% and 77.8% and for unsafe is between 0% and 77.8% respectively. This area is a plot for the linguistic term “fairly safe”. For the value x ≥ 0.75, the membership grade for safe is between 82% and 100 % and for unsafe is 0%. This area is a plot for the linguistic term “most likely safe”. For clarification, the following section will briefly explain by reusing Figure 5.5 and then designate a map area for the three classifications.

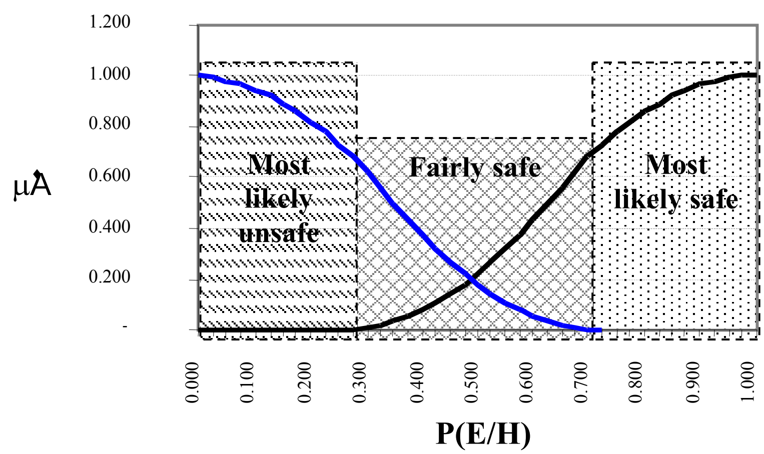


Figure 5.6. Classification Map Area Developed from Figure 5.5

The grades of membership are shown in Table 5.4 (safe function row and unsafe function row) and the map area is shown in Figure 5.6. The occurrence of an accident or the likelihood score of an accident to occur can be seen in Table 5.3. With reference to these two tables (Table 5.3 and 5.4), the application of method to classify high-level of safety of construction practice will be demonstrated using all high-level of safety construction practice images in Figure 5.4.

5.4.2. Application of The Method to Classify High-Level of Safety of Construction Practice

This section will demonstrate the application of the method of classifying high-level of safety of construction practice explained in section 5.4.1 using Figure 5.4 image number 8.

Re-illustrated Figure 5.4 image number 8

Step 1: Use of The prior Likelihood Scores Obtained From Image Definition

Referring to Figure 5.4 image number 8, this image was defined as high level of safety of construction practice and has a score of *P(H/E)* = 1 (see Table 5.3 column Z). From the same table, it reveals that the image has a score of *P(E/H)* = 0.890 (see Table 5.3 column B) means that a safety administrator was assumed the construction practice being used therefore the information in the image also consider safety construction practice for particular activity.

Step 2: To Determine The Grade of Membership of Safe/Unsafe Construction Practice

Based on the score of *P(E/H)* then the score referred to Table 5.4 where it was used for x. From the table, it can be seen that the grade of membership of x = 0.890 is close to the value of x = 0.900. The value of x = 0.900 has a grade of membership of 0.964 or 96.4% for a safe membership function and 0.000 or 0% for an unsafe membership function. This means that by observing the image, it can be stated that the current construction practice for access scaffold shown in that image 96.4% represents a safe practice and 0% unsafe practice based on the safe access scaffold attributes.

Step 3: Mapping The Value into Classification Map Area

When the value is then plotted into Figure 5.6, the value of 96.4% will be on “most likely safe” area so image number 8 in Figure 5.4 can be classified as a most likely safe construction practice.

Classifications were undertaken for all images that defined as high level of safety of construction practice. The result of the classifying process for all high-level of safety of practice images in Figure 5.4 are: two images are “most likely safe” (Figure 5.4 images number 8 and 16); five images are “fairly safe” (Figure 5.4 images number 1, 5, 6, 7, and 17); and one image is “most likely unsafe” (Figure 5.4 image number 18). Method such as this can be utilized to classify high level of safety of construction practice and this method is incorporated in the safety assessment system.

5.5. Storing Images in A Database (ACT 3)

A database is an object for organizing and storing structured information in such a way that allows quick and efficient information retrieval. Usually to organize information, it needs to break down into tables each of which stores different entities e.g. project name, activity, definition, case ID. In addition, the relationship between tables e.g. one-to-many, one-to-one, many-to-many, and one-to-one, can be defined that allows users to combine information from multiple tables.

For example, the developed database in this research is designed as a case library. It stores cases and their information. Each case has its own image, information and different with other cases. Based on this scenario, a case has to be unique, double case ID would not allow.

A right relationship between an image and a case ID in this research is one-to-many (each image can be related to more than a case ID but each case ID is related to only an image). This scenario allows an image to be used for more than once means can be used for many cases (many case ID), but a case ID only refers to an image. By doing this storage system, double case ID would not allow.

A storage process is done manually. Each narrative information, e.g. case ID, project name, definition, classification has to manually typed every time doing a new case storage process in a database. This process is completely separate with assessment process and comes after it.

5.6. Case-Based Reasoning in The Safety Assessment System for The Reuse of Information From Past Experience

The theory of case-based reasoning (CBR) and an example of its application has been discussed and demonstrated in section 4.5. The model which was adapted in developing the safety assessment system, is an interpretive one. Interpretive case-based reasoning is a process of evaluating situations or solutions in the context of previous experience. Evaluation in context is something done every day and a common way to evaluate such situations is to remember old situations that are similar to the new one and to compare and contrast them.

Interpretive case-based reasoning is useful in three areas: justification (show cause or proof of the rightness of an argument, position, or solution), interpretation (try to place a new situation in context), and projection (predicting the effects of a solution). Interpretive tasks, in turn, support a variety of reasoning goals, including classification, situation assessment, troubleshooting, and solution evaluation and reparation. Interpretive processes take as input a situation, whereas their output is a classification of the situation and an argument supporting the classification or solution.

The interpretive case-based reasoner must perform a situation assessment to determine which features of the current situation are really relevant (see section 4.5.1). For example: A safety engineer in a construction firm with a new project can only use bamboo for scaffolding. Previously, on another project, he used bamboo and he has stored that information/safety record of using it.

Firstly, he assesses the new situation defining and classifying the situation observing and taking images from the on-going project relevant with the assessment. The defining method is briefly explained in section 5.2 and the classifying method in section 5.3. Secondly, based on the results, the reasoner retrieves relevant prior cases, bamboo-scaffolding cases, from the database. This contains explanations of cases, including definitions, classification, hazard identification, solutions, and photographic images.

Third, the reasoner then compares prior cases with the new situation to discover which interpretations apply to determine how to erect bamboo scaffolding safely. Previous cases should give details of hazards and their solutions and its have photographic images as well, and so the reasoner can choose the safest system.

Fourth, the current situation and its interpretation are then saved as a new case on which to base future reasoning. In doing this, every situation in an ongoing project can be safely planned and controlled and benefit from previous projects.

5.7. Discussion of The Development of A Safety Assessment System (SAFE AS)

Issues derived from preliminary investigation are re-using personal past experience or that of other persons regarding particular construction methods and making relatively similar judgments about them based on interpretation of construction images (see section 4.2). It is assumed dissimilar judgments stemmed from different interpretations of information caused by uncertainty.

The literature revealed that methods from Artificial Intelligence in particular the expert system could be used to solve problems related with uncertainty. Chapter 4 proposed methods solving problems revealed in the preliminary investigation.

The problem of dissimilar judgments it is proposed can be solved by providing safety guidelines and quantifying methods by giving safety scores to qualitative information observed from images. Furthermore, this information can be calculated mathematically using the Bayes' Theorem formula to reveal a degree of confidence or likelihood of a safe practice being used as a Hypothesis, given information from image as Evidence occurred (referred as *P(H/E)*).

The application of this method demonstrates it can be used to define construction practice to solve problems of dissimilar safety judgments from the same image. However, results show that from the same definition of construction practice, a high-level of safety, there are several likelihood scores of *P(E/H)*. It assumes that each score has its meaning giving more specific classification of a high-level of safety. The Bayes' Theorem cannot be used to solve this problem.

Fuzzy logic theory is known as theory dealing with uncertainty reasoning primarily concerned with quantifying and reasoning using natural language in which many words are ambiguous e.g. *a little, very much*, and so on. It was chosen to classify high-level of safety of construction practice, to give a meaning to different scores of *P(E/H)* as mentioned previously and its application proved it can be used.

The demonstrations in sections 5.3.2 and 5.4.2 show that it is possible to use the proposed methods to define and classify construction practice shown in images and these two methods verified their use as practical ways to solve a problem related with uncertain interpretations from images. They are very useful for those who have experienced a situation similar to that in an image. Those without previous experience of a similar situation derive little benefit. To make the proposed methods available to anyone, images and descriptions, including definition and classification, need to be stored in a database called a case library so that information can be re-used in future. Paper-based databases have now become unpopular, as retrieving information is time-consuming. In this research the image database is, therefore, computerized.

Although these two methods have shown a practical ways of assessing construction safety practices using images, as well as defining and classifying practices however, the problem related with using past experience revealed in preliminary investigation still remains. Case-Based Reasoning has been discussed and proposed as an approach to solve this problem (see section 4.5). Section 5.6 is given a brief explanation and an example of the CBR method application in the safety assessment system.

The demonstrations of the methods are conducted manually using MS Excel spreadsheets. Meanwhile, a case library was computerized. Although the manual calculation using spreadsheets also used a computer, the processes of calculation and storing information in the case library were separate and time-consuming. As project management needs faster document storage and retrieval for effective decision-making (see section 2.4.4) a Web-based safety assessment system that able to handle automated safety assessment, store images and descriptions in a database and retrieve images was needed.

5.8. Conclusion of The Development of A Safety Assessment System (SAFE AS)

The preliminary investigation revealed problems related with uncertainty and past experience. The uncertainty problem, related to interpretation of uncertain information from images could be solved using two methods from Artificial Intelligence, the Bayes' Theorem and fuzzy logic theory. Problems concerning past experience particularly re-using information from past experience were solved using the Case-Based Reasoning method.

Application of these methods for defining and classifying construction practice using information from images demonstrates it is possible to utilize them for safety assessment. A method based on Bayes' Theorem can be used to define construction practice into a high-level of and a low-level of safety. A classifying method based on the fuzzy logic theory can also be used to classify high-level of safety construction practice into three: most likely safe, fairly safe, and most likely unsafe. The two processes were achieved by manual calculation.

However, the safety assessment process undertaken manually takes a great amount of time, especially if the assessment, storing new cases and retrieving past experience information in and from a database were separated. To overcome this problem, a Web-based safety assessment system able to handle an automated safety assessment process to store and retrieve information in and from a database needed to be developed. Chapter 6 will explains the development of the Web-based safety assessment system.

Chapter 6

THE DEVELOPMENT OF THE WEB-BASED SAFETY ASSESSMENT SYSTEM (SAFE AS)

6.1. Introduction to The Development of The Web-based Safety Assessment System

Proposed methods to overcome problems revealed in the preliminary investigation have been discussed in Chapter 4 and the development of a safety assessment system utilizing these methods manually has been outlined in Chapter 5. The application and results of the safety assessment process (section 5.3.2) demonstrated that it could be used to assess, define, and classify construction practice safety. The problem identified in Chapter 5 was that the manual safety assessment process and the accessing a database are separate with each needing a great deal of time to accomplish the overall task. For effective decision-making, this is not practical, so there is a need to develop an effective, efficient and systematic way to complete an assessment and updated database, respectively.

Chapter 2 section 2.4.2 has explained the benefit to use Information Technology (IT) application. In addition, the World Wide Web (WWW) is the technology that best facilitates a collaborative working environment in a construction project. Recent reviewed studies revealed that a Web-based system, a system that combines database and web technology, is considered significantly beneficial for the coordination and collaborative process. Therefore, this Chapter 6 describes the development of a Web-based safety assessment system as the answer of the need to overcome problem mentioned in Chapter 5.

First, section 6.2 will describe a Web-based application component, including an Active Server Pages (ASP) in section 6.2.1, an Internet Information Server (IIS) in section 6.2.2, a Structure Query Language Server (SQL Server) in section 6.2.3, the Web request and response process in section 6.2.4, the architecture of Web-based application in section 6.2.5.

Second, the development of Web-based Safety Assessment System will be described in section 6.3 then third, the application of developed Web-based safety assessment system will be demonstrated in section 6.4 and at the end the developed system will be concluded in section 6.5.

6.2. Web-based Application Component

Use of database that provides a structured way to storage data for easier data retrieval is commonplace. However, retrieving a particular old document stored in a paper-based database could be time-consuming. Today this is unacceptable. In particular in a safety assessment system a rapid assessment of safety and its remedial action need a fast and reliable database to provide the required information.

Computerized databases have now replaced the paper-based ones, as the computerized database provides fast document storage and retrieval. To further improve its use, a computerized database is often built in the form of a Web-based system. The Web using the Internet’s infrastructure, has become the platform of choice for online or offline browsing as they are being developed and maintained everyday (Darwish, 2003; Hassan and Holt, 2004).

The following sections will describe the components needed to build the Web-based application for the safety assessment system, an Active Server Pages (ASP) in section 6.2.1, an Internet Information Server (IIS) in section 6.2.2, a Structure Query Language Server (SQL Server) in section 6.2.3, the Web request and response process in section 6.2.4, the architecture of Web-based application in section 6.2.5.

6.2.1. Active Server Pages (ASP)

Some of the most common frameworks in Web application development are: Active Server Pages (ASP), Java Server Pages (JSP), Netscape Server Pages (NSP), and Allaire Cold Fusion (CF). An ASP has been chosen as a Web application to develop a Web-based safety assessment system. The reason of this choice is because ASP has two benefits, it is Language-Independent and it is for Non-Programmers.

Regarding the first benefit, the ASP engine does not depend on a single language instead it is a language-independent scripting host. It works with any scripting language that is compatible with the Microsoft Scripting Host requirements, such as the HTML script, VBScript, and JavaScript. It even works with code written in multiple scripting languages on the same page. The second benefit, that ASP is for Non-Programmer, indicates anyone can use it. It based on the idea that programmer can create reusable general-purpose entities (the block) and anybody especially ordinary people (or non-programmer) can then hook them together to create complex program. Although to build simple ASP one may not need to be a programmer, however one needs to become a programmer to build ASP application.

An ASP page is basically a HyperText Markup Language (HTML), which is a tagged text file format, used to format Web content for display. HTML is a very simple layout language with only a few commands which inform the computer about the content of a document e.g. a paragraph, a table or an image. An ASP itself is an Internet Server Application Programming Interface (ISAPI) application that allows several operations to be performed, the three most important of which are: process information from clients, access databases and files and make *If...Then* decisions. The explanations of these are as follows.

a. Process Information From Clients

ASP provides several inhabitant objects to access data, make decisions, alter the data, store data and send it back to the client or user. The ASP objects make it easy to process client data.

b. Access Databases and Files

ASP by itself has no database connectivity, however a user can initial the ActiveX Data Object (ADO) to access databases and the Microsoft Scripting Runtime FileSystemObject and TextStream objects to read and write text files.

c. Make *If…Then* Decisions

Most programming is about making simple decisions. Assume a user wants to choose an item from a drop-down list, then ASP will do one thing or another depending on which item is chosen. This means it can make a decision. For example:

```
If user clicked Scaff then
       ‘Save user’s selection in a variable
       Session(“LastUserSelection”) = “Scaff”
       Show list of activity in Scaffolding
ElseIf user clicked Lift then
       ‘Save user’s selection in a variable
       Session(“LastUserSelection”) = “Lift”
       Show list of activity in Lifting
End If
```

The code shows that ASP is going to make a decision based on which state abbreviation is selected from a list. It will probably save the user’s selection for future use, and then display a new list of activities.

So, these features of ASP can be used to make an automated assessment of safety also store and retrieve data that indeed, really needed in this developed safety assessment system to improve it.

6.2.2. Internet Information Server (IIS)

Active Server Pages is a component of the Internet Information Server (IIS) and so cannot be separated from it. The Internet Information Server (IIS) is the Web server that is provided with Microsoft Windows NT and Microsoft Windows 2000. It is extremely fast Web server and important because of its valuable features. Firstly, IIS provides integrated security. On the Internet most sites allow anybody connection, but there are some sites that have restrictions, known as secured sites. They use either integrated security or login and password security. IIS supports both methods and allows security restriction to set up on a site-by-site basis. Secondly, it also provides access to content. All Web servers can deliver HTML files, but differ in how to treat other types of content.

IIS integrates directly into the Windows registry meaning it natively understands how to treat most common Windows file format, such as text (TXT) files, executable (EXE) files, Microsoft Word (DOC) documents, Power Point (PPT) presentations, Excel (XLS) spreadsheets, and many others. Thirdly, it provides an Interface for Component Object Model (COM) as well and exposes a COM interface through a set of objects called the IIS Admin object. Using it, one can use these objects with ASP or any COM-compliant language to alter the metabase, a special database that stores settings and Web information for IIS 4 and higher versions, programmatically.

IIS provides the basic Web server functionality required to serve Web pages. However, the heart of the toolset for building Web application is the ASP component of IIS called Visual InterDev development tool. The Visual InterDev development tool is used for creating Web pages and working with Structure Query Language (SQL) Server to build a Web-based application.

6.2.3. The Structure Query Language (SQL) Server

An explanation of Structure Query Language (SQL) begins with an explanation of a database. A database is an object for storing structured information. This means database is stored information that organised in such a way that allows quick and efficient information retrieval (SYBEX, 2001). The organization of information such as the information is broken down into tables each of which stores different entities. In addition, the relationship between tables can be defined, which is allows users to combine information from multiple tables.

Information is stored into and recalled from the database by a special program known as a database management system (DBMS), the software that manages and maintain all information in a database. An example of a DBMS is the Structure Query Language Server (SQL Server). SQL Server is a relational database server that encompasses many different technologies that are still evolving: relational database management systems, local area networks, and client-server computing (Nath, 1990). It basically relies on the client-server model and is intended primarily for use in local area network (LAN) environments.

While DBMS managed and maintained all information in a database, information stored in it can be accessed by users through statements, called a query, made in Structure Query Language (SQL), a language for specifying high-level operations (SYBEX, 2001).

6.2.4. The Web Request and Response Process Used for Web-based Safety Assessment System

The previous three sections have described the three components needed to build a Web-based application: ASP, IIS and SQL Server. To know how they work together for a Web-based application, the following section will give explanation of the Web request and response process (see Figure 6.1 for the illustration of the process). The example wills specific state its application for a safety assessment system.

1. A Web request requires two components: a Web server and a client. A client is usually a browser, such as an Internet Explorer and a Netscape Navigator. The Internet Information Server (IIS) as an example of a Web server is the server provided by Microsoft through Microsoft Windows NT and Microsoft Windows 2000 applications. One of the key features of IIS is it comes with Active Server Pages (ASP).

   A Web request begins when a user interacts with a client through HTML documents (Web pages). Whenever a user enters a Uniform Resource Locator (URL) into a browser's address field, such as: http://localhost/project.asp, then click a link or submit a form, the browser sends that information to the server as a Web request. The URL used as an example is the address of a Web-based safety assessment system developed in this research. A “localhost” in address bar shows that the client and server are in one computer. If the client and server are in separate computer, the “localhost” has to replace by the Internet Protocol (IP) address of the server.

2. After the request sent by a client received by the Web server, then the server checks for the requested file. If the server needs to access a database, it must contact a Database Management Systems (DBMS) through an ActiveX component. The Web server’s role is to generate HTML documents and then it can begin sending responses back to the client.

The following Figure 6.1 shows the process of a Web request and response.

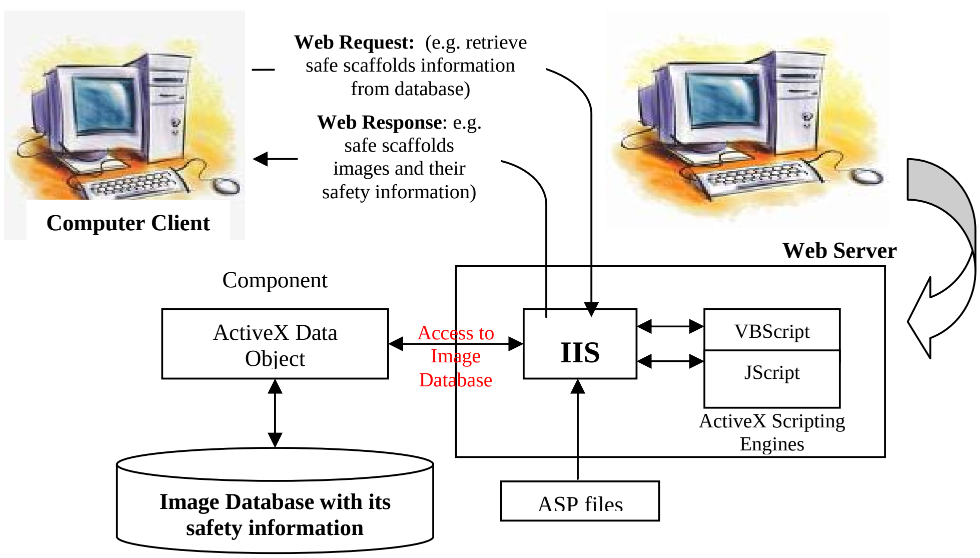


Figure 6.1. Web Request and Response Process for Retrieving Safe Scaffolds Information from Image Database

Note:

In Figure 6.1, the client’s computer and the web server’s computer are illustrated separated but they can be integrated in one computer.

To show how the entire process works, Web-based database application architecture will now be described.

6.2.5. Web-based Database Application Architecture

The development of a Web-based database application is based on three tiers application. The first is the client (browser) which interacts with the user through HTML documents (Web pages) as in Figure 6.1. The user here can be the database safety administrator who has access into the database to manipulate it, or a construction engineer who only has access into the system without the ability to manipulate it. Thus, a Web page may contain control (security) where the user can enter information and submit it to the server. The browser to the Web server channels all requests in the middle tier.

The Internet Information Server (IIS) is the middle tier. If the Web server needs to access a database, it must contact a Database Management System (DBMS). The SQL Server is a DBMS and in this three-tier architecture, the DBMS with its database stands in the third tier.

The tier of a Web application need not reside and execute on different computers (see “Note” in section 6.2.4 in Figure 6.1). It means the DBMS may be running on the same computer as the Web server. One can even run all three tiers on the same computer but the DBMS will authenticate the Web server and not allow it to view information unless it has the appropriate privileges.

For this research, to develop a Web-based safety assessment system, therefore, a SQL Server database and an ASP application need to be built. The SQL Server database will consist of information in the form of text information and image (photo) information. The ASP application will provide the user interface for interaction between user (the safety administrator or the construction engineer) and the database.

6.3. The Development of The Web-based Safety Assessment System

The Web-based safety assessment system was built to achieve the aim of this research which is to investigate the usefulness of a descriptive database of construction methods for safety assessment (see section 1.3) and also the third objectives of this research (see sections 1.3 and 2.6). The system consists of the assessment function, case-search function and photographic image database. The first two are integrated into the system to answer the problem mentioned in Chapter 5, the need of a program to integrate the safety assessment system and the database. The case-search function is a provided feature as an answer for problems related with reusing past experience revealed from preliminary investigation.

The assessment function has been developed using the safety system explained in Chapter 5. An interface is needed to integrate a user's needs e.g. assessing safety, storing new cases and retrieving stored cases, and a database developed in Microsoft Structure Query Language (SQL) server. This integration uses the Active Server Pages (ASP) program. The following sections will explain the Web-based safety assessment system setting.

6.3.1. Uses of The System

In this Web-based safety system, there would be two kinds of users: a safety administrator and a construction engineer. An administrator maintains the database and uses it to assess safety and has authorization to update it. An engineer can only retrieve information and does not have authorization to update it. Hence, there are two settings have to build in the safety system, depending on the kind of user. Both settings are as follows (see Figure 6.2 for the flowchart):

a. Use of The Safety System by A Safety Administrator

An administrator is allowed to:

1. Access the database and update it through a "safety portal" which is login name and password.
2. Inputting a new photographic image and giving a safety assessment based on observation from that new image. The definition and classification of construction practice from the new image is the result of that assessment. These two results can be derived automatically from the system.

3. Identify the possible hazard from the new image that has been defined and classified; and give a solution based on the identification.
4. Store an image and its description in the database as a new case.

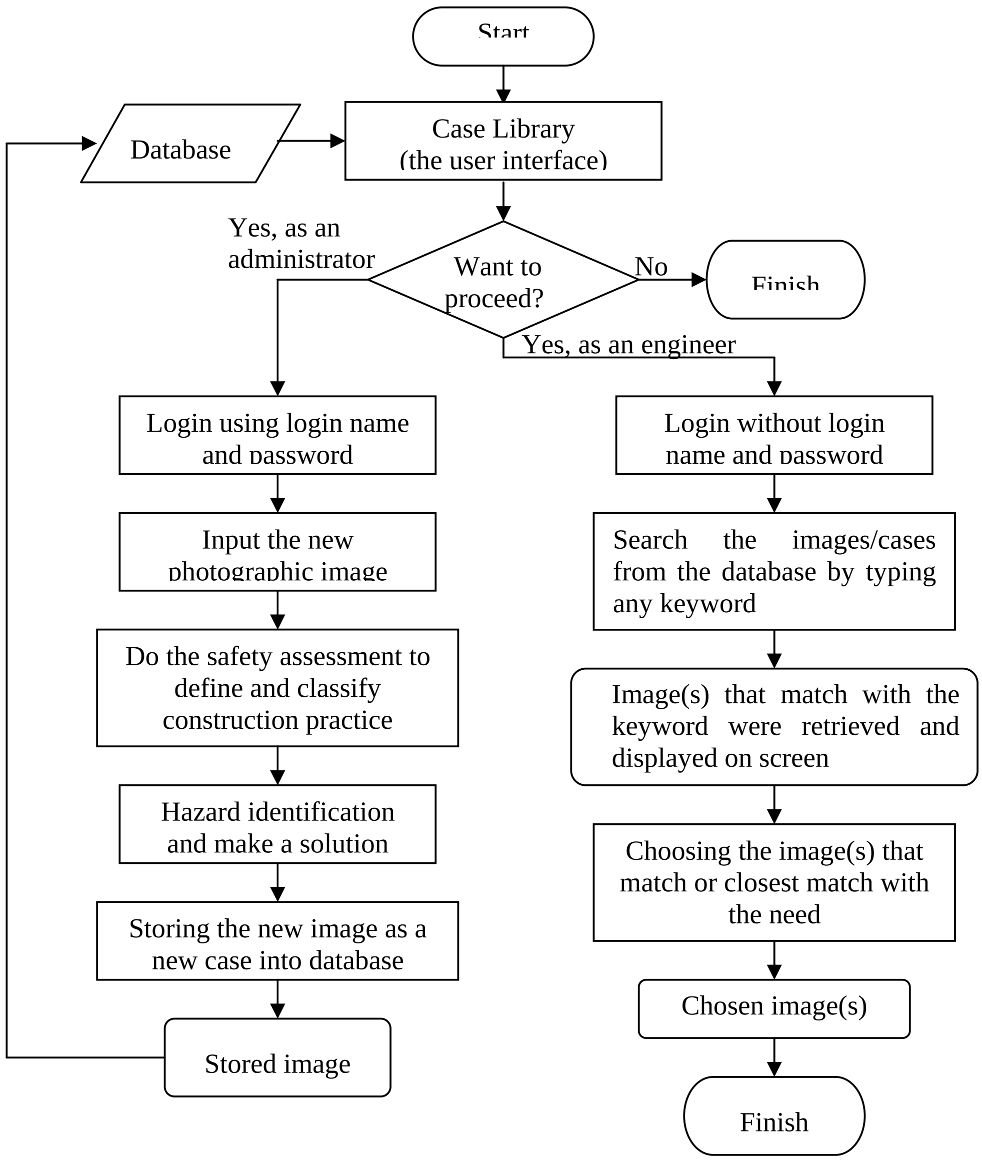


Figure 6.2. Flowchart of a Web-based Safety Assessment System Setting

b. Use of the Safety System by a Construction Engineers

An engineer is allowed to:

1. Access data from the database without manipulate it. No requirement for types login name and password.

2. Search for stored images (or cases), which are fit with his/her needs by typing any word associated with the predicted keyword or "meta search".

The all images that are associated with the keyword will be revealed and displayed on the computer screen.

6.3.2. The Web-based Interface for Safety Assessment System

The interface is the gateway to access the data contained in the photographic image database or a case library, namely Image Description for Case Library, which is accessed via the Internet domain address: http://localhost/project.asp. It is also the point where data are entered, assessed, and stored automatically. The interface consists of the administrator and the engineer templates (refer to Figure 6.2).

a. The Safety Administrator Template

For security reasons database is designed to have an account login template for a safety administrator. So that information is protected. Not everyone has access to manipulate information so its authenticity is guaranteed. Only an administrator and/or authorized person to enter the database have username and password (see Figure 6.3). By entering the correct username and password, the user can access to the various built-in functions, such as: Adding a case, assessing a case, giving a description, and storing a case. The administration for thus has total control of data from inputting, assessing and saving it.

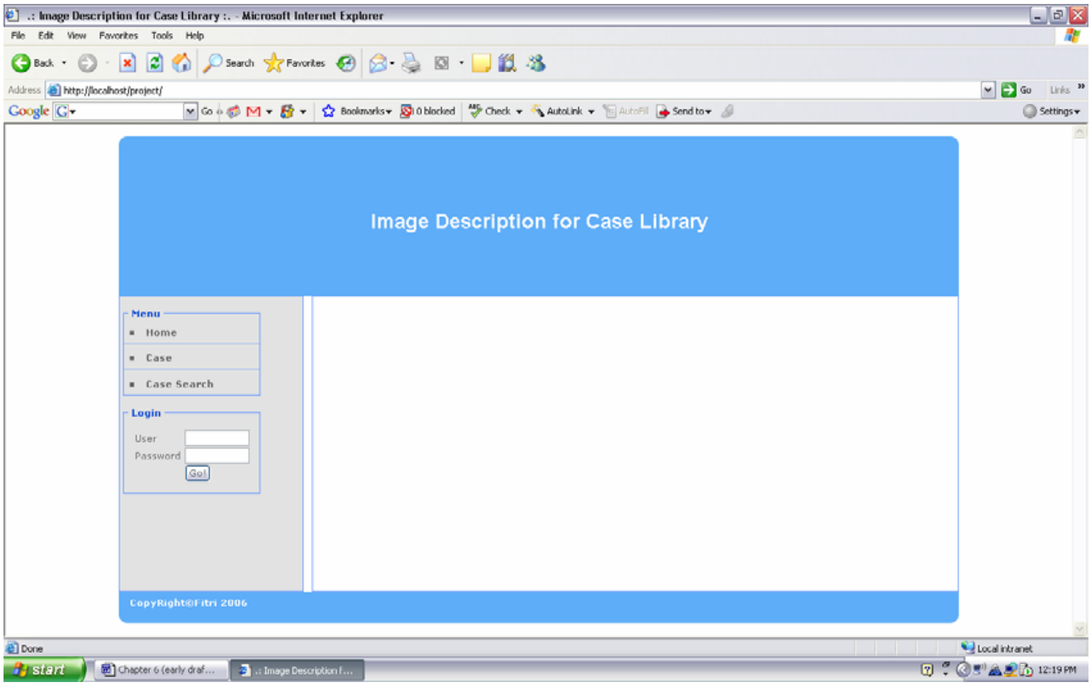


Figure 6.3. User Interface for an Administrator to Enter the Database

b. The Construction Engineer Template

Access for both a safety administrator and a construction engineer to the database to search and find all stored cases are through user interface shown in Figure 6.4. To arrive at this page, either an administrator or an engineer is unnecessary to login because the database is designed to be an open source enabling anyone to access and find information. A setting for searching a case is same, no one needs to login into the system. The user interface to find the stored cases that fit with a need is shown in Figure 6.5.

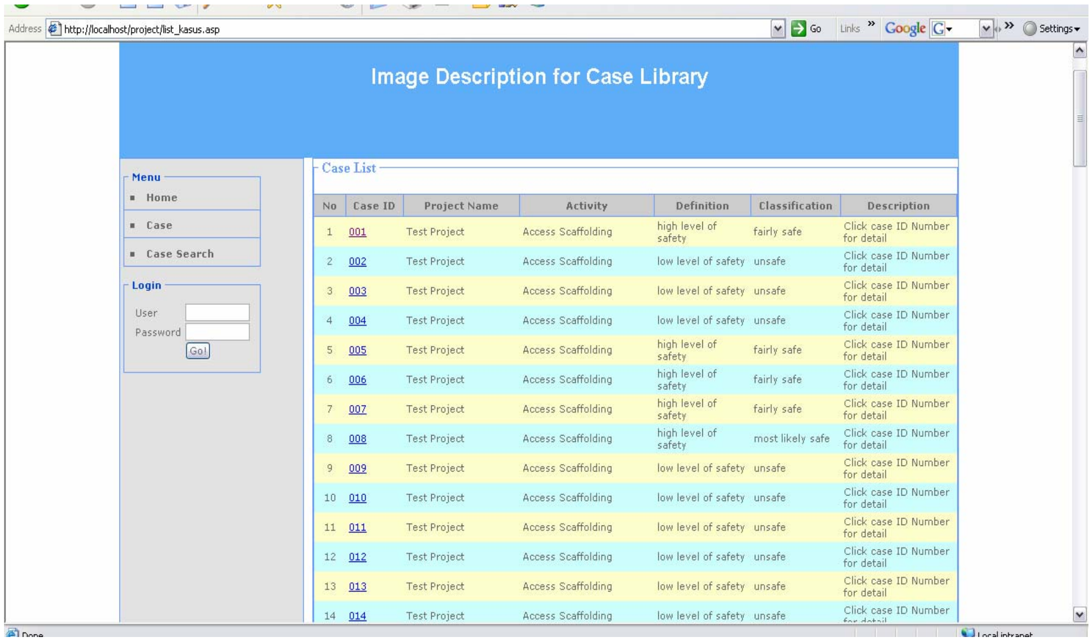


Figure 6.4. User Interface for Observing All Stored Cases

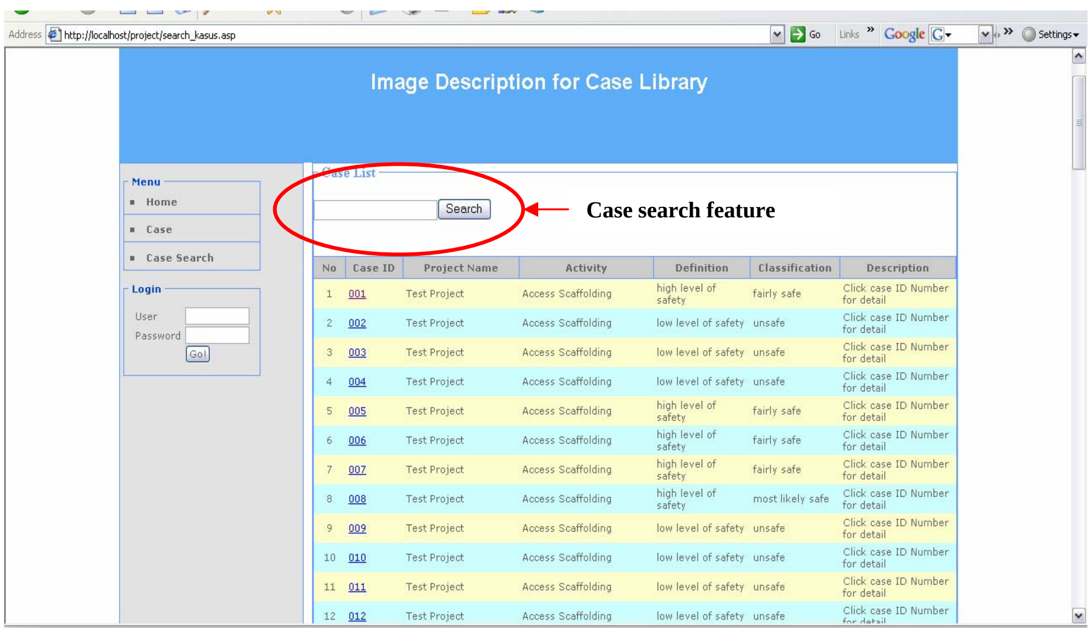


Figure 6.5. User Interface to Search a Case

Figures 6.4 and 6.5 show the user interface for a case function that enables a user to access all stored cases and a case search function that enables a user to access selected cases that match with the keyword.

6.3.3. The Knowledge Base

The knowledge base contains a summary of expert advice and guidelines that are vital for safety and health management. It plays a supporting role to complement the automated assessment system by providing practical advice to hazards identification. As the system will use by two kinds of user, a safety administrator and a construction engineer, therefore the safety knowledge base in this system act differently.

For an administrator, upon completion of the entry of the photographic image data via the template, the built-in program will automatically give a data safety score, a definition and a classification. The administrator or a safety expert then observes the image for hazard identification. Expert advice in the form of solution for identified hazard will be given continuing it.

For an engineer, the stored images in the database and their safety information can be used as safety knowledge base for anything related to construction safety, to enhance their safety knowledge. They can use it to design and plan safe construction activities, practices, project site lay out, etc.

6.3.4. The Data-Entry Process

A brief account on how the system works in practice now follows. It is operated through a Web-based interface and is performed by an administrator or an authorized person that have to login by entering user name and password (see Figure 6.2) to begin process.

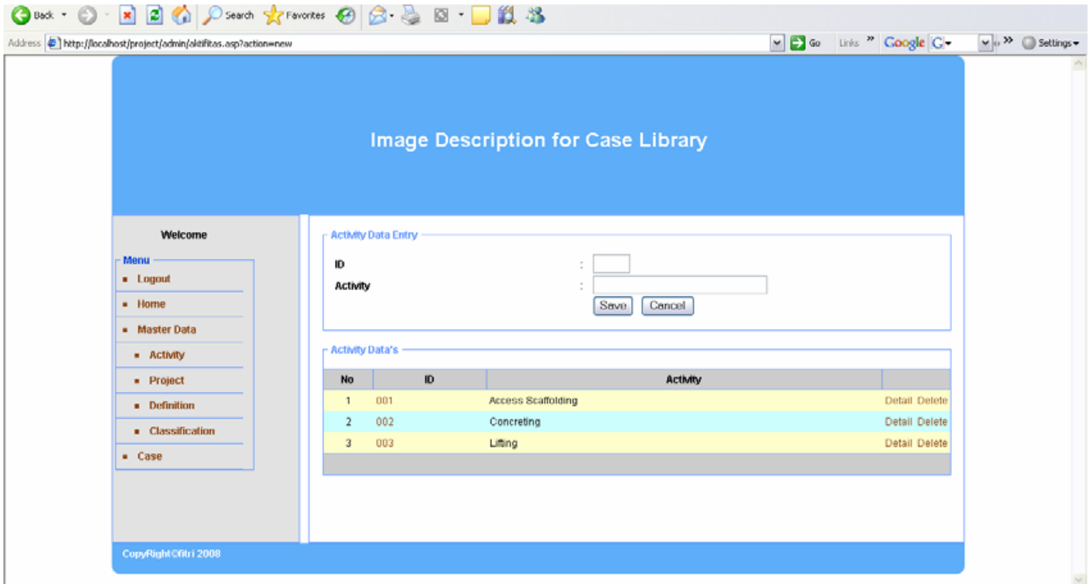


Figure 6.6. User Interface for Activity Feature

An administrator can choose the “home” of the datum by selecting the available project or creating the new one. Then, an activity from the list can be chosen or a new activity added (see Figure 6.6). Every activity has its safety attributes and sub attributes (see Figure 6.7).

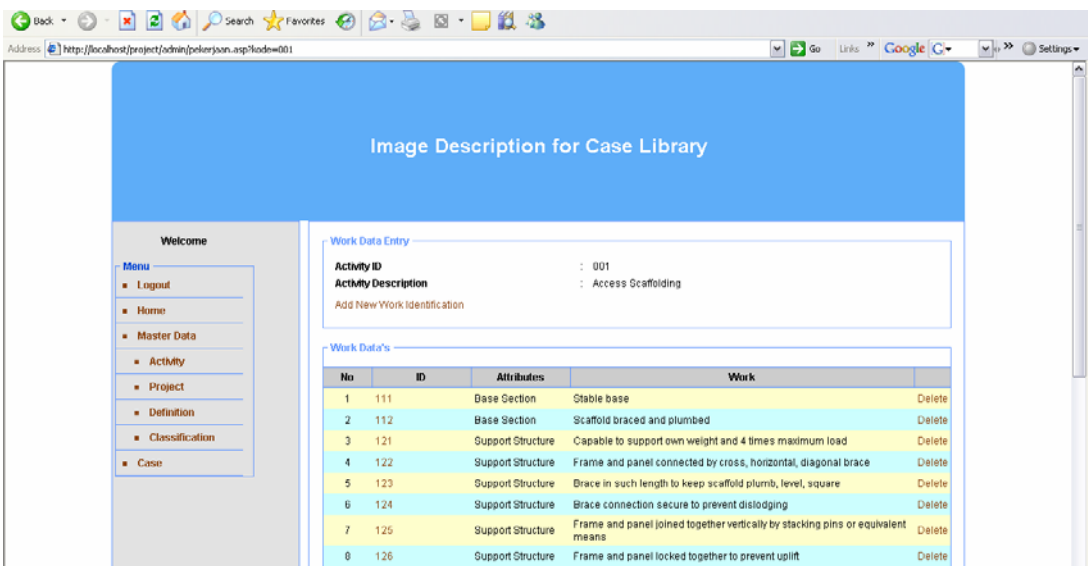
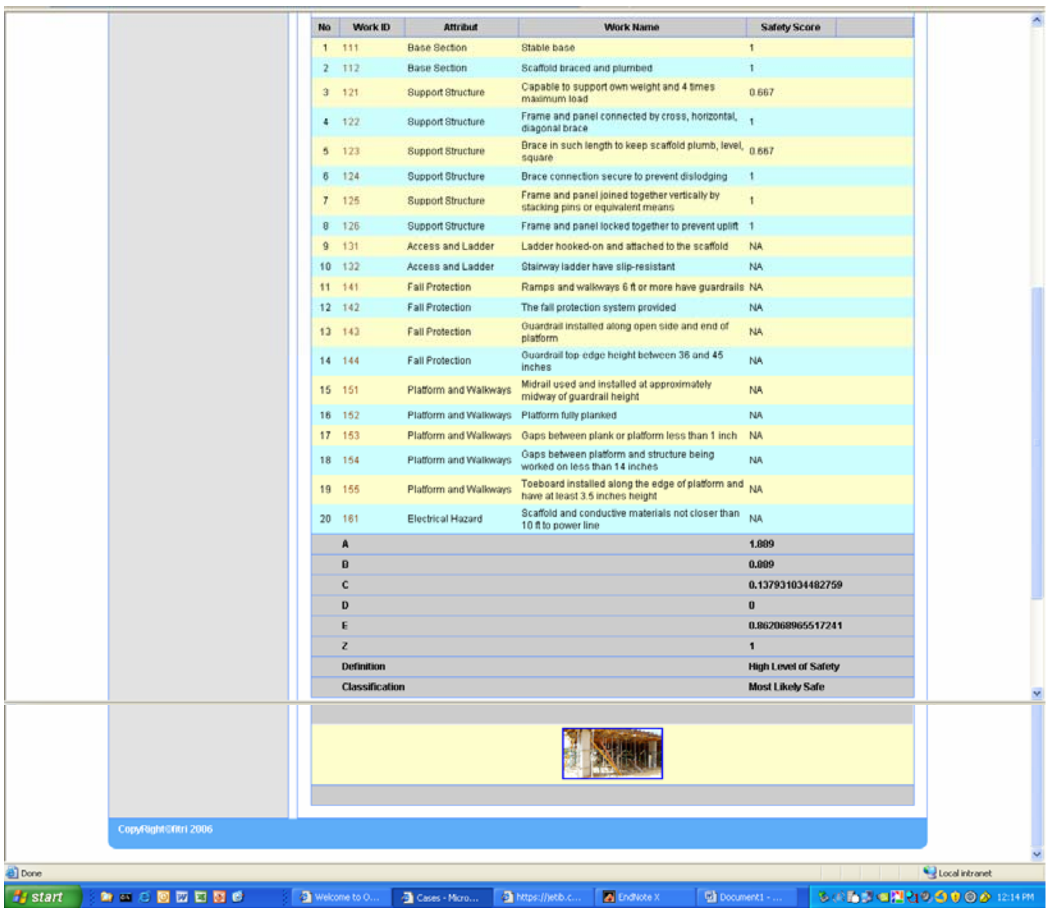


Figure 6.7. User Interface for Activity’s Attributes and Sub Attributes Feature

The final step is a process to add a new case in the database. An administrator can give a “score” by selecting the box within the Safety Score under which four certain values and N/A (Not Available) choices are provided. The scores are: 0-unsafe, 0.333-likely unsafe, 0.667-likely safe, and 1-safe. The N/A choice is provided if the safety attributes and sub attributes cannot be observed from the image. The user interface for safety assessment is shown in Figure 6.8.



No	Work ID	Attribut	Work Name	Safety Score
1	111	Base Section	Stable base	1
2	112	Base Section	Scaffold braced and plumbed	1
3	121	Support Structure	Capable to support own weight and 4 times maximum load	0.667
4	122	Support Structure	Frame and panel connected by cross, horizontal, diagonal brace	1
5	123	Support Structure	Brace in such length to keep scaffold plumb, level, square	0.667
6	124	Support Structure	Brace connection secure to prevent dislodging	1
7	125	Support Structure	Frame and panel joined together vertically by stacking pins or equivalent means	1
8	126	Support Structure	Frame and panel locked together to prevent uplift	1
9	131	Access and Ladder	Ladder hooked-on and attached to the scaffold	NA
10	132	Access and Ladder	Stairway ladder have slip-resistant	NA
11	141	Fall Protection	Ramps and walkways 6 ft or more have guardrails	NA
12	142	Fall Protection	The fall protection system provided	NA
13	143	Fall Protection	Guardrail installed along open side and end of platform	NA
14	144	Fall Protection	Guardrail top-edge height between 36 and 45 inches	NA
15	151	Platform and Walkways	Midrail used and installed at approximately midway of guardrail height	NA
16	152	Platform and Walkways	Platform fully planked	NA
17	153	Platform and Walkways	Gaps between plank or platform less than 1 inch	NA
18	154	Platform and Walkways	Gaps between platform and structure being worked on less than 14 inches	NA
19	155	Platform and Walkways	Toeboard installed along the edge of platform and have at least 3.5 inches height	NA
20	161	Electrical Hazard	Scaffold and conductive materials not closer than 10 ft to power line	NA
	A			1.889
	B			0.889
	C			0.137931034482759
	D			0
	E			0.862068965517241
	Z			1
	Definition			High Level of Safety
	Classification			Most Likely Safe

Figure 6.8. User Interface for Safety Assessment Scoring Process

6.3.5. Output

The output of this system is a case description containing, the project name, activity name, image definition, image classification, description, hazard identification, solution, and the image. The user interface of the output can be seen in Figure 6.9.

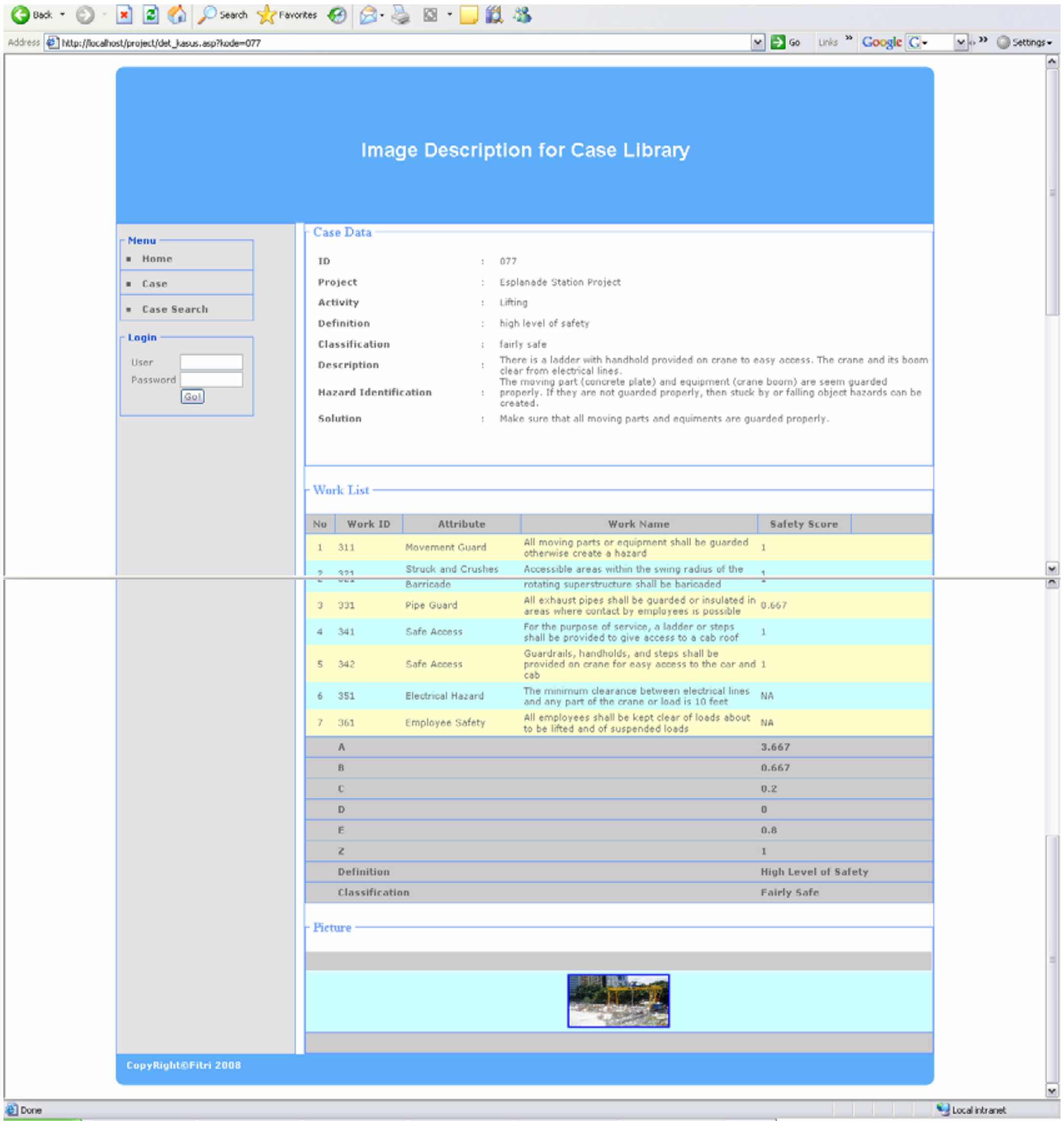


Figure 6.9. User Interface Output

By noting the output, a construction engineer can see the safety practice by observing the image, the potential hazard and the solution to avoid accident occurrence. The administrator/observer does two jobs on the same time, making an assessment of the construction practice being used and updating the database as well.

6.4. The Demonstration of Application of The Developed Web-based Safety Assessment System

This section will demonstrate the application of the developed Web-based safety assessment system, including assessing construction practice safety and case searching. The assessment uses the same 20 images that were used to calibrate the manual system so as to compare the results with manual and automated calculation.

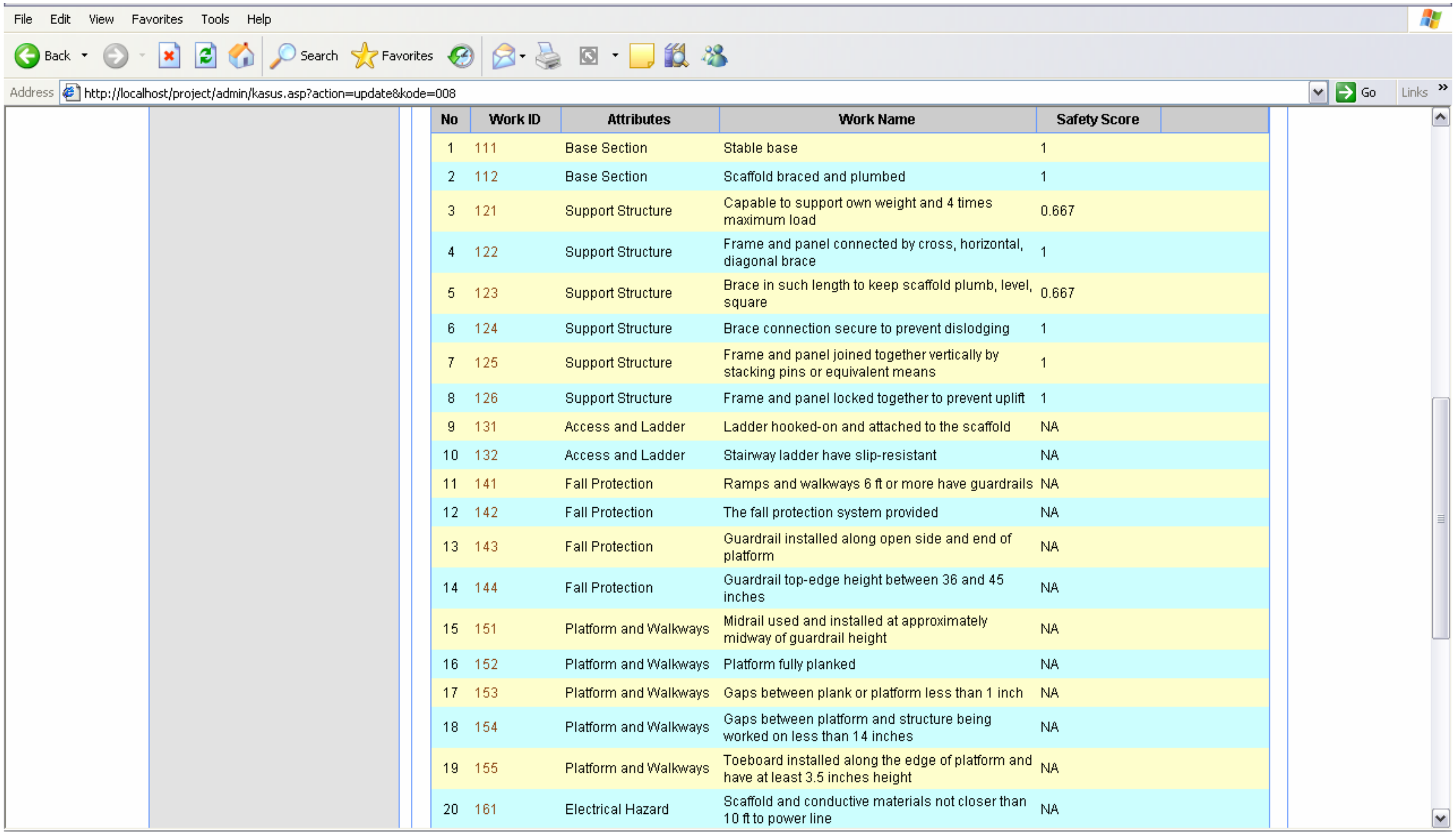
a. Assessing Construction Practice Safety

Figure 6.10. An Image of Scaffolding Activity (re-draw Figure 5.4 Image Number 8)

This example of the automated assessment process uses the image in Figure 6.10, which was earlier, identified as Figure 5.4 image number 8 in previous chapter (see Chapter 5 section 5.3.2). The safety score for the image in Figure 6.10 is shown below (see Table 6.1); scores are taken from Table 5.2 in section 5.3.2 with highlight image number 8 used as the example. The "Work IDs" are as shown in Figure 6.11 and presents safety sub attributes for particular activity. The same safety scores have used on both systems, manual system in Chapter 5 (see Table 6.1) and the automated Web-based system in this chapter (see Figure 6.11).

Table 6.1. Safety Score of Figure 5.5 Image Number 8 (re-write with modification of Table 5.2)

Image #	Work ID 111	Work ID 112	Work ID 121	Work ID 122	Work ID 123	Work ID 124	Work ID 125	Work ID 126	Work ID 131	Work ID 132	Work ID 141	Work ID 142	Work ID 143	Work ID 144	Work ID 151	Work ID 152	Work ID 153	Work ID 154	Work ID 155	Work ID 161
1	N/A	1.000	1.000	1.000	1.000	0.670	0.670	0.670	1.000	0.670	1.000	1.000	0.670	1.000	N/A	N/A	N/A	1.000	1.000	1.000
2	1.000	0.670	0.670	0.670	0.670	0.670	0.670	0.670	N/A	N/A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
3	N/A	0.670	0.670	0.330	0.670	0.330	0.670	0.330	N/A	N/A	0.000	0.000	0.000	0.000	0.000	0.330	0.330	N/A	N/A	1.000
4	0.670	0.670	0.670	0.000	0.000	0.000	0.670	0.670	0.000	N/A	0.000	0.000	0.000	0.000	N/A	N/A	N/A	0.00	N/A	0.000
5	0.670	0.670	1.000	0.670	1.000	0.670	0.670	0.670	N/A	N/A	1.000	0.670	0.670	1.000	0.670	0.670	1.000	0.670	1.000	1.000
6	0.670	0.670	0.670	1.000	1.000	0.670	0.670	0.670	N/A	N/A	1.000	1.000	0.670	N/A	1.000	N/A	1.000	1.000	1.000	1.000
7	N/A	0.670	0.670	1.000	1.000	1.000	1.000	1.000	1.000	N/A	1.000	1.000	0.330	1.000	1.000	N/A	1.000	1.000	1.000	1.000
8	1.000	1.000	0.670	1.000	0.670	1.000	1.000	1.000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9	N/A	0.670	0.670	1.000	0.670	N/A	N/A	N/A	N/A	N/A	0.000	0.000	0.000	0.000	N/A	N/A	N/A	N/A	0.000	1.000
10	1.000	0.670	0.330	0.000	0.330	0.670	0.670	0.670	N/A	N/A	0.000	0.000	0.000	0.000	0.670	N/A	0.670	0.000	0.000	1.000
11	N/A	0.670	0.670	0.670	0.330	0.330	0.670	0.670	N/A	N/A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
12	N/A	0.330	0.670	1.000	1.000	0.670	N/A	0.670	N/A	N/A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
13	N/A	0.670	0.670	0.000	0.000	0.000	0.670	0.670	N/A	N/A	0.000	0.000	0.000	0.000	N/A	N/A	1.000	0.00	0.00	0.330
14	N/A	0.670	0.670	0.330	0.670	0.670	0.670	0.670	N/A	N/A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
15	N/A	N/A	0.670	0.330	0.670	0.670	0.670	0.000	N/A	N/A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
16	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.670	N/A	N/A	1.000	1.000	0.670	1.000	1.000	1.000	1.000	1.000	1.000	1.000
17	N/A	0.670	1.000	1.000	1.000	1.000	0.670	0.670	N/A	N/A	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
18	N/A	0.670	1.000	1.000	0.670	0.670	0.670	0.670	0.670	N/A	1.000	1.000	0.670	1.000	1.000	0.670	0.670	0.330	1.000	1.000
19	N/A	0.670	0.670	0.330	0.000	0.330	0.670	0.670	N/A	N/A	0.000	0.000	0.000	0.000	0.330	0.330	0.330	0.00	0.00	1.000
20	1.000	0.670	1.000	0.670	0.670	0.670	0.670	0.330	N/A	N/A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000



No	Work ID	Attributes	Work Name	Safety Score
1	111	Base Section	Stable base	1
2	112	Base Section	Scaffold braced and plumbed	1
3	121	Support Structure	Capable to support own weight and 4 times maximum load	0.667
4	122	Support Structure	Frame and panel connected by cross, horizontal, diagonal brace	1
5	123	Support Structure	Brace in such length to keep scaffold plumb, level, square	0.667
6	124	Support Structure	Brace connection secure to prevent dislodging	1
7	125	Support Structure	Frame and panel joined together vertically by stacking pins or equivalent means	1
8	126	Support Structure	Frame and panel locked together to prevent uplift	1
9	131	Access and Ladder	Ladder hooked-on and attached to the scaffold	NA
10	132	Access and Ladder	Stairway ladder have slip-resistant	NA
11	141	Fall Protection	Ramps and walkways 6 ft or more have guardrails	NA
12	142	Fall Protection	The fall protection system provided	NA
13	143	Fall Protection	Guardrail installed along open side and end of platform	NA
14	144	Fall Protection	Guardrail top-edge height between 36 and 45 inches	NA
15	151	Platform and Walkways	Midrail used and installed at approximately midway of guardrail height	NA
16	152	Platform and Walkways	Platform fully planked	NA
17	153	Platform and Walkways	Gaps between plank or platform less than 1 inch	NA
18	154	Platform and Walkways	Gaps between platform and structure being worked on less than 14 inches	NA
19	155	Platform and Walkways	Toeboard installed along the edge of platform and have at least 3.5 inches height	NA
20	161	Electrical Hazard	Scaffold and conductive materials not closer than 10 ft to power line	NA

Figure 6.11. Safety Scoring Using the Web-based Safety Assessment System Interface

It can be seen from Table 6.1 and Figure 6.11, there are eight sub attributes can be observed from example image. Sub attribute 1 (Work ID 111) has score of 1, sub attribute 2 (Work ID 121) has score of 1, and so on. All scores used are exactly the same. The result from manual calculation is shown below, and derived from Table 5.3 in section 5.3.2:

Table 6.2. Safety Assessment Result of Figure 6.1

Image #	B	C	D	E	Z
1	0.640	0.00006	0.000	0.99994	1.000
2	0.000	0.00024	0.000	0.99976	0.000
3	0.000	0.00024	0.000	0.99976	0.000
4	0.000	0.00006	0.219	0.99994	0.000
5	0.350	0.00024	0.000	0.99976	1.000
6	0.465	0.00024	0.000	0.99976	1.000
7	0.527	0.00006	0.000	0.99994	1.000
8	0.890	0.01563	0.000	0.98437	1.000
9	0.000	0.00024	0.000	0.99976	0.000
10	0.000	0.00024	0.000	0.99976	0.000
11	0.000	0.00024	0.000	0.99976	0.000
12	0.000	0.00024	0.000	0.99976	0.000
13	0.000	0.00024	0.098	0.99976	0.000
14	0.000	0.00024	0.000	0.99976	0.000
15	0.000	0.00098	0.000	0.99902	0.000
16	0.867	0.00024	0.000	0.99976	1.000
17	0.596	0.00024	0.000	0.99976	1.000
18	0.236	0.00006	0.000	0.99994	1.000
19	0.000	0.00024	0.000	0.99976	0.000
20	0.000	0.00024	0.000	0.99976	0.000

Note:

B = P*(E/H)* C = *P(H)*

D = *P(E/H')* E = *P(H')*

Z = *P(H/E)*

The result from automated calculation is shown in Figure 6.12. Please note that the column's names, such as B, C, D, E, Z in Table 6.2 were refer to row's names in Figure 6.12 with the same alphabets: B, C, D, E, Z. These alphabets are as described in section 5.3.2.

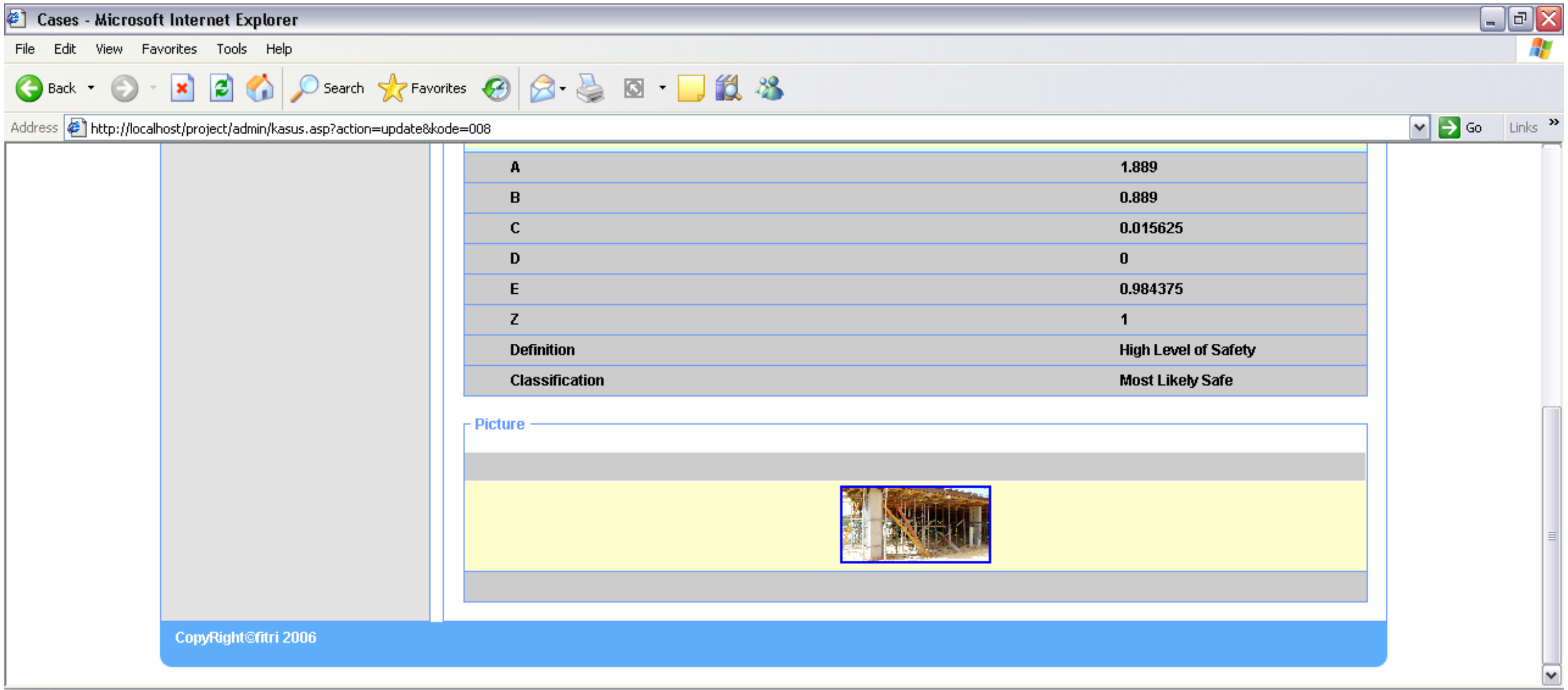


Figure 6.12. Result of Safety Assessment for Image Number 8

Result from manual calculation shows that B = 0.890, C = 0.01563, D = 0.000, E = 0.98437, and Z = 1 (see Table 6.2). Result from automated calculation shows that B = 0.889, C = 0.015625, D = 0, E = 0.984375, and Z = 1 (see Figure 6.12). It can be seen that the result from both calculations is same; rounding system causes the difference value between both calculations.

Figure 6.12 also shows that after safety scoring step finished, the score of B, C, D, E, and Z will appear automatically, along with the definition and classification of construction practice. For the complete result of calibrating automated safety assessment system using the 20 images, see appendix 1.

b. Case Searching

Another feature of the Web-based safety assessment system is the case search function which enables all users to retrieve stored information (an image and its description) from the database.

There are two kinds of search methods: specific method which searches with a certain or known keyword and "meta" search searches without certain keyword. This safety assessment system enables both search methods to be applied. The project name or the construction activity was examples of the known keyword and the "meta" search uses a keyword such as fairly safe, low-level of safety. An example output of case search function in this Web-based safety assessment system the using keyword: "fairly safe" can be seen in Figure 6.13.

It can be observed from Figure 6.13 that by typing the keyword "fairly safe" all stored data (or cases) that termed "fairly safe" will appear on the computer screen. On screen, twelve cases are shown at a same time thus the user can get twelve "fairly safe" cases at the same time no matter the case ID, project name, or activity, etc. Clicking the case ID button will allow information inside that particular case to be retrieved (see "description" column in Figure 6.13).

Using this function, users can get information that suits their needs. It is especially good for engineers who do not have prior experience.

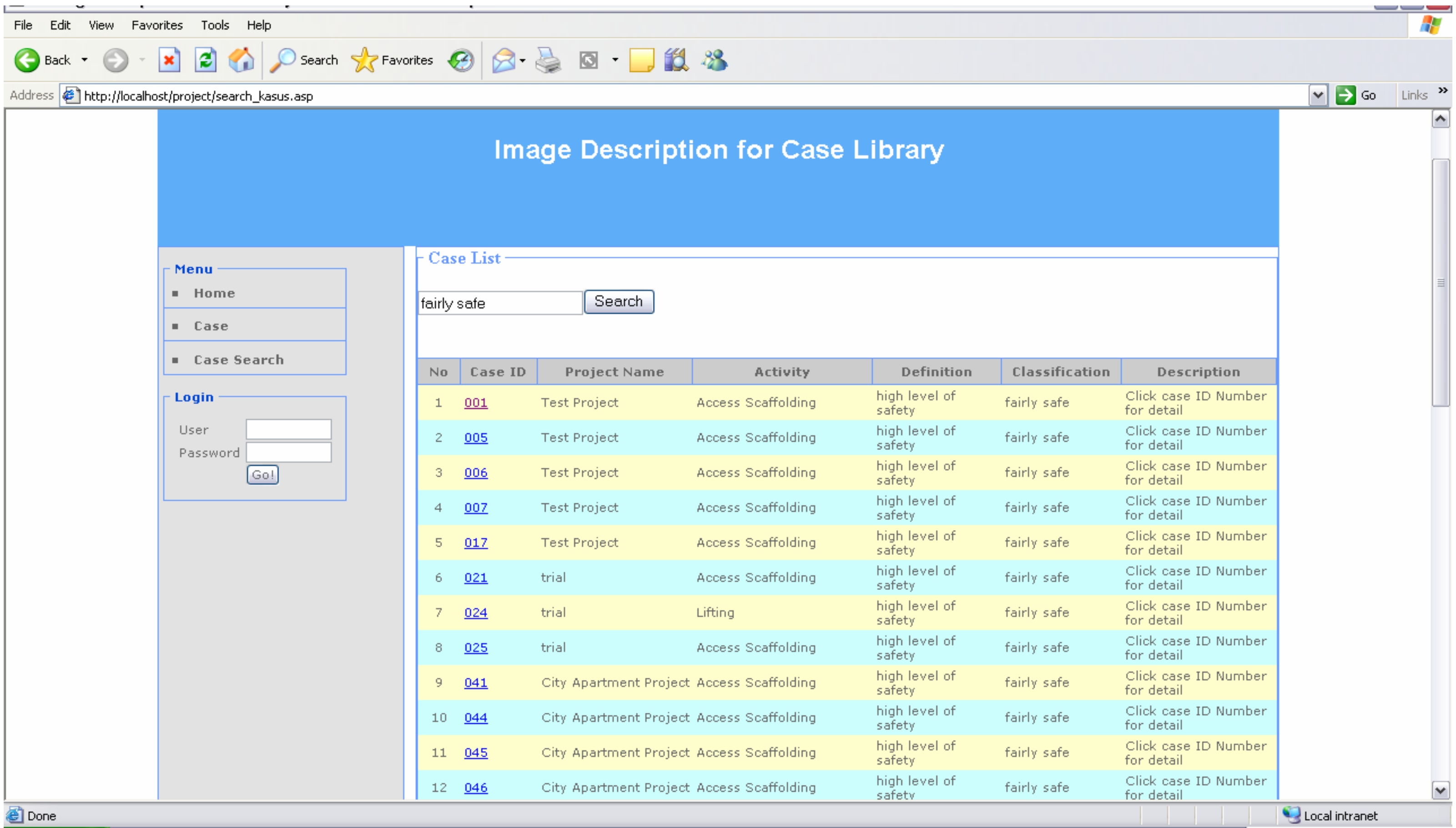


Figure 6.13. Case Search Function Output

c. Discussion of Developed Web-based Safety Assessment System

Results from automated calculation with the same given safety scores as manual calculation show that the automated calculation produces the same score for B, C, D, E, and Z. As a reminder, B represents $P(E_{comb}/H)$ score, C represents $P(H)$ score, D represents $P(E_{comb}/H')$ score, E represents $P(H')$ score, and Z represents $P(H/E_{comb})$ score. This result verifies that the Web-based safety assessment system could be used as a safety assessment tool for both data analysis and as a data search tool for case-based reasoning.

6.5. Conclusion of The Development of Web-based Safety Assessment System

Construction safety is recognized as a way to minimize the occurrence of construction accidents. A manager needs a system that can provide up-to-date information on a construction site safety, so that a construction manager can monitor and control safe construction site, and also obtain updated information for effective decision-making.

This chapter has described the development of a Web-based safety assessment system. The purpose of which was to integrate safety assessment process and store the results in a database. This system also has a case search feature enabling users to retrieve all stored information from a database.

Basically, the system has two main users, construction engineers and an administrator. For security reasons, the construction engineers can only use the information already stored in the database without the ability to update it, while the administrator has the authority to update it and ass new information.

The example using the same 20 images that had been used to test manual calculation has revealed the same results. It can be concluded that the Web-based safety assessment system could be used as data analysis tool for research data. The application of the safety assessment system to analyse research data and its practical use on-site will be demonstrated in Chapter 7.

Chapter 7

THE SAFETY ASSESSMENT SYSTEM (SAFE AS): APPLICATION AND USE

7.1. Introduction for A Safety Assessment System (SAFE AS)

Chapter 5 explains the safety assessment system using 20 images to verify that it could assess safety. However, as storing and retrieving data in and from a database separate from the assessment process took a lot of time and both of them were done manually, a Web-based system that could comprehensively assess, store, and retrieve information in and from a database automatically was required. Chapter 6 explains and demonstrates how this was achieved by developed a Web-based Safety Assessment System and tested using the same images producing the same results suggesting that it could be used for larger amounts of data. The system, either manual or automated, called the safety assessment system (SAFE AS).

This chapter will demonstrate and discuss the application and the use of the safety assessment system (SAFE AS) that had been developed and tested in Chapter 6. In this application, researcher that acts as a safety administrator undertakes the demonstration. Section 7.2 will be explained image collection as research data. Used of research data for SAFE AS demonstration will be described in section 7.3. The automated process of the SAFE AS and its results will be demonstrated in section 7.4 and section 7.5 will be discussed the SAFE AS.

Section 7.6 will explain the method used to refine the safety system, including proposed refinement method of the system and its example (section 7.6.1) and discussion of the refined assessment system (section 7.6.2). The used of safety assessment results will describe in section 7.7, including project-based trend tests (section 7.7.1), activity-based trend tests (section 7.7.2), prediction test (section 7.7.3) and discussion of the used of safety assessment results (section 7.7.4).

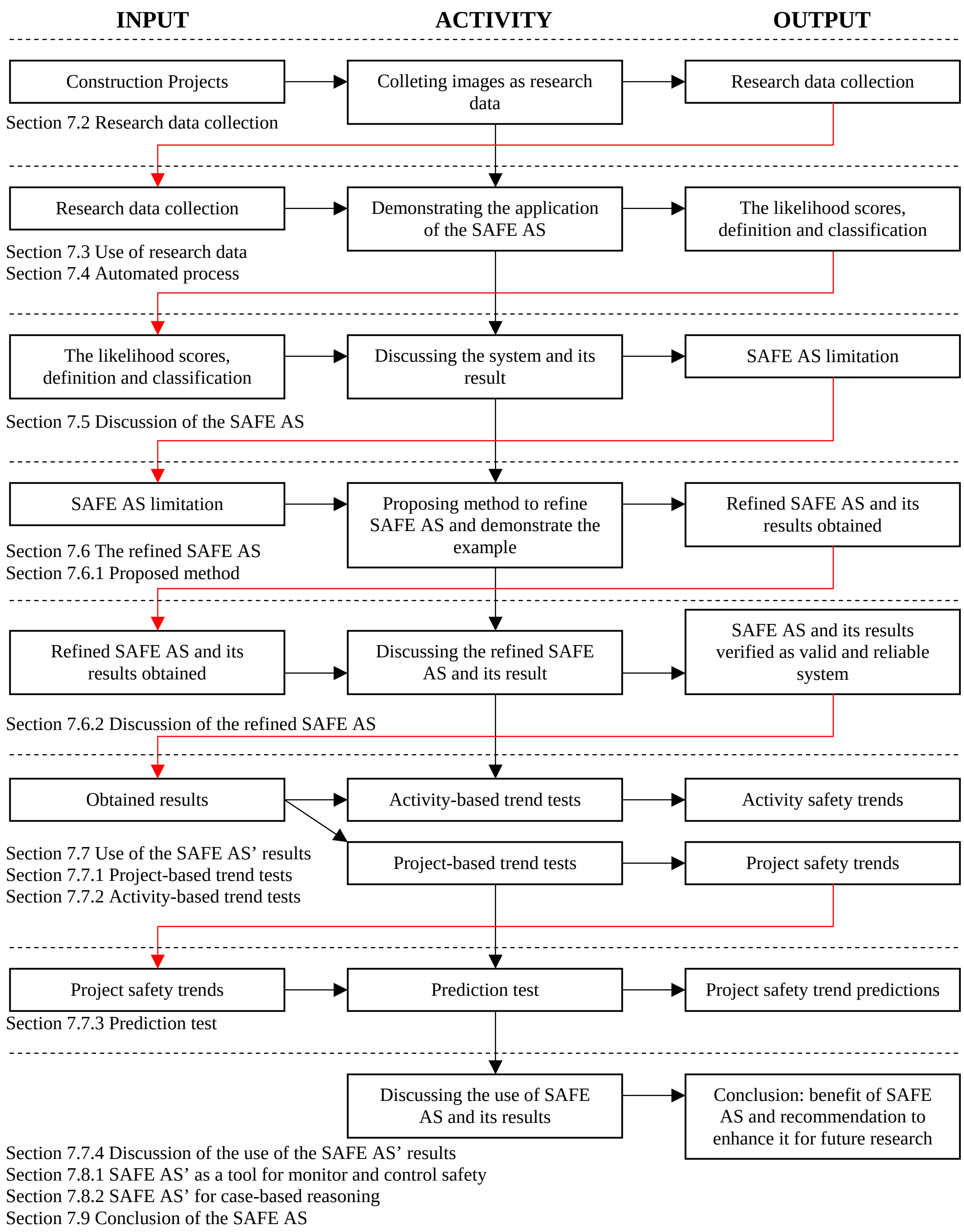


Figure 7.1. A Structure of Chapter 7

Section 7.8 will explain and discuss how to utilize the safety assessment system, including utilizing the system as a project safety monitor and control tool (section 7.8.1) and utilizing the system for Case-Based Reasoning (section 7.8.2). Finally, a conclusion of the safety assessment system will present in section 7.9. The structure of this chapter is illustrated in Figure 7.1

7.2. Research Data Collection for The Safety Assessment System

The data needed in this research, selection of samples, sites and kinds of images, the collection process and data storage were discussed (section 3.2.6). Three different activities were taken from four different construction sites in the Perth metropolitan area (section 3.2.6.a).

Data, construction activities images, were collected mostly from a distance and produced un-detailed activity construction project images. Only a few were detailed. The projects were a bridge over a highway, a train station, a multi-level residential/apartment block and a single level educational building. 189 images of access scaffolding, lifting and concreting were collected and stored as a digital photo files. Images were then chosen that fulfilled the need of the safety assessment process providing information to answer the safety checklist for each activity. Based on this need, only 69 images could be used (see Appendix 2).

As there were three kinds of activities (access scaffolding, lifting and concreting), three safety checklists were required to assess safety in construction project (section 3.2.6.b). One activity dealt with access scaffolding, the safety checklist of which has been shown in Chapter 5 (see Table 5.1 in section 5.3.1). The two other checklists for concreting and lifting are shown in Tables 7.1 and 7.2.

Table 7.1. The Attributes and Sub Attributes for Safe Concreting

Attributes	Sub Attributes
Supported Structure	1. The structure or portion of the structure is capable to support the loads
Reinforcing Steel	1. All protruding reinforcing steel are guarded to eliminate the hazard of impalement 2. Reinforcing steel for vertical structures are adequately supported
Employee Safety	1 There is no employee behind the jack during tensioning operation except those authorized person 2. There is sign and barrier erected to limit employee access to the post-tensioning area 3. There is no employee permitted to ride concrete bucket
Concrete Bucket Safety	1. There is no employee permitted to work under concrete buckets while buckets are being elevated 2. Concrete buckets are routed so that no employee exposed to falling buckets hazard
Protective Equipment	1. The employee is wearing protective equipment
Formwork Safety	1. The formwork is capable to support without failure all loads that may applied to formwork 2. All equipments are in firm contact and secured with the foundation and the form

(Source: www.osha.gov)

Table 7.2. The Attributes and Sub Attributes for Safe Lifting

Attributes	Sub Attributes
Movement Guard	1. All moving parts or equipment shall be guarded otherwise create a hazard
Struck and Crushes Barricade	1. Accessible areas within the swing radius of the rotating superstructure shall be barricaded
Pipe Guard	1. All exhaust pipes shall be guarded or insulated in areas where contact by employee is possible
Safe Access	1. For the purpose of service, a ladder or steps shall be provided to give access to a cab roof 2. Guardrails, handholds and steps shall be provided on crane for easy access to the car and cab
Electrical hazard	1. The minimum clearance between electrical lines and any part of the crane or loads is 10 feet
Employee Safety	1. All employees shall be kept clear of loads about to be lifted and of suspended loads

(Source: www.osha.gov)

The hypothesis of this research is to assess safe construction practice is being used (refer to section 5.3.1) so all sub attributes in Tables 7.1 and 7.2 refer to safe practice and used as evidence. Lists of evidence for the three activities are as follows:

Table 7.3. List of Evidence (E) for Concreting Activity

Attributes	Sub Attributes
Supported Structure (E_1)	1. The structure or portion of the structure is capable to support the loads (e_1)
Reinforcing Steel (E_2)	1. All protruding reinforcing steel are guarded to eliminate the hazard of impalement (e_1) 2. Reinforcing steel for vertical structures are adequately supported (e_2)
Employee Safety (E_3)	1 There is no employee behind the jack during tensioning operation except those authorized person (e_1) 2. There is sign and barrier erected to limit employee access to the post-tensioning area (e_2) 3. There is no employee permitted to ride concrete bucket (e_3)
Concrete Bucket Safety (E_4)	1. There is no employee permitted to work under concrete buckets while buckets are being elevated (e_1) 2. Concrete buckets are routed so that no employee exposed to falling buckets hazard (e_2)
Protective Equipment (E_5)	1. The employee is wearing protective equipment (e_1)
Formwork Safety (E_6)	1. The formwork is capable to support without failure all loads that may applied to formwork (e_1) 2. All equipments are in firm contact and secured with the foundation and the form (e_2)

Table 7.4. List of Evidence (E) for Lifting Activity

Attributes	Sub Attributes
Movement Guard (E_1)	1. All moving parts or equipment shall be guarded otherwise create a hazard (e_1)
Struck and Crushes Barricade (E_2)	1. Accessible areas within the swing radius of the rotating superstructure shall be barricaded (e_1)
Pipe Guard (E_3)	1. All exhaust pipes shall be guarded or insulated in areas where contact by employee is possible (e_1)
Safe Access (E_4)	1. For the purpose of service, a ladder or steps shall be provided to give access to a cab roof (e_1) 2. Guardrails, handholds and steps shall be provided on crane for easy access to the car and cab (e_2)
Electrical hazard (E_5)	1. The minimum clearance between electrical lines and any part of the crane or loads is 10 feet (e_1)
Employee Safety (E_6)	1. All employees shall be kept clear of loads about to be lifted and of suspended loads (e_1)

Table 7.5. List of Evidence (E) for Access Scaffolding Activity

Attributes	Sub Attributes
Base section (E_1)	1. The supported scaffold should be set on a stable object, such as base plates, mud sills, other adequate firm foundation (e_1) 2. The supported scaffold should be plumbed and braced to prevent swaying and displacement (e_2)
Support structure (E_2)	1. The supported scaffold and scaffold components should be capable to support their own weight and at least four times maximum intended load without failure (e_1) 2. Frames and panels are connected by cross, horisontal, or diagonal braces, to secure vertical members laterally (e_2) 3. Cross braces is in such length as will automatically keep the scaffold plumb, level, and square (e_3) 4. Brace connections are secure to prevent dislodging (e_4) 5. Frames and panels are joined together vertically by coupling or stacking pins or equivalent means (e_5) 6. Frames and panels are locked together to prevent uplift (e_6)
Access and ladders (E_3)	1. The hook-on and attachable ladder is specifically designed for use with the type of scaffold on which they are used (e_1) 2. Stairway-ladders must have slip-resistant treads on all step and landings (e_2)
Fall protection (E_4)	1. Fall protections which are consists of either personal fall-arrest system or guardrail system should be provided on any scaffold ten feet or more above a lower level (e_1) 2. Guardrail are installed along all open sides and ends of platforms (e_2) 3. The top edge height of toprails on supported scaffold should be between 36 and 45 inches (e_3) 4. If midrails are used, they should be installed at a height approximately midway between the top edge of the guardrail system and the platform surface (e_4)
Platform and walkways (E_5)	1. Each platform should be fully planked between the front uprights and the guardrail supports (e_1) 2. The gaps between adjacent planks or between platforms and uprights are not greater than one inch (e_2) 3. There is no more than a 14-inch gap between the scaffold platform and the structure being worked on (e_3) 4. The toeboard should be installed along the edge of platform those more than ten feet above the lower level and have at least 3.5 inches high from the top edge (e_4) 5. Ramps and walkways which is six feet and more above lower level should have guardrails (e_5)
Electrical hazard (E_6)	1. The scaffold and their conductive materials, such as building materials, paint roller extensions, scaffold components, that may be handled on them should not closer than ten feet to the power line, or scaffolds may be closer to overhead power lines than ten feet but they do has either de-energised the lines (grounded) or relocated the lines or installed protective coverings to prevent accidental contact with the lines (e_1)

7.3. The Use of Research Data for The Safety Assessment System

The flowchart of the system is presented in Figure 5.1 but the demonstration of an application of the system in this research is only covered three activities, defining (ACT 1), classifying (ACT 2) and storing images (ACT 3) (see section 5.1). The case-based reasoning (ACT 4) will be briefly presented using a sample activity.

Research data are collected from sites and stored as digital photo files then used as input in safety assessment process. The assessment process began with image observation concerning construction practice relating to a particular activity to answer questions in the safety checklist. For example, in the concreting safety checklist, images only covered a concreting activity. For each image, points were given based on concreting safety sub attributes (see Table 7.3). This activity is a part of defining construction practice safety (refer to Figure 5.1 ACT 1) and described in detail in section 5.3.

After image observation, scores based on the safety checklist for chosen points were given based on the degree of confidence of safety assessor to utilize information from an image. The scoring process describes in Chapter 5 (section 5.3.1) can be seen in the flowchart in Figure 5.3 and re-presented in Figure 7.2 which details the safety assessment process analysis, an example of which follows.

An example of the use of data to assess safe concreting practice

Information revealed from construction images comes solely from individual interpretations of things/evidence. To avoid dissimilar safety judgment Chapter 5 sections 5.3.1.a to 5.3.1.c are described a systematic way of information interpretation. Furthermore a Bayes' Theorem formula was employed and its formula is as follows (see section 4.3).

$$P(H/E_1 \cap E_2 \cap ...E_N) = \frac{P(E_1 \cap E_2 \cap ....E_N / H)P(H)}{P(E_1 \cap E_2 \cap ...E_N / H)P(H) + P(E_1 \cap E_2 \cap ...E_N / H')P(H')}$$

(Equation 4.2)

It can be seen from Equation 4.2, there is five prior probabilities that have to calculate before calculating the likelihood of safe construction practice being used given information from an image. The prior probability is a probability from an assumption made based on a hypothesis (see section 4.3.2). The steps in this stage is illustrated in Figure 5.3 and re-figured in Figure 7.2.

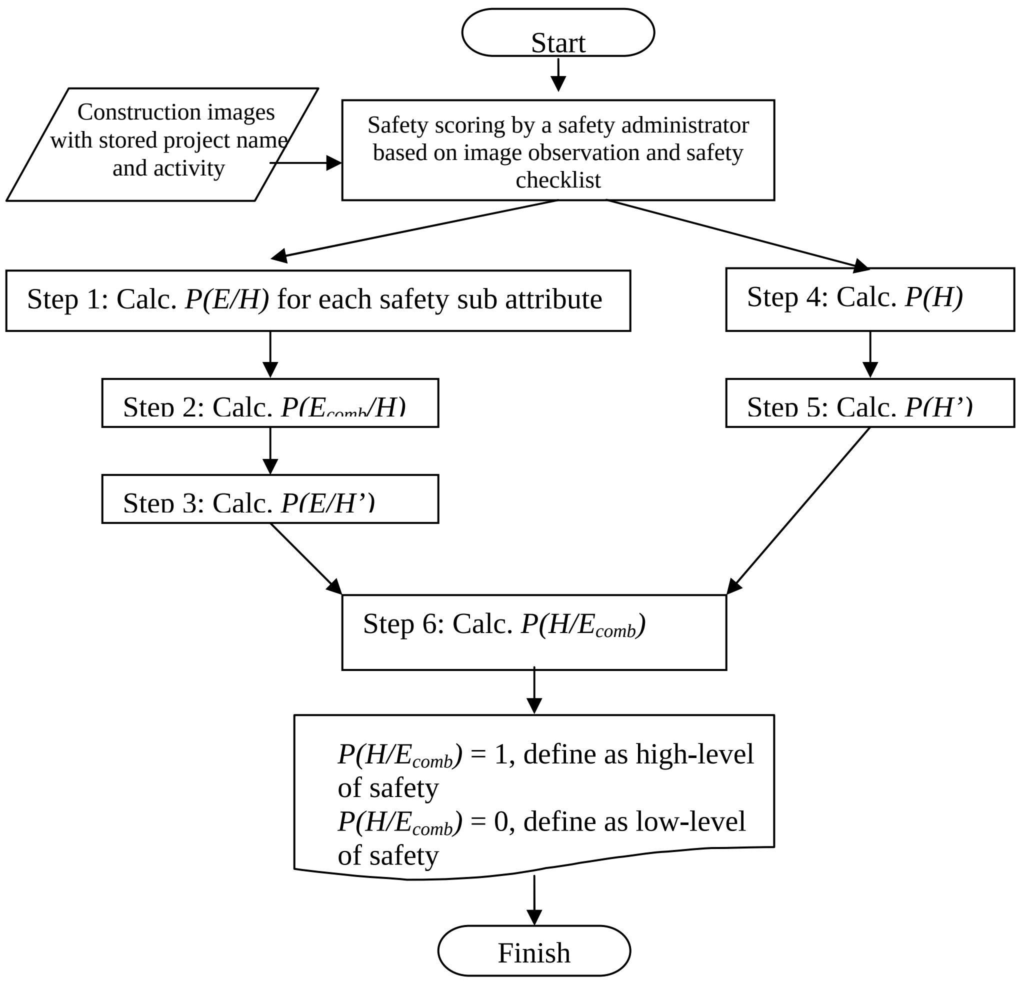


Figure 7.2. Flowchart of Safety Assessment Process Analysis in The Safety Assessment System

An example is using concreting activity image that can be seen in Figure 7.3.

Figure 7.3. Concreting Activity

Referring to flowchart in Figure 7.2, the safety assessment process of safe concreting construction practice shown in that image begins with observation and scoring based on concreting safety checklist set out in Table 7.3. The step-by-step processes refer to flowchart in Figure 7.2 using the image in Figure 7.3 are as follows:

a. **Step 1: Use of image data to calculate the prior likelihood of safe construction practice being used for particular activity based on each observed sub attribute.**

For example, reinforcing steel (attribute 2 or E_2) that has two sub attributes: all protruding reinforcing steel are guarded to eliminate the hazard of impalement (e_1) and reinforcing steel for vertical structures are adequately supported (e_2) (see Table 7.3). The degree of confidence in the complete evidence or complete attribute, E, is dependent on the partial evidence or sub attribute, e, by *P(E/e)* (section 4.3.1). If all evidences or sub attribute is known, then E = e.

Using the image in Figure 7.3 and Table 7.3, the safety attribute states that: "All protruding reinforcing steel are guarded to eliminate the hazard of impalement (attribute 2 = E_2, sub attribute 1 = e_1)". The information revealed by visual observation in Figure 7.3 assumes that all protruding reinforcing steels are not guarded. This assumption is based on no lids can be seen on all the protruding reinforce steel (refer to Figure 7.2 marked as A and B). The unavailability of lids can be dangerous, however the steels were erected above man base therefore hazard of impalement was limited. Based on this observation the likelihood to judge sub attribute 1 is safe given that a safe construction practice is being used (Hypothesis) or $P(e_1/H)$ was 33.3%. Likewise, for sub attribute 2 (e_2), the information revealed by visual observation assumes that all reinforcing steel for vertical structures are adequately supported. The assumption is based on the availability of red formworks and supported bar close to the vertical reinforced steels (refer to Figure 7.3 marked as C), however only one supported bar can be observed therefore the formwork cannot be judged as totally safe. Based on this assumption the likelihood to judge sub attribute 2 is safe given that safe construction practice is being used (Hypothesis) or $P(e_2/H)$ was 66.7%.

As the two sub attributes (e_1 and e_2) are known, then the likelihood of attribute 2 (E_2) given two sub attributes e_1 and e_2 occurred or $P(E_2/e_1 \cup e_2)$ = an average of the likelihood scores of two sub attributes = (33.3%+66.7%)/2 = 50% (section 4.3.1). From this, the likelihood of attribute 2 (E_2) is safe given that safe construction practice is being used (Hypothesis) or $P(E_2/H)$ = 50% or 0.50. Calculations were undertaken for all of the attributes with observed sub attributes. The list of attributes with sub attributes for concreting activity refers to Table 7.3. The results of this step were as follows:

- **Use of image data to calculate the prior likelihood of safe construction practice being used for Supported Structure (Attribute 1 or E_1) based on one sub attribute (e_1)**

  The prior likelihood of safe construction practice is being used for sub attribute 1 (e_1) or $P(e_1/H)$ = 100%

  Since attribute 1 (E_1) only has sub attribute 1 (e_1) and so $E_1 = e_1$. Then, the likelihood of supported structure (E_1) is safe given that sub attribute 1 (e_1) is safe or $P(E_1/e_1)$ = 100%

  Thus, the prior likelihood of safe construction practice is being used for safe supported structure (E_1) or $P(E_1/H)$ = 100%

  This result means that a safety assessor 100% confidence to judge that the supported structure is safe caused by safe construction practice is being used based on information showed in the image.

- **Use of image data to calculate the prior likelihood of safe construction practice being used for Reinforcing Steel (Attribute 2 or E_2) based on two sub attributes (e_1 and e_2)**

  The prior likelihood of safe construction practice is being used for safe sub attribute 1 (e_1) or $P(e_1/H)$ = 33.3%

  The prior likelihood of safe construction practice is being used for safe sub attribute 2 (e_2) or $P(e_2/H)$ = 66.7%

  Since attribute 2 (E_2) has two sub attributes e_1 and e_2, so $E_2 = e_1 \cup e_2$. Then, the likelihood of reinforcing steel (E_2) is safe given that sub attribute 1 (e_1) and sub attribute 2 (e_2) are safe or $P(E_1/ e_1 \cup e_2)$ = (33.3%+66.7%)/2 = 50% (see Equation 4.3)

  Thus, the prior likelihood of safe construction practice is being used for safe reinforcing steel (E_2) or $P(E_2/H)$ = 50%

  {see the example above}.

- **Use of image data to calculate the prior likelihood of safe construction practice being used for Protective Equipment (Attribute 5 or E_5) based on one sub attribute (e_1)**

  The prior likelihood of safe construction practice is being used for safe sub attribute 1 (e_1) or $P(e_1/H)$ = 100%

  Since attribute 5 (E_5) only has sub attribute 1 (e_1) and so $E_5 = e_1$. Then, the likelihood of protective equipment (E_5) is safe given that sub attribute 1 (e_1) is safe or $P(E_5/e_1)$ = 100%

Thus, the prior likelihood of safe construction practice is being used for safe protective equipment (E_5) or $P(E_5/H)$ = 100%

- **Use of image data to calculate the prior likelihood of safe construction practice being used for Formwork Safety (Attribute 6 or E_6) based on two sub attributes (e_1 and e_2)**

The prior likelihood of safe construction practice is being used for safe sub attribute 1 (e_1) or $P(e_1/H)$ = 100%

The prior likelihood of safe construction practice is being used for safe sub attribute 2 (e_2) or $P(e_2/H)$ = 100%

Since attribute 6 (E_6) has two sub attributes e_1 and e_2, so $E_6 = e_1 \cup e_2$. Then, the likelihood of formwork safety (E_6) is safe given that sub attribute 1 (e_1) and sub attribute 2 (e_2) are safe or $P(E_6/ e_1 \cup e_2)$ = (100%+100%)/2 = 100%

Thus, the prior likelihood of safe construction practice is being used for safe formwork safety (E_6) or $P(E_6/H)$ = 100%

b. Step 2: Use the step 1 results to calculate the prior likelihood of safe construction practice being used for particular activity based on all observed sub attributes.

The next step after calculating *P(E/H)* for each attribute as individual evidence, was to calculate it in the form of compound evidence because all of it was in one image. Compound evidence was then translated into a mathematical form as an intersection. Calculation reveals the prior likelihood of safe construction practice being used for particular activity based on all observed sub attributes is as follows:

E_1 : supported structure (attribute 1)

E_2 : reinforcing steel (attribute 2)

E_5 : protective equipment (attribute 5)

E_6 : formwork safety (attribute 6)

H : safe construction practice is being used (Hypothesis)

All scores of $P(E_N/H)$ where N = 1, 2, 5, 6 are obtained from step 1.

$P(E_1/H)$: The prior likelihood of safe construction practice being used for safe supported structure (E_1) = 100%

$P(E_2/H)$: The prior likelihood of safe construction practice being used for safe reinforcing steel (E_2) = 50%

$P(E_5/H)$: The prior likelihood of safe construction practice being used for safe protective equipment (E_5) = 100%

$P(E_6/H)$: The prior likelihood of safe construction practice being used for safe formwork safety (E_6) = 100%

$P(E_{comb}/H)$: The prior likelihood of safe construction practice is being used for particular activity based on all observed sub attributes

$$P(E_{comb}/H) = P(E_1 \cap E_2 \cap \ldots E_N/H)$$

$$= P(E_1/H) * P(E_2/H) * P(E_5/H) * P(E_6/H) \quad \text{(Equation 4.4)}$$

$$= 100\% * 50\% * 100\% * 100\%$$

$$= 50\%$$

$$= 0.50$$

This means that a safety assessor can 50% confidently judge that the supported structure, reinforcing steel, protective equipment, and formwork are safe.

c. Step 3: Use the step 2 results to calculate the prior likelihood of unsafe construction practice being used for particular activity.

Mutually exclusive is the sum of all events that do not affect each other, such as hypothesis and hypothesis complement, and equal 1 (refer to section 5.3.1.d). In this research, as the hypothesis is to assess safe construction practice being used, then the hypothesis complement is unsafe construction practice being used. The mutually exclusive means that the construction practice cannot be both safe and unsafe at the same time. So the likelihood of unsafe construction practice being used was determined by subtracting the likelihood score as result from step 2 from 1. The results of this step are as follows:

$P(E_1/H')$: The prior likelihood of unsafe construction practice being used for safe supported structure (E_1) = 1 – $P(E_1/H)$ = 100% -100% = 0

$P(E_2/H')$: The prior likelihood of unsafe construction practice being used for safe reinforcing steel (E_2) = 1 – $P(E_2/H)$ = 100% -50% = 50%

$P(E_5/H')$: The prior likelihood of unsafe construction practice being used for safe protective equipment (E_5) = 1 – $P(E_5/H)$ = 100% -100% = 0

$P(E_6/H')$: The prior likelihood of unsafe construction practice being used for safe formwork safety (E_6) = 1 – $P(E_6/H)$ =100% -100% = 0

$P(E_{comb}/H')$ $= P(E_1 \cap E_2 \cap \ldots E_N/H')$

$= P(E_1/H') * P(E_2/H') * P(E_5/H') * P(E_6/H')$ (Equation 4.4)

$= 0 * 0.5 * 0 * 0 = 0$

d. Step 4: Use of image data to calculate the prior probability of safe construction practice being used.

The hypothesis and each attribute have four possible events which refer to four provided safety scores: 0.000, 0.333, 0.667, and 1.000. The possible event for a safe construction practice is only one (a safety score = 1.000). Sample space refers to all possible events from all observed evidences (attributes) and hypothesis. The probability of the safe construction practice being used was determined as the possible event of safe hypothesis divided by sample space (refer to section 5.3.1.d).

The image in Figure 7.3 is shown four attributes (E_1, E_2, E_5, E_6), so the total evidence was four. Each has four possible events; the hypothesis also has four possible events so the number of sample space was then $4^5 = 1024$.

P(H) = 1/1024 = 0.00098.

e. Step 5: Use of step 4 result to calculate the prior probability of safe construction practice complement being used.

The possible event for a safe construction practice only one (refer to safety score of 1) therefore the possible events of an unsafe construction practice are three referred to three other safety scores. The number of sample space was 1024 as stated in step 4. Thus, the probability of unsafe construction practice being used is:

P(H') = 3/1024 = 0.00293.

F. Step 6: Use the results from steps 1 to 5 to calculate the likelihood of a safe construction practice being used given information obtained from an image *P(H/E_{comb})*

Referring to equation 4.2 in Chapter 4,

$$P(H/E_1 \cap E_2 \cap \ldots E_N) = \frac{P(E_1 \cap E_2 \cap \ldots . E_N/H)P(H)}{P(E_1 \cap E_2 \cap \ldots E_N/H)P(H) + P(E_1 \cap E_2 \cap \ldots E_N/H')P(H')}$$

So simplifying $P(H/E_{comb})$ = (A*B)/(A*B+C*D)

Where:

A = $P(E_{comb}/H)$ = 0.50 (see step 2)

B = $P(H)$ = 0.00098 (see step 4)

C = $P(E_{comb}/H')$ = 0.0 (see step 3)

D = $P(H')$ = 0.00293 (see step 5)

Z = $P(H/E_{comb})$ = (0.50*0.00098)/(0.50*0.00098+0.000*0.00293) = 1.000.

The means of likelihood score of $P(H/E_{comb})$ = 1 is a safety assessor 100% confidence to judge that safe construction practice is being used (Hypothesis) given that several construction practices which are supported structure, reinforcing steel, protective equipment, and formwork safety information (compound Evidences (E_1, E_2, E_5, E_6)) collected from the image occurred. Thus, the construction practice in the image can be defined as high-level of safety.

7.4. The Automated Process of The Safety Assessment System

The previous section demonstrates safety assessment to define construction image as a datum. The assessment results are obtained from manual calculation process. Since the amount of data has increase automated calculation and storing data in a database for time efficiency is required. This is especially important for project managers who really need an accurate and instantly information for effective decision-making (see section 2.4.2).

A management information system is usually computer based, in that it uses an electronic computer to process amounts of information quickly. This research has developed a program that suits both needs: automated calculation and image database. The explanation of developed program is given in Chapter 6.

A flowchart of the automated process in safety assessment system is given in Figure 7.4. This figure is a modification of Figure 6.2 in Chapter 6 by adding a process shown in Figure 7.2, and symbolized as “A

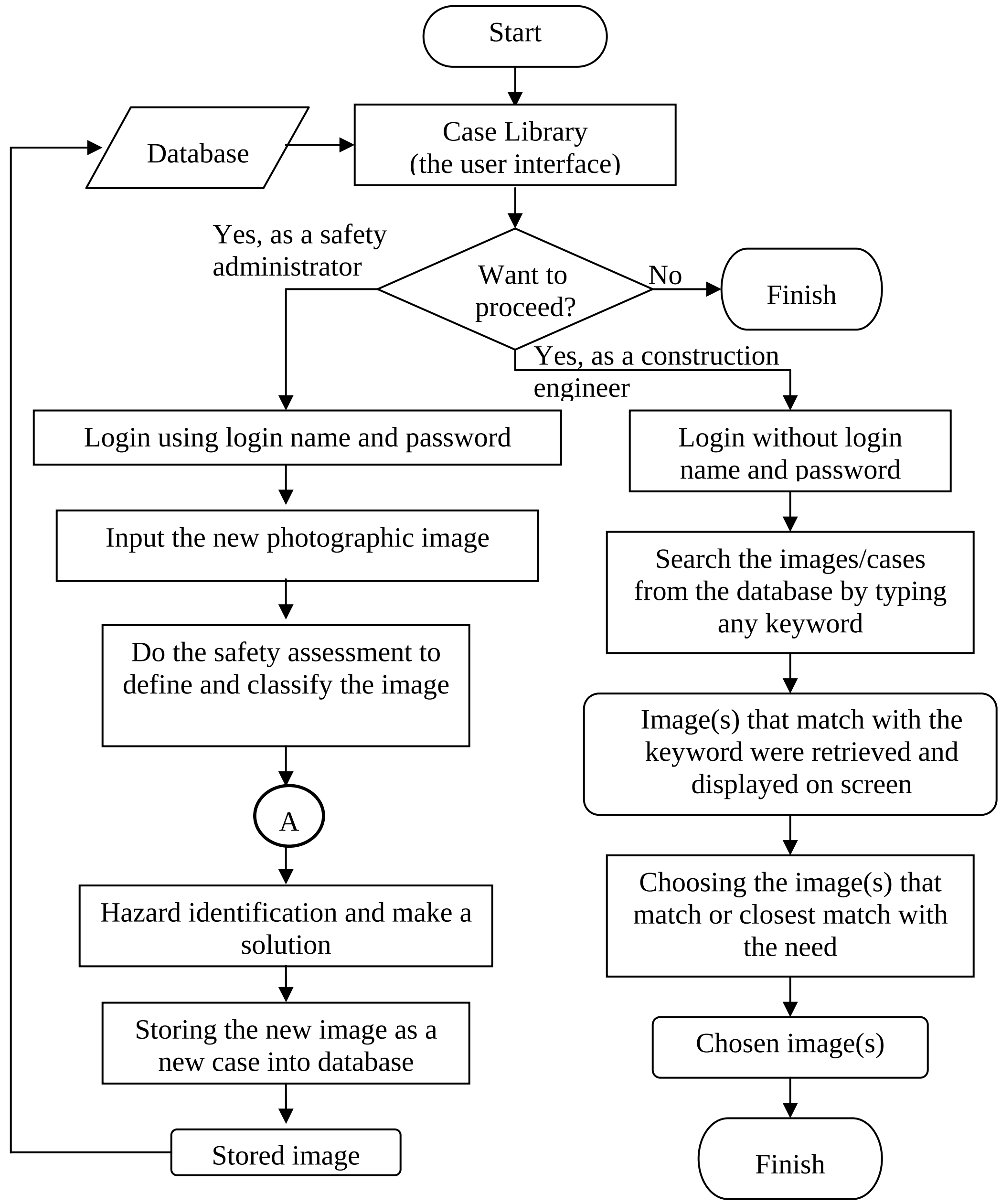


Figure 7.4. The Flowchart of An Automated Process in Safety Assessment System

Figure 7.4 shows that the system was designed to use by two kinds of users, a safety administrator and a construction engineer. The first has authorization to make an assessment and to update a database and the second only can use stored information. Detail explanation about a Web-based assessment system is presented in Chapter 6.

a. The Safety Assessment System: Automated Process

Stated previously that a safety administrator was done the example of manual assessment system (see section 7.1), therefore, the following example of automated process is done by a safety administrator as well. The automated process began with image collection, storage and observation. The images are taken from project's site and each is taken manually using digital camera, stored as image files and observed straight forward.

Image collection and storage process followed by computer process begin with logging-in in a database by a safety administrator who make an assessment and update information in a database. After logging-in in a database, a safety administrator begin to create an input for a new case: case ID, project name, activity, upload the image, then store it into a database by pressing the "Save" button (see Figure 7.5). The process of safety assessment was described in section 7.3 and using feature of automated safety assessment interface shown in Figure 7.6, the safety administrator is adding safety score, which then calculated automatically that arrive at its results, the likelihood scores (see Figure 7.6), then save this results in a database by pressing "Save" button. At the end of this process, the new case has its case ID, information, image and its automatically stored in the database.

b. An Example of The Automated Process

As an example, using image in Figure 7.3 and same scores given in manual calculation in sections 7.3.a through 7.3.f, the results for automated process is shown in Figure 7.6. The scores of B, C, D, E, Z in Figure 7.6 are similar to the scores of A, B, C, D, Z respectively in section 7.3.f.

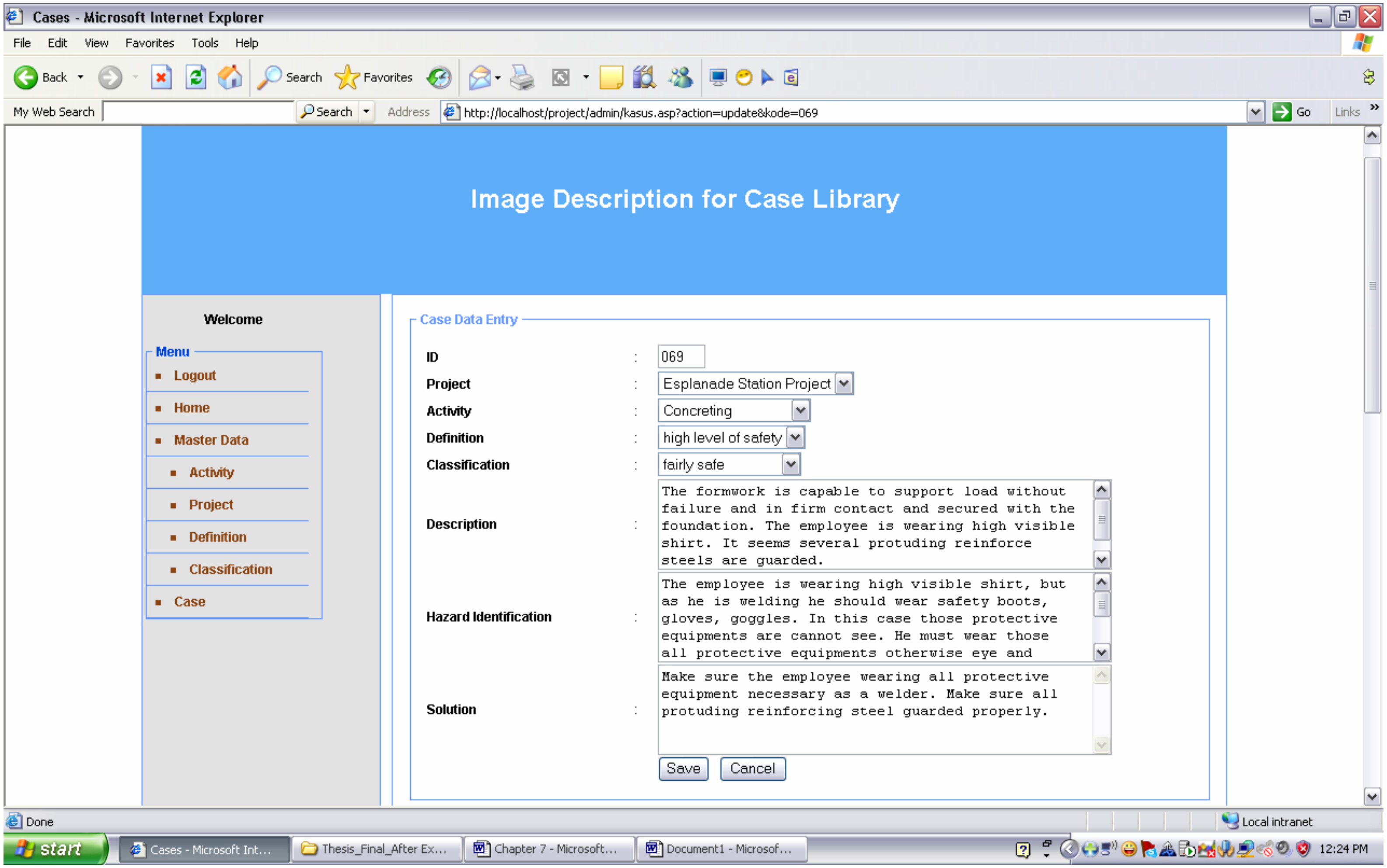
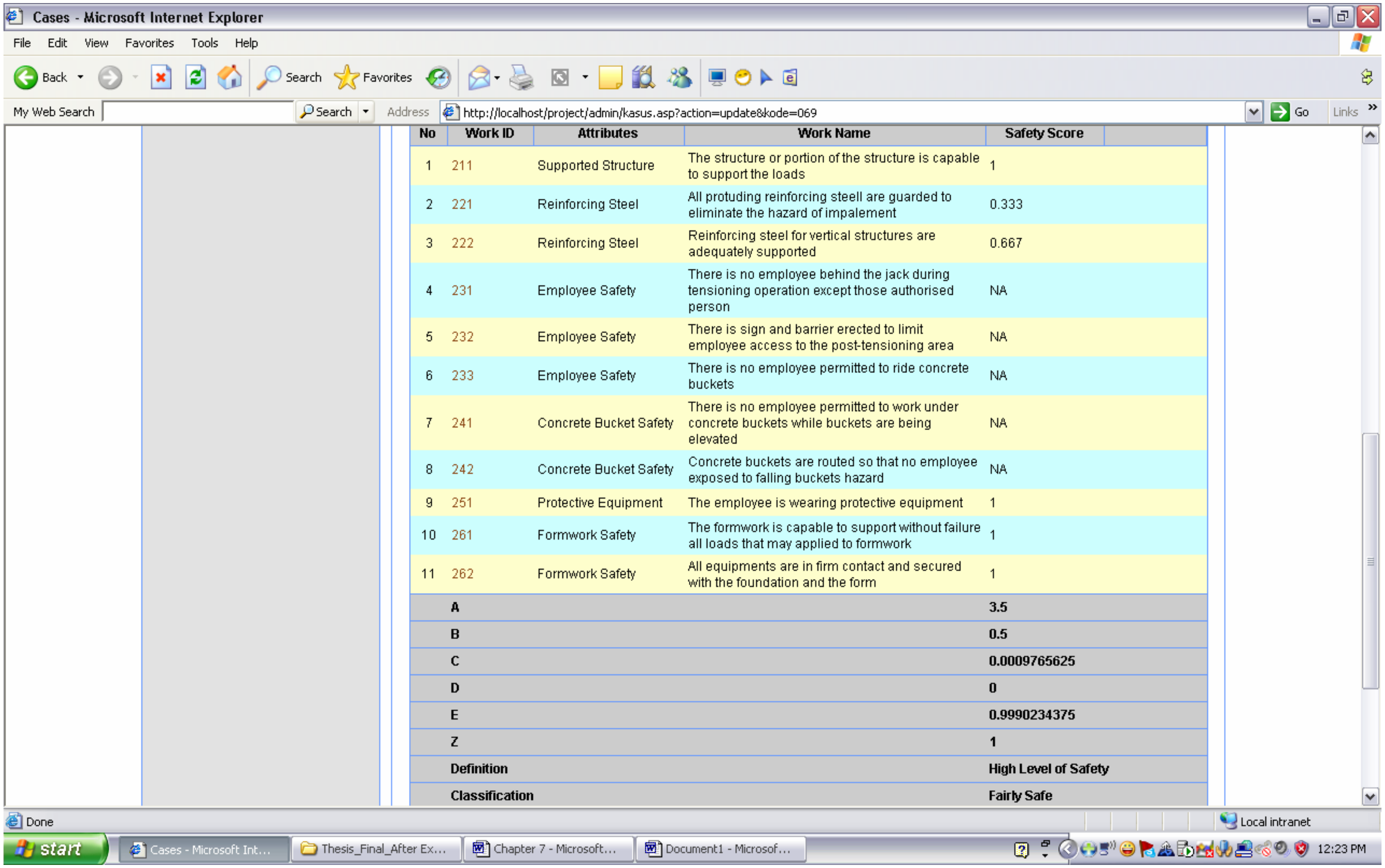


Figure 7.5. The User Interface of An Automated Process in Safety Assessment System for Adding Information (Project Name, Activity, Definition, Classification, Hazard Identification, and Solution)



No	Work ID	Attributes	Work Name	Safety Score
1	211	Supported Structure	The structure or portion of the structure is capable to support the loads	1
2	221	Reinforcing Steel	All protuding reinforcing steell are guarded to eliminate the hazard of impalement	0.333
3	222	Reinforcing Steel	Reinforcing steel for vertical structures are adequately supported	0.667
4	231	Employee Safety	There is no employee behind the jack during tensioning operation except those authorised person	NA
5	232	Employee Safety	There is sign and barrier erected to limit employee access to the post-tensioning area	NA
6	233	Employee Safety	There is no employee permitted to ride concrete buckets	NA
7	241	Concrete Bucket Safety	There is no employee permitted to work under concrete buckets while buckets are being elevated	NA
8	242	Concrete Bucket Safety	Concrete buckets are routed so that no employee exposed to falling buckets hazard	NA
9	251	Protective Equipment	The employee is wearing protective equipment	1
10	261	Formwork Safety	The formwork is capable to support without failure all loads that may applied to formwork	1
11	262	Formwork Safety	All equipments are in firm contact and secured with the foundation and the form	1
	A			**3.5**
	B			**0.5**
	C			**0.0009765625**
	D			**0**
	E			**0.9990234375**
	Z			**1**
	Definition			**High Level of Safety**
	Classification			**Fairly Safe**

Figure 7.6. The User Interface of An Automated Process in Safety Assessment System for Safety Assessment

Same processes were done for all 69 images as research data. The results of an automated process using three activities from four project is shown in Table 7.6

Table 7.6. Results of Automated Assessment Process

Project	Activ.	Likeli-hood	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 14
Leach Hwy	Scaff	P(E/H)	1	1	1	0.8335	1	1	0.8335	1	0.8335	0.8335	0.9445	1	1	1
		P(H/E)	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Espld Station	Scaff	P(E/H)	0.9445	0.9445	1	1	0.8335	0.8668	1	1						
		P(H/E)	1	1	1	1	1	1	1	1						
	Concrt	P(E/H)	1	0.5	0.5	0.6665	0.6665	0.3335	0.3335	0.5						
		P(H/E)	1	1	1	1	1	1	1	1						
	Lifting	P(E/H)	0.667	0.667	1	1	1	0.333	0.4449	0.667	1	1				
		P(H/E)	1	1	1	1	1	1	1	1	1	1				
City Apartm	Lifting	P(E/H)	0.4449	0.667	1	1	1	1	0.667	0.667	0.667					
		P(H/E)	1	1	1	1	1	1	1	1	1					
	Scaff	P(E/H)	0.4445	1	1	0.4723	0.4723	0.5	0.9334	1	1	1	1	0.889	1	
		P(H/E)	1	1	1	1	1	1	1	1	1	1	1	1	1	
Curtin Univ.	Concrt	P(E/H)	0.2221	0.667	0.667	0.6665	0.3335	0.3335	0.5							
		P(H/E)	1	1	1	1	1	1	1							

Note:

P(E/H) is a prior likelihood of safe construction practice being done

P(H/E) is a likelihood of safe construction practice being done

W is week refer to time of images collection

7.5. Discussion of The Safety Assessment System

An automated assessment process is done for 69 images as research data and their results are presented in Table 7.9. Discussion of the system are presented as follows.

a. Image collection and storage in a database

This research collects 189 images from four projects showing three activities, however, only 69 images use as research data or input for automated process (section 7.3). Those images had been assessed based on their activity and stored in a database, namely "Image Description for Case Library", with unique identification called "Case ID". Each case ID has information which consists of its ID, project name, activity, definition, classification, description, hazard identification, solution (see Figure 7.5) and safety scores with their likelihood scores (see Figure 7.6). In this way, no repeatable case ID allows.

b. Automated process findings

From image collection, storage and automated assessment process, it reveals that at this point, the application was undertaken without a problem shows that the system works perfectly and achieves its objective.

Mostly the images as research data were taken from a distance and produced un-detailed activity (see section 7.2). Although the safety checklists and the assessment method had been established to provide a same guideline to assess safe construction practice but safety score given by a safety administrator rely solely on the safety administrator's interpretation of information obtained from image. Instead of who make the interpretation, the problem is related to image that provide information for assessment process.

There is, however, a factor which may influence an interpretation, i.e. the image detail depends on the distance between an object and the photographer. The closer the distance between the object and the photographer result in the more detail image and it will permit more accurate interpretation of information. Less certain interpretation may result in a wrong decision. It therefore suggests refining the system by providing images showing more detail. Closer distances between an object and the photographer will produce these kinds of images. The idea and application of suggested method to refine the system will be presented in section 7.6.

7.6. The Refined Safety Assessment System

From the application of the safety assessment system, it was found that there is a factor that influenced the interpretation of the image (see section 7.5), an image detail, that depends on the distance between an object and the photographer. The explanation of the finding is as follows:

Figure 7.7. System Scaffolding on Construction Site

The image in Figure 7.7 which was taken in close distance between an object and photographer provides details of concrete column, timber form and system scaffolding. One of the questions in the safety checklist for scaffolding is: "The supported scaffold should be set on a stable object, such as base plates, mud sills, other adequate firm foundation" (see Table 7.5, Attribute 1, sub attribute 1). In the part marked by "A", it seems that the supported scaffold is not set on a base plate, whereas part "C" is. Part "B" cannot be certainty interpreted thus there is a problem related to an uncertain interpretation. What will happen if a safety administrator gives safety score of 1 for something that unsafe as a result of wrong interpretation? It might be resulted in unidentified hazard thus accidents can be occurred.

It can be understood that although the image in Figure 7.7 was taken in close distance but some parts remain unclear and wrong judgment as a result of wrong interpretation will has consequence of unidentified hazard. If this circumstance occurs for a whole image which is taken from faraway distance, it will obtain a worse result that increases the occurrence of accidents. The problem related to uncertain interpretation that depends on an image detail has to be solved.

In section 7.5, it is suggested the problem of uncertain interpretation can be solved using a more detail images hence for Figure 7.7's case more detail images should be taken further of the scaffold base sections. A method to use sets of detail images to give certain judgment thus refine the system will describe in section 7.6.1.

7.6.1. A Proposed Method to Refine The Safety Assessment System

The example of safety judgment of Figure 7.7 demonstrated why the uncertain interpretation occurs. As suggested, more detailed images should be provided to give certain judgment from image observation.

As refreshment, safety score was given for each safety attribute observed in an image (see section 7.2). From a first image of a project, all observed safety attributes have their safety score. On this image, it might be seen unclear parts that can lead to uncertain interpretation and wrong safety judgment. Of these unclear parts, further detail images need to be provided.

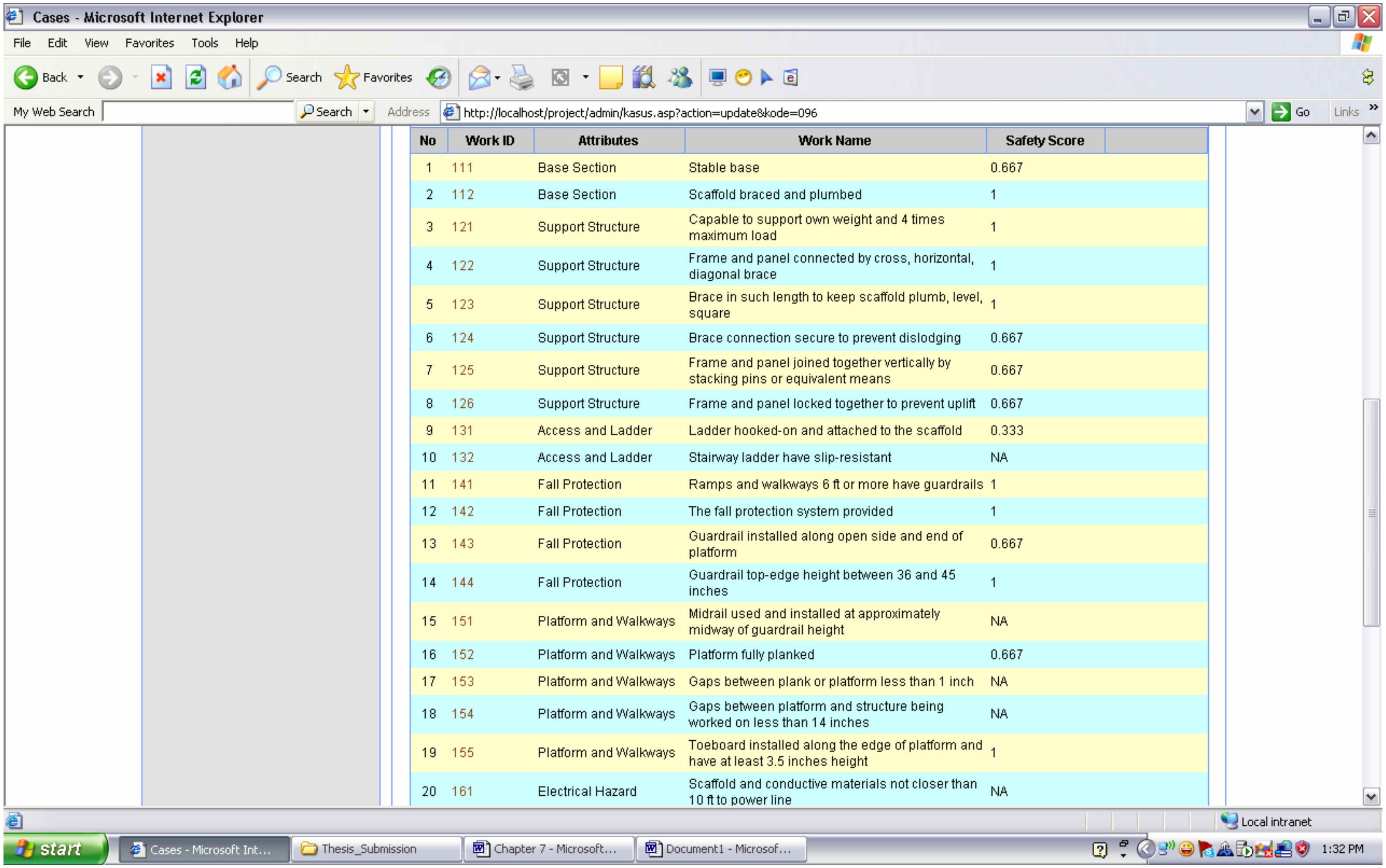
Based on new detailed images, certain safety judgments can be given. Noted that changes of given safety scores based on detailed images are not replaced all previous scores. Those changes only given for unclear parts so only scores related to unclear parts will changes. However, the changes will result in the changes of likelihood scores, consequently it may change construction practice definition and classification. Following example in sections a through e using sets of scaffolding images will demonstrate the proposed method to refine the system.

a. First image of scaffolding activity (case ID 096)

Refer to Figure 7.8 this image was taken from a distance. It can be seen that there is a scaffolding activity based on information obtained from image observation. The scaffolding has ladders, platform and walkways, guardrails with installed toeboard and scaffolding connector bars.

Figure 7.8. Construction Image Showing Scaffolding

Using the safety assessment system explained in Chapter 6 and the automated program described in section 7.4, the scaffolding activity safety assessment results using image shown in Figure 7.8 are as presented in Figures 7.9 and 7.10.



No	Work ID	Attributes	Work Name	Safety Score
1	111	Base Section	Stable base	0.667
2	112	Base Section	Scaffold braced and plumbed	1
3	121	Support Structure	Capable to support own weight and 4 times maximum load	1
4	122	Support Structure	Frame and panel connected by cross, horizontal, diagonal brace	1
5	123	Support Structure	Brace in such length to keep scaffold plumb, level, square	1
6	124	Support Structure	Brace connection secure to prevent dislodging	0.667
7	125	Support Structure	Frame and panel joined together vertically by stacking pins or equivalent means	0.667
8	126	Support Structure	Frame and panel locked together to prevent uplift	0.667
9	131	Access and Ladder	Ladder hooked-on and attached to the scaffold	0.333
10	132	Access and Ladder	Stairway ladder have slip-resistant	NA
11	141	Fall Protection	Ramps and walkways 6 ft or more have guardrails	1
12	142	Fall Protection	The fall protection system provided	1
13	143	Fall Protection	Guardrail installed along open side and end of platform	0.667
14	144	Fall Protection	Guardrail top-edge height between 36 and 45 inches	1
15	151	Platform and Walkways	Midrail used and installed at approximately midway of guardrail height	NA
16	152	Platform and Walkways	Platform fully planked	0.667
17	153	Platform and Walkways	Gaps between plank or platform less than 1 inch	NA
18	154	Platform and Walkways	Gaps between platform and structure being worked on less than 14 inches	NA
19	155	Platform and Walkways	Toeboard installed along the edge of platform and have at least 3.5 inches height	1
20	161	Electrical Hazard	Scaffold and conductive materials not closer than 10 ft to power line	NA

Figure 7.9. Safety Scores for Image Case ID 096 (Figure 7.8)

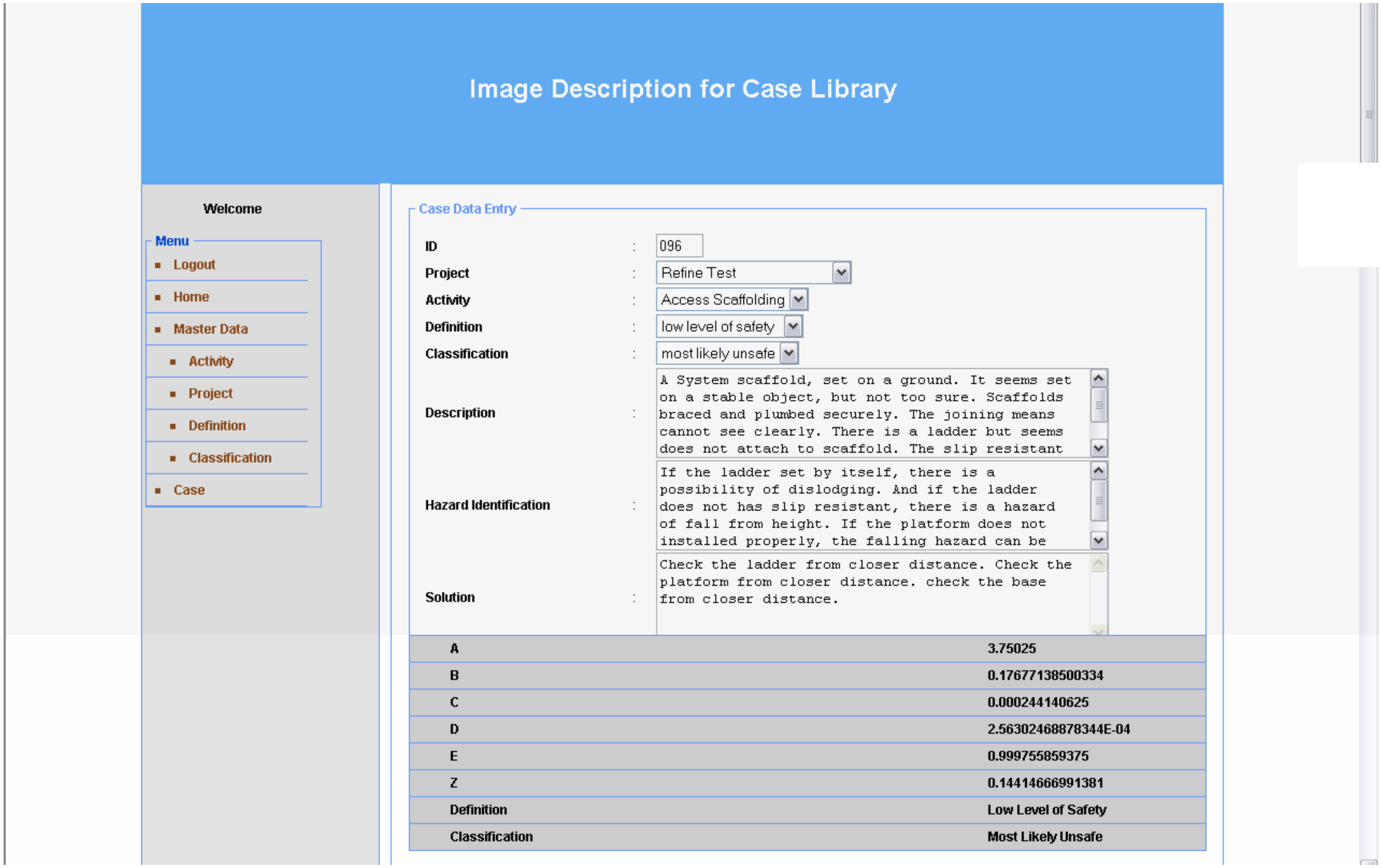


Figure 7.10. Results of Safety Assessment for Case ID 096 (Figure 7.8)

In Figure 7.10, the results of the construction practice of case ID 096 (Figure 7.8) are defined as low-level of safety (see "Definition"). The image in Figure 7.8 has prior likelihood score of safe construction practice *P(H)* = 0.0002 (see the score of "C"), prior likelihood score of unsafe construction practice *P(H')* = 0.9998 (see the score of "E"), prior likelihood score of safe construction practice being used *P(E/H)* = 0.1768 (see the score of "B"), prior likelihood score of unsafe construction practice being used *P(E/H')* = $2.6 * 10^{-4}$ (see the score of "D") and likelihood score of *P(H/E)* = 0.1441 (see the score of "Z"). The meaning of "prior likelihood" is the assumption likelihood based on belief by viewing evidences, whereas the meaning of "likelihood" is the likelihood as a result of a calculation based on prior likelihoods.

The result reveals that based on a safety administrator's assessment, the probability of safe construction practice being used is only 0.1441 or 14.41% based on information of particular activities obtained from the image. It also discloses that the prior probability to judge particular activities safety is only 0.1768 or 17.68% based on assumption that safe construction practice being used.

With reference to the safety scores from the interpretation of information obtained from image in Figure 7.8 there are several scores less than 1 (see Work ID 111, 124, 125, 126, 131, 143, 152 in Figure 7.9). In Figure 7.8, there is a base section (work ID 111) but it cannot be seen clearly. The observation assumed the scaffolding was set on a stable object and the unclear part was given a score of 0.667. This interpretation has been described in the image description (see "Description" in Figure 7.10). However as proposed in refined system to ensure the safety of the base section, that part needs to be investigated further.

As regards the support structure (Work ID 124, 125, and 126), parts cannot be seen clearly and need further investigation. All these parts have given safety score of 0.667. The access and ladder part (Work ID 131) is also not clear and it is assumed the ladder is not attached to the scaffold. This assumption has been added in the image description (see "Description" in Figure 7.10), and therefore it merits a safety score of 0.333. A possible hazard if this assumption is true has been identified (see "Hazard Identification" in Figure 7.10) and its solution suggested (see "Solution" in Figure 7.10).

Two other parts that cannot be certainty interpreted are fall protection (Work ID 143) and platform and walkways (Work ID 152). Several more detailed images need to be taken on those areas.

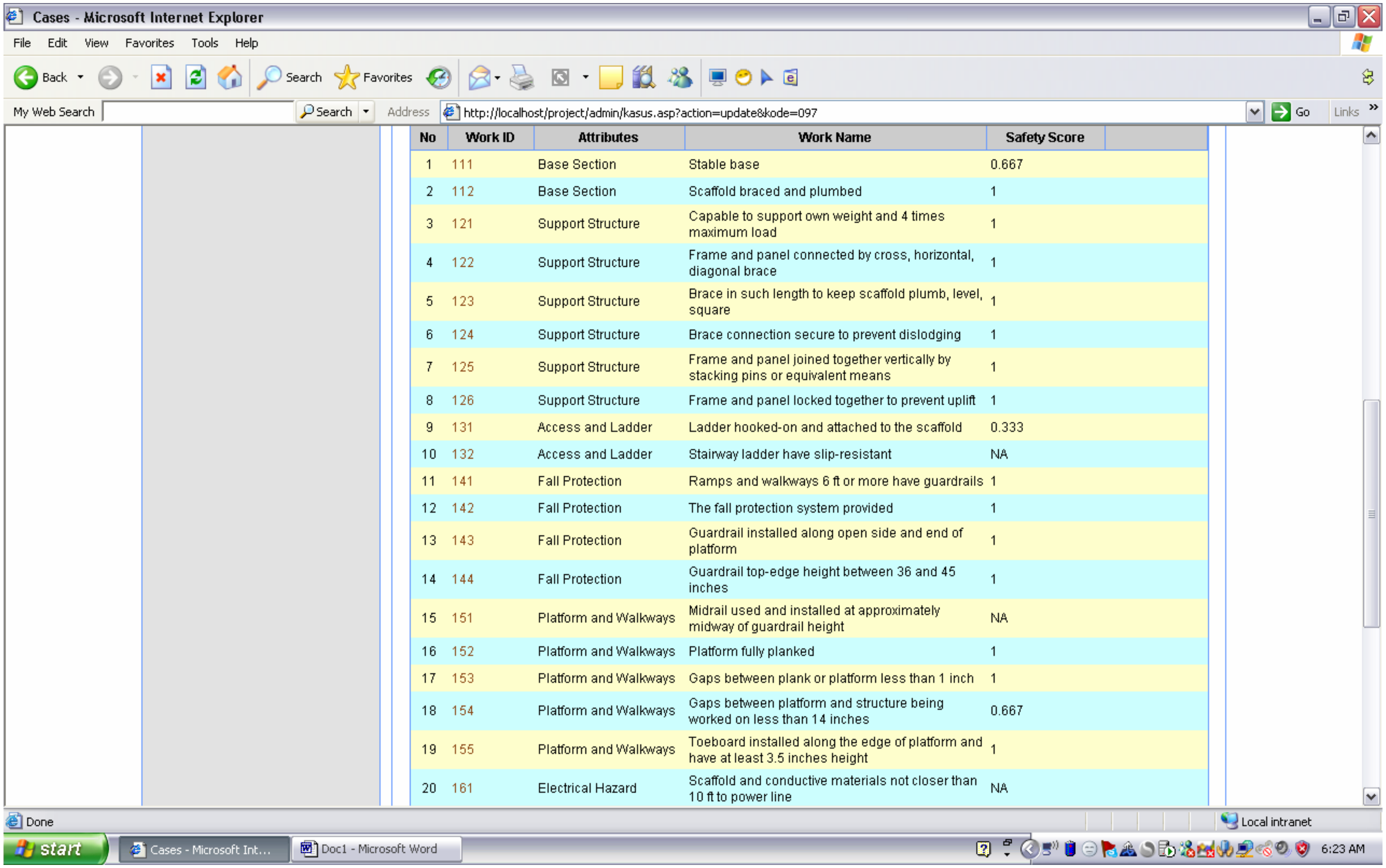
b. Second image of scaffolding activity (case ID 097)

A detailed imaged then taken to make unclear "support structure" parts become clear. The image and safety assessment based on the image are as follows

See figure 7.11:

Figure 7.11. An Image of Scaffolding Activity in Detail

The safety scores of the scaffolding activity in Figure 7.11 are recorded in Figure 7.12. Several safety scores based on image in Figure 7.11 have replaced safety scores based on image in Figure 7.8. The changed scores are scores for Work ID 124, 125, 126, 143, 152, and 154 (see Figure 7.9 for the old scores and Figure 7.12 for the new scores), but other scores remain the same.



No	Work ID	Attributes	Work Name	Safety Score
1	111	Base Section	Stable base	0.667
2	112	Base Section	Scaffold braced and plumbed	1
3	121	Support Structure	Capable to support own weight and 4 times maximum load	1
4	122	Support Structure	Frame and panel connected by cross, horizontal, diagonal brace	1
5	123	Support Structure	Brace in such length to keep scaffold plumb, level, square	1
6	124	Support Structure	Brace connection secure to prevent dislodging	1
7	125	Support Structure	Frame and panel joined together vertically by stacking pins or equivalent means	1
8	126	Support Structure	Frame and panel locked together to prevent uplift	1
9	131	Access and Ladder	Ladder hooked-on and attached to the scaffold	0.333
10	132	Access and Ladder	Stairway ladder have slip-resistant	NA
11	141	Fall Protection	Ramps and walkways 6 ft or more have guardrails	1
12	142	Fall Protection	The fall protection system provided	1
13	143	Fall Protection	Guardrail installed along open side and end of platform	1
14	144	Fall Protection	Guardrail top-edge height between 36 and 45 inches	1
15	151	Platform and Walkways	Midrail used and installed at approximately midway of guardrail height	NA
16	152	Platform and Walkways	Platform fully planked	1
17	153	Platform and Walkways	Gaps between plank or platform less than 1 inch	1
18	154	Platform and Walkways	Gaps between platform and structure being worked on less than 14 inches	0.667
19	155	Platform and Walkways	Toeboard installed along the edge of platform and have at least 3.5 inches height	1
20	161	Electrical Hazard	Scaffold and conductive materials not closer than 10 ft to power line	NA

Figure 7.12. Safety Scores for Image Case ID 097 (Figure 7.11)

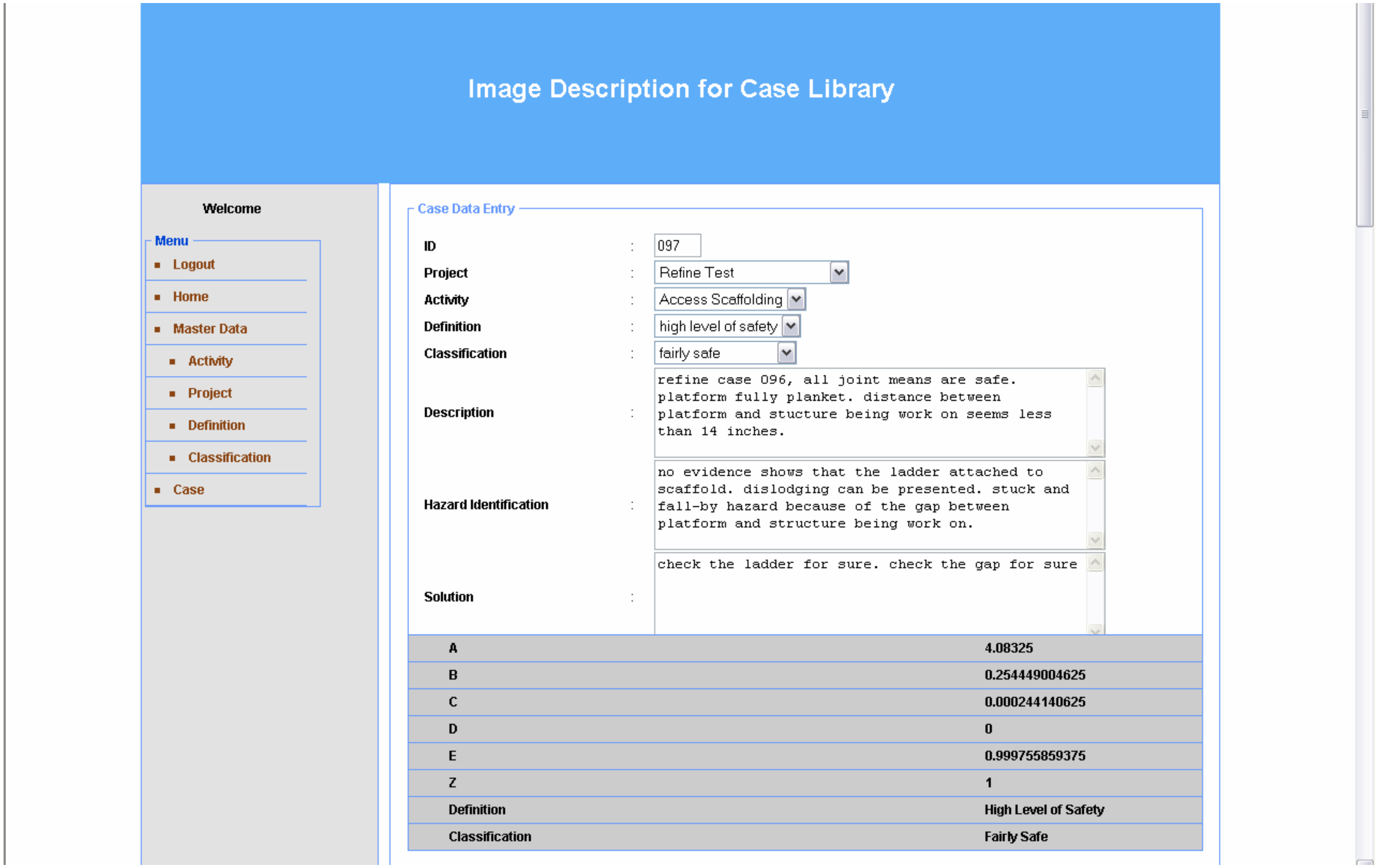


Figure 7.13. A Result of Safety Assessment System for Case ID 097 (Figure 7.11)

The image in Figure 7.11 was taken from the same project site of image in Figure 7.8 but from closer distance. The image provides more detail parts of the scaffolding, for example, the connection bars and their connector, also the platform and walkways. As these parts can be clearly seen, definite safety scores can be given (see Figure 7.13) resulting in the changes of the construction practice definition and classification.

In Figure 7.13, the results of the construction practice of case ID 097 (Figure 7.10) are defined as high-level of safety (see “Definition”). The image in Figure 7.10 has likelihood score of *P(H/E)* = 1 (represent by the score of “Z”) and prior likelihood score of *P(E/H)* = 0.2545 (represent by the score of “B”). The meaning of *P(H/E)* is the likelihood of safe construction practice being used (Hypothesis) given information in the image that safe particular activities are occurred (Evidence) whereas the meaning of *P(E/H)* is the prior likelihood of safe construction practice being used for particular activity based on observed attributes.

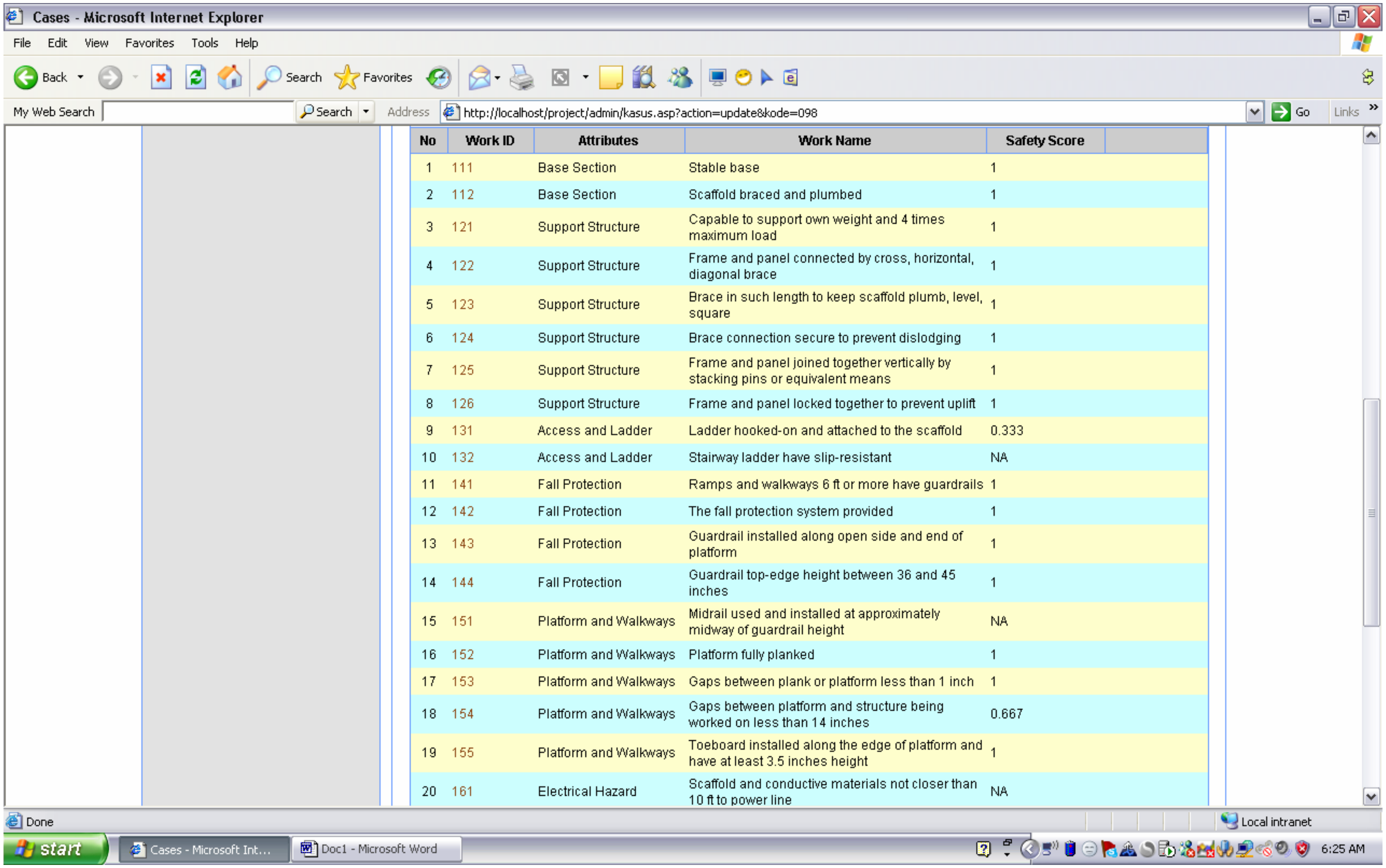
The result reveals that based on a safety administrator’s assessment, the probability of safe construction practice being used is only 100% based on information of particular activities obtained from the image. It also discloses that the prior probability to judge particular activities safety is 25.45% based on assumption that safe construction practice being used.

It can be noted from Figures 7.10 and 7.13 that change six sub attributes’ safety scores result in several changes: construction practice definition, classification, identified hazards and their solution. However, it can be seen in Figure 7.11 that several parts cannot be seen, e.g. base section (work ID 111), ladder (work ID 131), and gap between platform and structure being work on (work ID 154) therefore require images of those parts to be taken.

c. Third image of scaffolding activity (case ID 098)

Figure 7.14. Base Sections of Scaffolding Activity

The image in Figure 7.14 of base sections of scaffolding activity shows they are set on base plates. According to explanation of base section in scaffolding safety checklist (attribute 1, sub attribute 1): "The supported scaffold should be set on a stable object, such as base plates, mud sills, other adequate firm foundation" (see Table 7.4), the construction practice of setting scaffolding on base plates shown in Figure 7.14 qualifies for this requirement and is given a score of 1. This replaced the previous score in case ID 097 (see Figures 7.12 and 7.15, work ID 111).



No	Work ID	Attributes	Work Name	Safety Score
1	111	Base Section	Stable base	1
2	112	Base Section	Scaffold braced and plumbed	1
3	121	Support Structure	Capable to support own weight and 4 times maximum load	1
4	122	Support Structure	Frame and panel connected by cross, horizontal, diagonal brace	1
5	123	Support Structure	Brace in such length to keep scaffold plumb, level, square	1
6	124	Support Structure	Brace connection secure to prevent dislodging	1
7	125	Support Structure	Frame and panel joined together vertically by stacking pins or equivalent means	1
8	126	Support Structure	Frame and panel locked together to prevent uplift	1
9	131	Access and Ladder	Ladder hooked-on and attached to the scaffold	0.333
10	132	Access and Ladder	Stairway ladder have slip-resistant	NA
11	141	Fall Protection	Ramps and walkways 6 ft or more have guardrails	1
12	142	Fall Protection	The fall protection system provided	1
13	143	Fall Protection	Guardrail installed along open side and end of platform	1
14	144	Fall Protection	Guardrail top-edge height between 36 and 45 inches	1
15	151	Platform and Walkways	Midrail used and installed at approximately midway of guardrail height	NA
16	152	Platform and Walkways	Platform fully planked	1
17	153	Platform and Walkways	Gaps between plank or platform less than 1 inch	1
18	154	Platform and Walkways	Gaps between platform and structure being worked on less than 14 inches	0.667
19	155	Platform and Walkways	Toeboard installed along the edge of platform and have at least 3.5 inches height	1
20	161	Electrical Hazard	Scaffold and conductive materials not closer than 10 ft to power line	NA

Figure 7.15. Safety Scores for Image Case ID 098 (Figure 7.14)

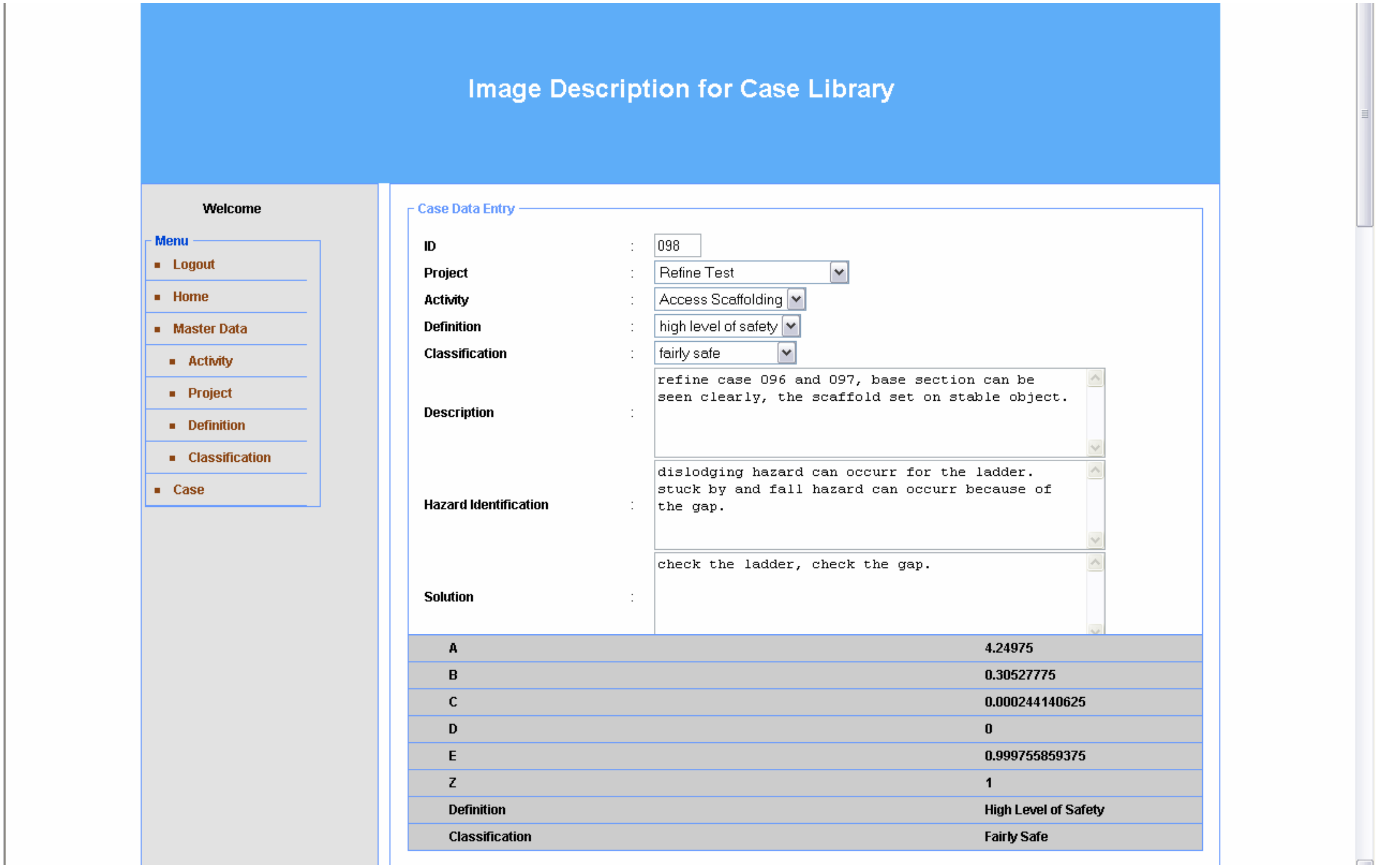


Figure 7.16. Results of Safety Assessment for Case ID 098 (Figure 7.14)

In Figure 7.16, the results of the construction practice of case ID 098 (Figure 7.14) are defined as high-level of safety (see "Definition"). The image in Figure 7.14 has likelihood score of *P(H/E)* = 1 (represent by the score of "Z") and prior likelihood score of *P(E/H)* = 0.3053 (represent by the score of "B"). The meaning of *P(H/E)* is the likelihood of safe construction practice being used (Hypothesis) given information in the image that safe particular activities are occurred (Evidence) whereas the meaning of *P(E/H)* is the prior likelihood of safe construction practice being used for particular activity based on observed attributes.

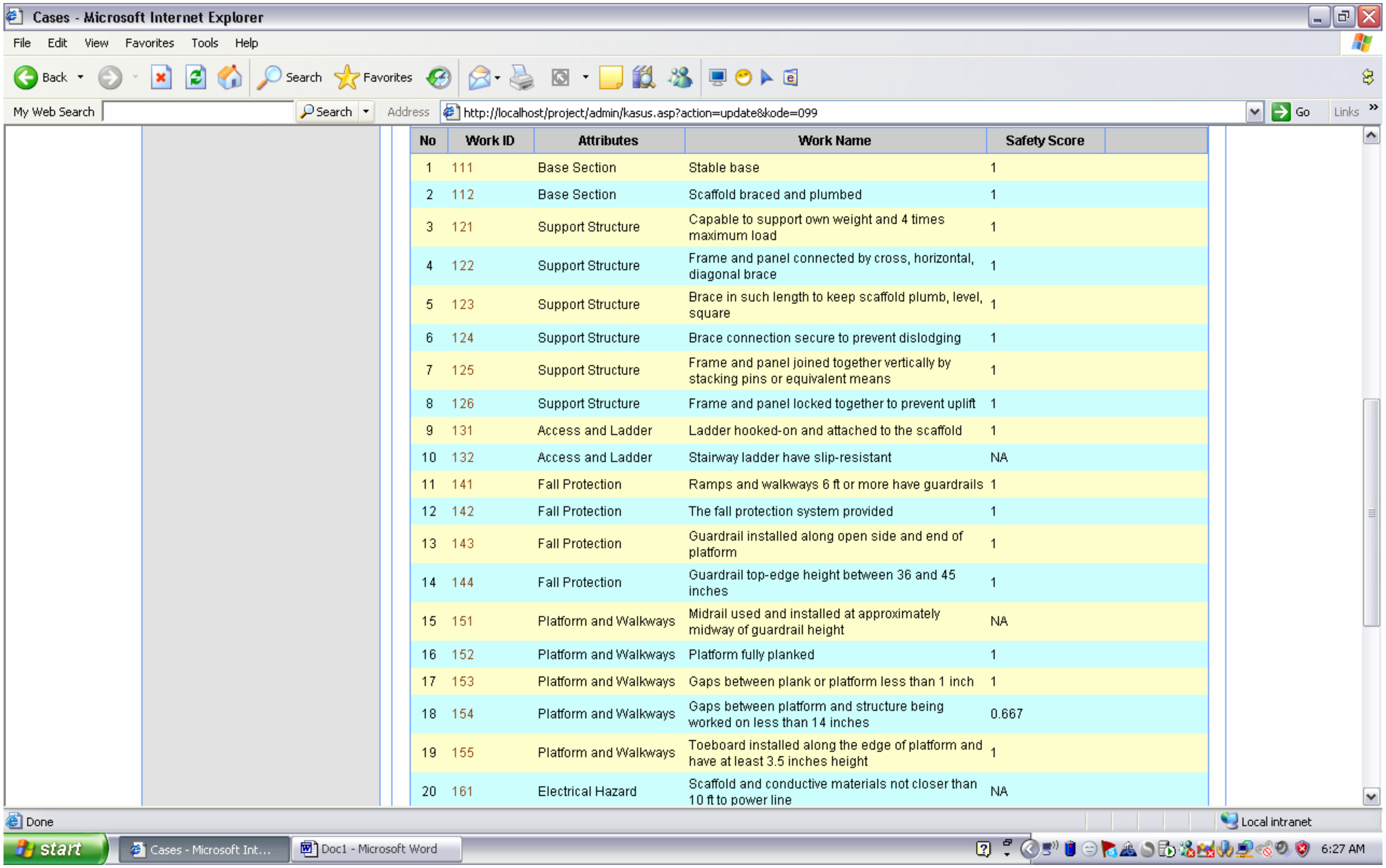
The result reveals that based on a safety administrator's assessment, the probability of safe construction practice being used is only 100% based on information of particular activities obtained from the image. It also discloses that the prior probability to judge particular activities safety is 30.53% based on assumption that safe construction practice being used.

The results in Figure 7.16 revealed a change of the *P(E/H)* score (see the score of "B") but not the *P(H/E)* score (see the score of "Z"). Previously, because of the given safety scores configuration of image in Figure 7.11 so the *P(E/H)* score was 0.2545 (see the score of "B" in Figure 7.13), then based on image in Figure 7.14 the safety scores configuration changing and the *P(E/H)* score is 0.3053 (see the score of "B" in Figure 7.16). With reference to "hazard identification" and "solution" in Figure 7.16, there are two parts still needing investigation which are the ladder and the gap between the platform and structure being worked on. Images of those parts need to be taken further in detailed.

d. Fourth image of scaffolding activity (case ID 099)

Figure 7.17. Ladder Parts of Scaffolding Activity

As seen on Figure 7.17, ladders have been attached to the scaffolding as part of the system. Based on this information, the safety score of the ladder is 1 replacing a previous score. This change can be seen in Figure 7.18, work ID 131.



No	Work ID	Attributes	Work Name	Safety Score
1	111	Base Section	Stable base	1
2	112	Base Section	Scaffold braced and plumbed	1
3	121	Support Structure	Capable to support own weight and 4 times maximum load	1
4	122	Support Structure	Frame and panel connected by cross, horizontal, diagonal brace	1
5	123	Support Structure	Brace in such length to keep scaffold plumb, level, square	1
6	124	Support Structure	Brace connection secure to prevent dislodging	1
7	125	Support Structure	Frame and panel joined together vertically by stacking pins or equivalent means	1
8	126	Support Structure	Frame and panel locked together to prevent uplift	1
9	131	Access and Ladder	Ladder hooked-on and attached to the scaffold	1
10	132	Access and Ladder	Stairway ladder have slip-resistant	NA
11	141	Fall Protection	Ramps and walkways 6 ft or more have guardrails	1
12	142	Fall Protection	The fall protection system provided	1
13	143	Fall Protection	Guardrail installed along open side and end of platform	1
14	144	Fall Protection	Guardrail top-edge height between 36 and 45 inches	1
15	151	Platform and Walkways	Midrail used and installed at approximately midway of guardrail height	NA
16	152	Platform and Walkways	Platform fully planked	1
17	153	Platform and Walkways	Gaps between plank or platform less than 1 inch	1
18	154	Platform and Walkways	Gaps between platform and structure being worked on less than 14 inches	0.667
19	155	Platform and Walkways	Toeboard installed along the edge of platform and have at least 3.5 inches height	1
20	161	Electrical Hazard	Scaffold and conductive materials not closer than 10 ft to power line	NA

Figure 7.18. Safety Scores of Image Case ID 099 (Figure 7.17)

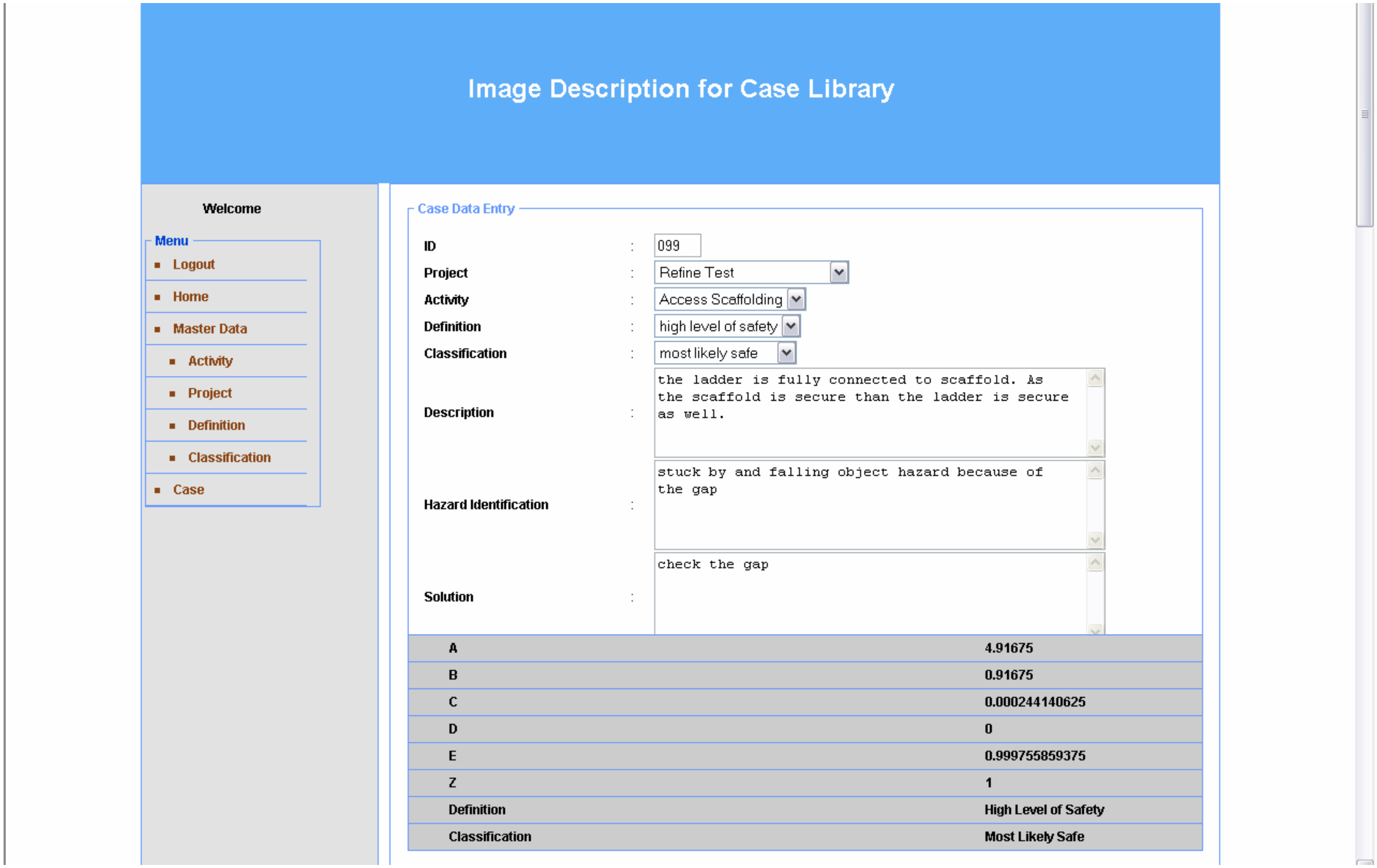


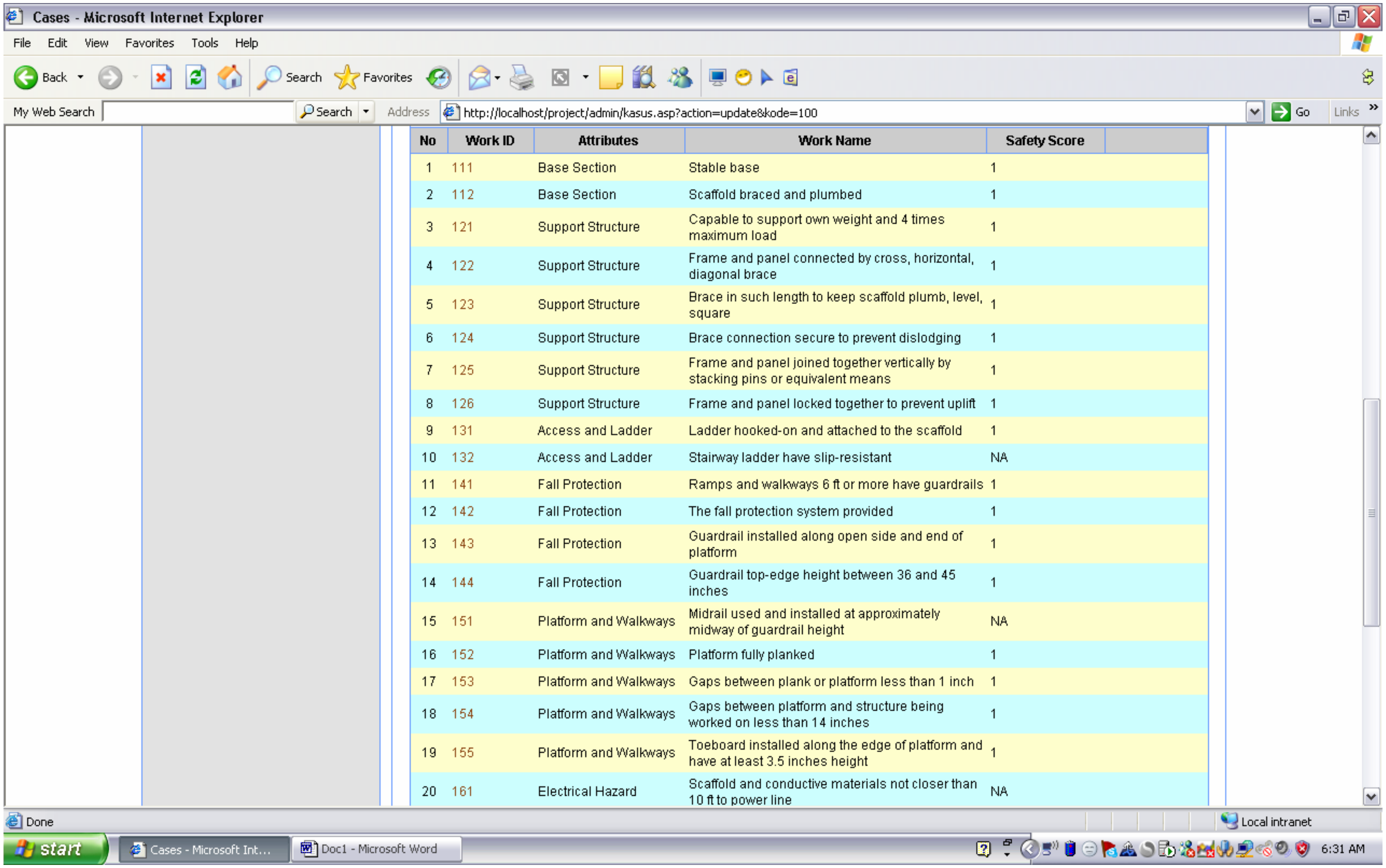
Figure 7.19. Results of Safety Assessment for Case ID 099 (Figure 7.17)

Figure 7.19 shows the change in the ladder safety score significantly changes the likelihood score of *P(E/H)*. Previously, it was 0.3053, now it is 0.9168. Refer to the meaning of *P(E/H)* that is the prior likelihood of safe construction practice being used for particular activity based on observed attributes, it means that the prior probability to judge particular activities safety is 91.68% based on assumption that safe construction practice being used. At this point, the safety administrator believes, based on an improvement of information certainty, that the construction practice safety is 91.68% out of 100%. However, there is still a hazard identified that gap between the platform and the structure being worked on which needs further investigation using detailed image.

e. Fifth image of scaffolding activity (case ID 100)

Figure 7.20. A Detailed Image of The Gaps Between The Platform and Structure Being Worked On

Information provided by Figure 7.20 shows that the gaps between the platform and the structure being worked on are quite narrow and it assumes gaps' width is less than 14 inches. Thus, with confidence, a safety administrator can give a score of 1 for work ID 154 and replacing the previous one (see Figure 7.21).



No	Work ID	Attributes	Work Name	Safety Score
1	111	Base Section	Stable base	1
2	112	Base Section	Scaffold braced and plumbed	1
3	121	Support Structure	Capable to support own weight and 4 times maximum load	1
4	122	Support Structure	Frame and panel connected by cross, horizontal, diagonal brace	1
5	123	Support Structure	Brace in such length to keep scaffold plumb, level, square	1
6	124	Support Structure	Brace connection secure to prevent dislodging	1
7	125	Support Structure	Frame and panel joined together vertically by stacking pins or equivalent means	1
8	126	Support Structure	Frame and panel locked together to prevent uplift	1
9	131	Access and Ladder	Ladder hooked-on and attached to the scaffold	1
10	132	Access and Ladder	Stairway ladder have slip-resistant	NA
11	141	Fall Protection	Ramps and walkways 6 ft or more have guardrails	1
12	142	Fall Protection	The fall protection system provided	1
13	143	Fall Protection	Guardrail installed along open side and end of platform	1
14	144	Fall Protection	Guardrail top-edge height between 36 and 45 inches	1
15	151	Platform and Walkways	Midrail used and installed at approximately midway of guardrail height	NA
16	152	Platform and Walkways	Platform fully planked	1
17	153	Platform and Walkways	Gaps between plank or platform less than 1 inch	1
18	154	Platform and Walkways	Gaps between platform and structure being worked on less than 14 inches	1
19	155	Platform and Walkways	Toeboard installed along the edge of platform and have at least 3.5 inches height	1
20	161	Electrical Hazard	Scaffold and conductive materials not closer than 10 ft to power line	NA

Figure 7.21. Safety Scores of Image Case ID 100 (Figure 7.20)

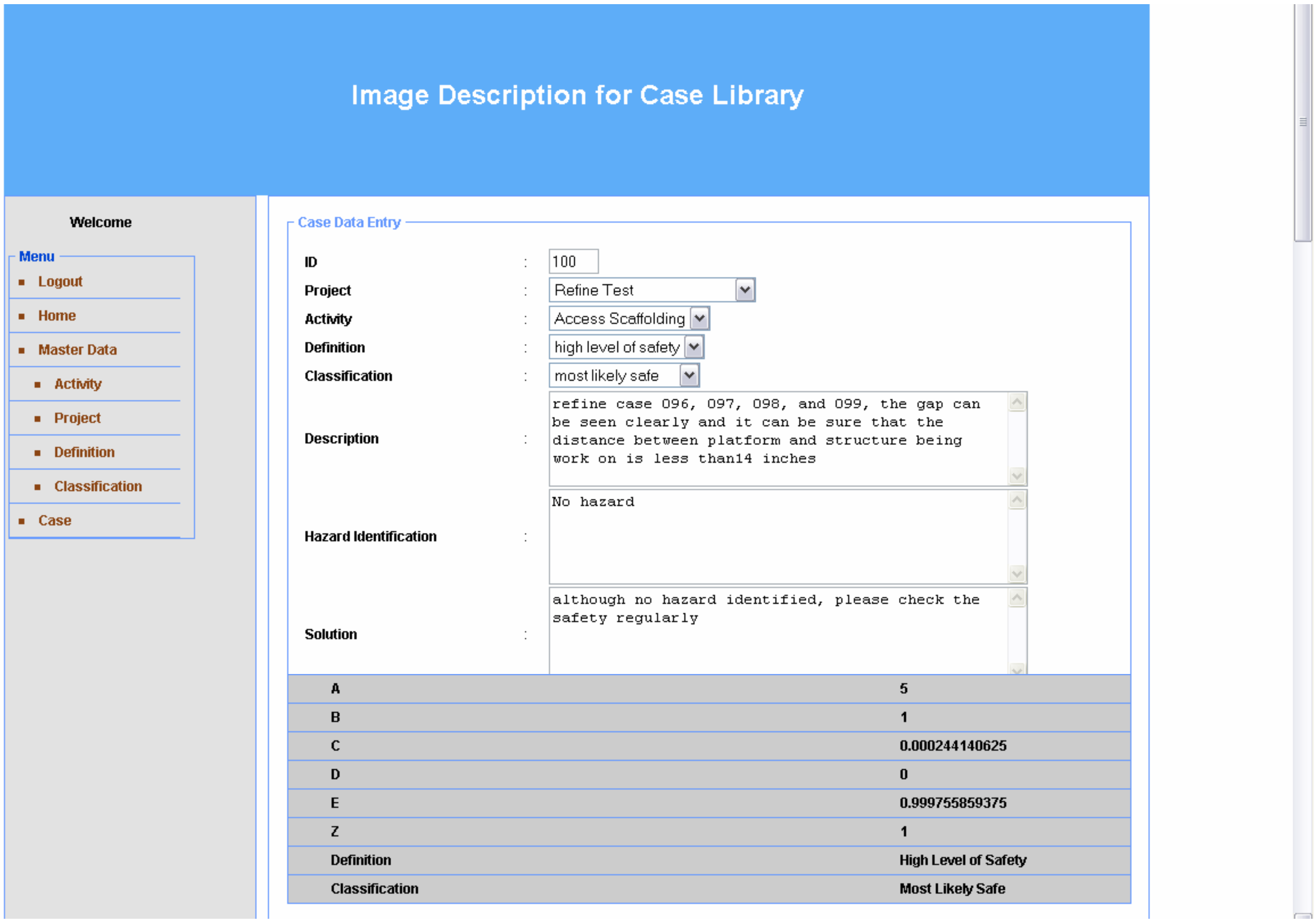


Figure 7.22. Results of Safety Assessment for Case ID 100 (Figure 7.20)

In summary, the assessment process using refined safety assessment system is as follows:

1. The first assessment revealed that construction practice showed in Figure 7.8 defined as low level of safety (see Figure 7.10). As seen in Figure 7.9, several parts have safety score less than 1 (work IDs 111, 124, 125, 126, 131, 143, 152) and several parts cannot be seen or not available (work IDs 132, 151, 153, 154, 161).
2. The second assessment using more detailed image of support structure showed in Figure 7.11 revealed that the practice now defined as high level of safety and classified as fairly safe (see Figure 7.13). Up to this stage, as seen in Figure 7.12, there were parts which have safety score less than 1 (work IDs 111, 131, 154) and several parts cannot be seen (work IDs 132, 151, 161). Compare with previous stage, some parts now can be seen clearly (work IDs 124,125,126, 152) and one part that previously cannot be seen now can be seen (work ID 154).
3. The third assessment using detailed image in Figure 7.14 revealed that up to this stage the practice still defined as high level of safety and classified as fairly safe (see Figure 7.16). As showed in Figure 7.15, there were only two parts having scored less than 1 (work IDs 131, 154) and still three parts not available (work IDs 132, 151, 161).
4. The fourth assessment using detailed image in Figure 7.17 revealed that now the practice classified as most likely safe (see Figure 7.19) with only one part has score less than 1 (see Figure 7.18 work ID 154) and still three parts not available (see Figure 7.18 work IDs 132, 151, 161).
5. The fifth assessment using detailed image in Figure 7.20 revealed its result in Figure 7.21 which are 17 safety sub attributes can be seen clearly and three safety sub attributes not available (work IDs 132, 151, 161).

From the five stages mentioned above it can be seen that refined assessment system using sets of detailed images revealed that all available sub attributes now have safety scores of 1. Thus the outcome is the likelihood score of *P(E/H)* also equals 1 (see B score in Figure 7.22). At this point, no hazard was identified (see "Hazard Identification" in Figure 7.22), however, safety check should be conducted regularly (see "Solution" in Figure 7.22).

7.6.2. Discussion of A Refined Safety Assessment System

The problem of the safety assessment system is an interpretation of uncertain information provided by an image and it assumed is influenced by image detail (section 7.5). This suggested that more detailed images of uncertain or unclear parts of construction activity shown in an image need to be taken to refine the system.

An example of the application of the proposed method to refine the assessment system using one construction activity has been demonstrated in section 7.6.1. The results of the assessment process changed significantly as previously the access scaffolding was defined as low-level of safety (see Figure 7.10) because of uncertain interpretation of several parts of the scaffolding that could not be clearly seen in the image.

Further investigation of the uncertain parts was then conducted by taking more detailed images of those parts so certain interpretation could be obtained and safety scores could be given with confidence. As all safety scores finally equaled 1, the access scaffolding defined as high-level of safety and classified as most likely safe (see Figure 7.22).

From the example demonstrated in section 7.6.1, interpretation of uncertain information may cause wrong decisions to be made. The activity previously defined as low-level of safety, was in fact, after further clarification using detailed images it defined as high-level of safety.

The final results of the safety assessment using more detailed images e.g. safety scores, definition and classification might be remained the same with before, however, further investigation by obtaining images showing more detail will improve their certain interpretation and lead to more confident decision-making.

7.7. The Use of The Safety Assessment Results

The demonstrations of application of the safety assessment system in section 7.5 and its refinement in section 7.6 are showed that the system verify its practical, fast, effective and efficient way to assess site safety is produced safety likelihood scores of construction activities, e.g. access scaffold, lifting and concreting.

Another advantage of the system's result is that the images and their safety-related information stored in a database can be used in future to provide better safety knowledge.

For a purpose of site safety monitoring and controlling, the result has potential use to provide safety trends that exist during a construction phase. Firstly, the trends will give figure of project's safety performance based on its likelihood score. Secondly, the trends will give figure of construction activities' safety performance, also based on their likelihood scores. Third, safety trends existed can be used to predict safety likelihood. These potential uses of the safety assessment results will explain and demonstrate in detail in following sections and begin with a brief explanation of a trend test.

The term 'longitudinal' has been used to describe a variety of studies that are gathered data over an extended period of time, e.g. a short-term investigation may take several weeks or months; a long-term study can take over many years. One particular study is a trend study in which a few selected factors are studied continuously over time (Cohen et al., 2007). In trend study, new samples are drawn at each stage of the data collection, but focusing on the same factors. Essentially, the trend study examines recorded data to establish patterns of change that have already occurred in order to predict what will likely occur in future.

Basically, the trend test employs correlation, a statistical technique used to measure and describe a relationship between two variables (Gravetter and Wallnau, 2007). Generally the two variables are merely observed as they exist naturally in the environment and there is no attempt to control or manipulate them. They require two scores each, identified as X and Y. The pairs of scores can be listed in a table or presented graphically in a scatter plot the advantage of which allows any patterns or trends in the data to be noted.

In this research, the safety trend test was undertaken after the application of the system, that has been mentioned in section 7.6, to observe the safety trend for each activity in each project to obtain information about the safe construction practice being performed. The two variables were time (on a weekly basis) and the likelihood score, *P(E/H)* which indicates the prior likelihood of safe construction practice being used for particular activity based on observed attributes. By noting the trend, one will know whether safe practice is being performed throughout the period of project or not. It also can be used as a safety alert for everyone involved in the project.

For example, if the trend line is downward it means that currently people involved in the project are performing less safety than before. A flowchart of the safety assessment results used for the trend test is illustrated in Figure 7.23.

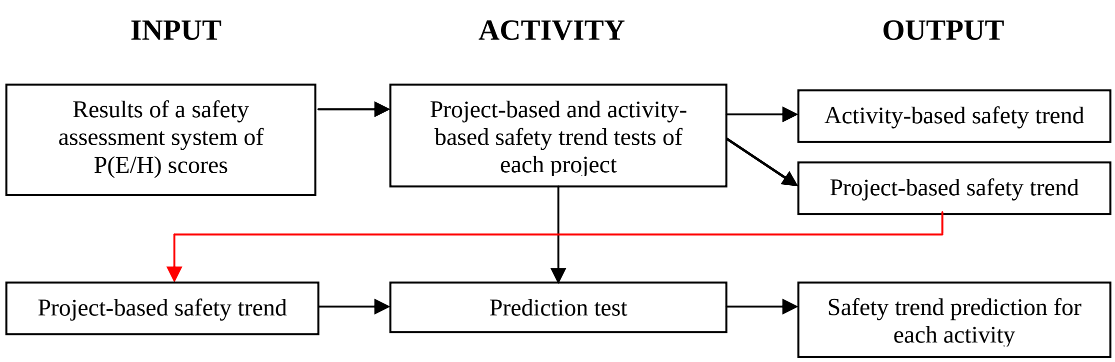


Figure 7.23. Flowchart of A Trend Test

In Tables 7.7 to 7.13, there is a score of Z which represents the $P(H/E_{comb})$ score. This is indicates the likelihood of safe construction practice being used (Hypothesis) given information in the image that safe particular activities are occurred (Evidence) (see section 7.6). There are two possible scores of Z, 1.0000 or 0.0000. If Z = 1.000 then the construction practice showed in the image defined as a high level of safety, and if Z = 0.000 then construction practice showed in the image defined as a low level of safety (see section 5.3.1).

With reference Figure 7.23 first input for a trend test is result of the assessment system which *P(E/H)* scores (see Appendix 3 for the automated calculations results). It is found that all data from four projects in this research have the score of Z = 1.000, consequently the construction practice shown in the images as research data are defined as high level of safety.

There are two trend tests have been undertaken, a project-based safety trend test and an activity-based safety trend test. The first is conducted to obtain safety trends for each project and the second is conducted to obtain safety trends for each construction activity. The results of the safety trend tests will be confirmed as follows.

7.7.1. Project-Based Safety Trend Tests Using Likelihood Score Based on Bayes' Theorem

a. The Leach Highway Bridge Project

During the data collection period, the activities covered in the Leach Highway Bridge Project were access scaffolding, earth moving, and road pavement. The chosen activities for data samples were access scaffolding, lifting, and concreting (see section 3.2.6.a), therefore on this particular project, only one activity could be used as data, access scaffolding.

The data collection, on a weekly basis (see section 3.2.6.b) took 14 weeks. Results of safety assessment are presented in Appendix 3 and the scores of Z and B (represents P(H/E) and P(E/H) respectively) are shown in Table 7.7. The trend line of B scores is likely horizontal but tends downward insignificantly after week 7 (see Figure 7.24).

Table 7.7. The Leach Highway Access Scaffolding Likelihood Scores

	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W10	W11	W12	W13	W14
B	1	1	1	0.8335	1	1	0.8335	1	0.8335	0.8335	0.9445	1	1	1
Z	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Where:

- B is *P(E/H)* and represents the likelihood of safe construction practice being used (Hypothesis) that can cause information of construction practices in the image (Evidence). An example of a *P(E/H)* calculation can be seen in section 7.2.1.
- Z is $P(H/E_{comb})$ and represents the likelihood of safe construction practice being used (Hypothesis) given information that safe construction practices are occurred obtained from the image (compound Evidence (E_1, E_2,..E_N)). An example of a $P(H/E_{comb})$ calculation can be seen in sub section 7.2.1.
- W is week and refer to image time collection

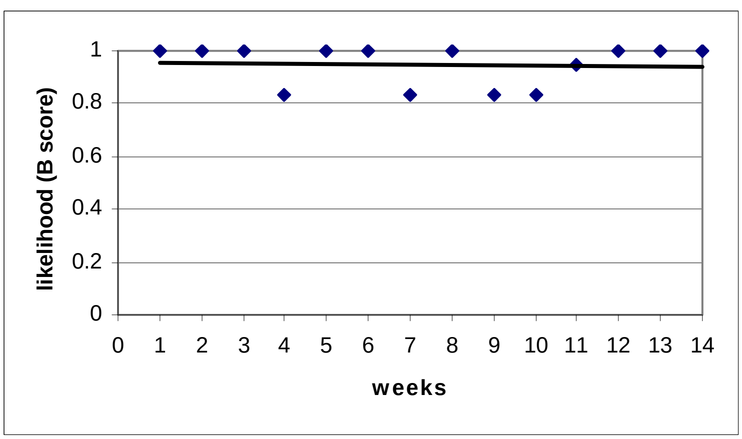


Figure 7.24. The Leach Highway Access Scaffolding Trend Tests

As shown in Table 7.7, the likelihood scores from week 1 to week 7 have only two score less than 1, but after week 7 there are three weeks with a score less than 1. This explains why the trend line tends a little bit downward after week 7. Although less than 1, the likelihood scores are still high and more than 0.75. These scores are classified as most likely safe (see section 5.4.1).

b. The Esplanade Train Station Project

In the Esplanade Train Station Project data was collected on a weekly basis (section 3.2.6.b). There were four activities: access scaffolding, lifting, concreting, and earth moving. The first three activities were chosen as data sample activities (see section 3.2.6.a). From the project, data on lifting activity was gathered over 10 weeks, whereas data collection of access scaffolding and concreting lasted only eight weeks. Results of the assessment process are presented in Appendix 3. The result of Z and B scores are tabulated in Tables 7.8, 7.9 and 7.10. The trend lines of B scores are varied; horizontal for access scaffolding, downward for concreting, and upward for lifting (see Figures 7.25, 7.26 and 7.27).

Table 7.8. The Esplanade Station Project Access Scaffolding Likelihood Scores

	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8
B	0.9445	0.9445	1	1	0.8335	0.8668	1	1
Z	1	1	1	1	1	1	1	1

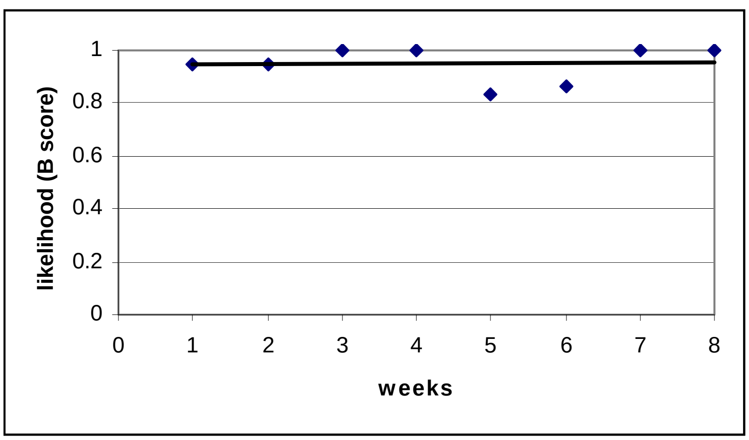


Figure 7.25. The Esplanade Station Project Access Scaffolding Trend Tests

Shown in Table 7.8, the likelihood scores for access scaffolding from week 1 to week 8 had four score less than 1 and four equal to 1. This explains why the trend line is horizontal (see Figure 7.25). However, although less than 1, the likelihood scores are still high and more than 0.75. These scores are classified as most likely safe (see section 5.4.1).

Table 7.9. The Esplanade Station Project Concreting Likelihood Scores

	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8
B	1	0.5	0.5	0.6665	0.6665	0.3335	0.3335	0.5
Z	1	1	1	1	1	1	1	1

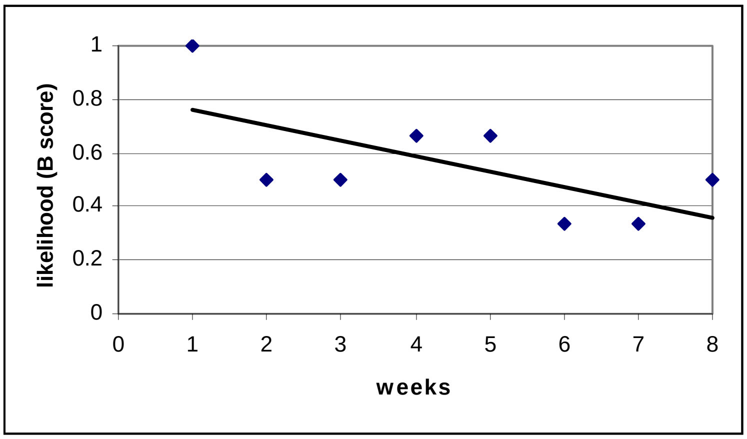


Figure 7.26. The Esplanade Station Project Concreting Trend Tests

In Table 7.9, the likelihood scores for concreting were perfect at week 1, but getting worse at week 2 and week 3. In these two weeks, the likelihood scores were classified as fairly safe with score between 0.25 and 0.75 (see section 5.4.1). In weeks 4 and 5, the scores were a little bit better but still in a fairly safe classification. At week 6 and week 7 the likelihood scores were worst. Both weeks have score 0.3335 which was approached the low limitation of fairly safe classification. Although still considered as fairly safe, the scores showed that the practice observed from images was most likely unsafe indicating the right action should be given to prevent any possible accident.

In week 8, the score increased brightly, a good sign as the classification is still fairly safe. That is why the trend line shown in Figure 7.26 tends downward from week 1 to week 8. This trend line indicates that the safety for concreting was not good. The right action should be made for preventing accident from happening.

Table 7.10. The Esplanade Station Project Lifting Likelihood Scores

	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W10
B	0.667	0.667	1	1	1	0.333	0.4449	0.667	1	1
Z	1	1	1	1	1	1	1	1	1	1

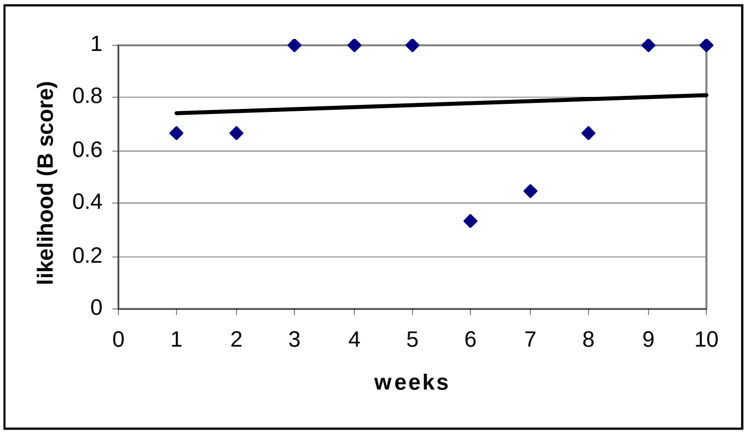


Figure 7.27. The Esplanade Station Project Lifting Trend Tests

For lifting activity, the trend line is tends upward (see Figure 7.27). This is looking good, however, based on the likelihood scores on the whole 10 weeks the scores were up and down (see Table 7.10). In safety point of view, this is not a good indication. The scores showed that sometime the construction people doing a good safety practice but sometime there are not. The best indication is the activity has reach score absolute 1 (see section 5.4.1) and be able to maintain that score throughout construction project.

c. The City Apartment Project

For the period of data collection, the activities in the City Apartment Project were access scaffolding, lifting, and concrete pouring. The chosen activities for data sample were access scaffolding, lifting, and concreting (see section 3.2.6.a). Refer to that, for this project only two activities can be collected as data, that access scaffolding and lifting.

The data collection was on weekly basis (see section 3.2.6.b) in which data can be taken for maximum period of 13 weeks for access scaffolding activity and nine weeks for lifting activity. After calculated (see Appendix 3). The result for Z score and B score as shown in Tables 7.11 and 7.12. The trend lines of the series of B score are both increase (see Figures 7.28 and 7.29).

7.11. The City Apartment Project Lifting Likelihood Scores

	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9
B	0.4449	0.667	1	1	1	1	0.667	0.667	0667
Z	1	1	1	1	1	1	1	1	1

The likelihood scores for lifting were quite low at week 1, but getting better at week 2 (see Table 7.11). Both weeks were classified as fairly safe. At week 3 to week 6, the scores were equal 1. This is a good achievement, as the highest score is 1. At those weeks, the likelihood scores were classified as most likely safe. Unfortunately, in the rest of period that week 7 to week 9, the likelihood scores were less than 1, and the classification went back to fairly safe. Although in the last three weeks the scores were little bit low, but from previous four weeks the scores were highest. This can explain why safety trend line tends a little bit upward (see Figure 7.28).

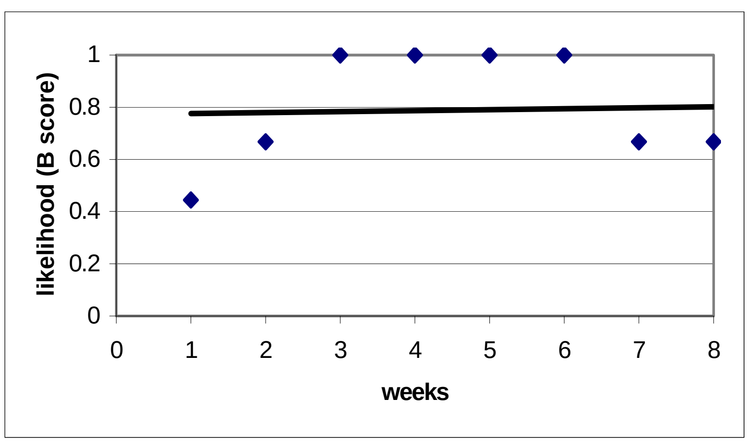


Figure 7.28. The City Apartment Project Lifting Trend Tests

Table 7.12. The City Apartment Project Access Scaffolding Likelihood Scores

	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W10	W11	W12	W13
B	0.4445	1	1	0.4723	0.4723	0.5	0.9334	1	1	1	1	0.889	1
Z	1	1	1	1	1	1	1	1	1	1	1	1	1

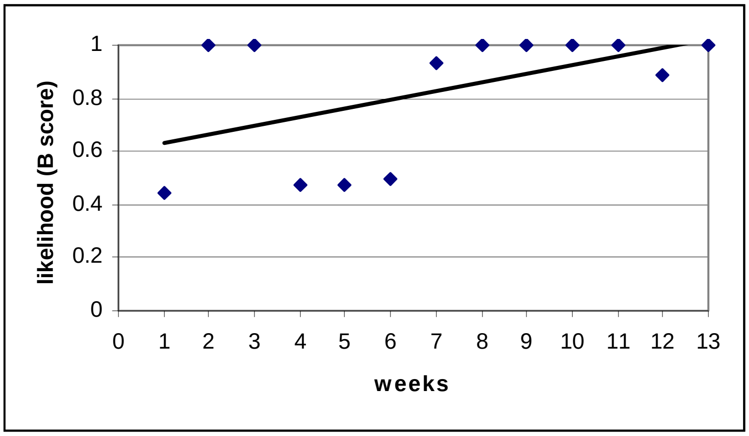


Figure 7.29. The City Apartment Project Access Scaffolding Trend Tests

For access scaffolding activity, the safety trend line tends upward significantly (see Figure 7.29). This is a good sign from safety point of view. It is an indicator that there was a good achievement of safety practice. Shown in Table 7.12, from week 1 to week 6, the scores mostly below 0.75, which is the limit of most likely safe classification. But start at week 7 until week 13 the scores were more than 0.75 and classified as most likely safe. However, as stated earlier, the best practice is when the practice has likelihood score of 1 and maintains that score throughout the construction project.

d. The Curtin University Project

The Curtin University Project is carried out these following activities in data collection period: concreting and earth moving. The first activity was chosen as data sample activity (refer to section 3.2.6.a). The data collection was in weekly basis (refer to section 3.2.6.b). From this project, data can be taken for a period of seven weeks. After calculation (see Appendix 3) the result for Z score and B score as shown in Table 7.13. The trend line of the series of B scores is shown in Figure 7.30.

Table 7.13. The Curtin University Project Concreting Likelihood Scores

	W 1	W 2	W 3	W 4	W 5	W 6	W 7
B	0.2221	0.667	0.667	0.6665	0.3335	0.3335	0.5
Z	1	1	1	1	1	1	1

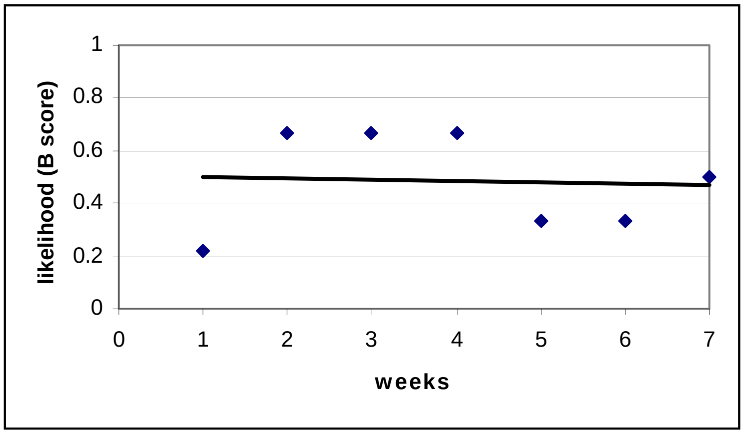


Figure 7.30. The Curtin University Project Concreting Trend Tests

As shown in Table 7.13, the likelihood score at week 1 was the worst one because that score was below 0.25 and classified as most likely unsafe (refer to section 5.4.1). Week 2 has score of 0.667 and classified as fairly safe. This is a good effort. This score was maintained until week 4. Although construction people could maintain the score however the construction people should not only maintain but also upgrade it in order to be able to reach the likelihood score of 1. This situation was getting worse since the score getting lower from 5 to week 6. Although the score was little bit higher at week 7, but the increase was not significant and still classified as fairly safe. This also showed in Figure 7.30 that the safety trend line tends a little bit downward from week 1 to week 9.

7.7.2. Activity-Based Safety Trend Tests Using Likelihood Score Based on Bayes' Theorem

The goal of activity safety trend test is to observe the likelihood of safety practice being used for particular activity. After defined into high level of safety, a construction practice showed in the image should classify into one of three classifications: most likely safe, fairly safe, and most likely unsafe (see Chapter 5). Each classification has a range of *P(E/H)* score. The classification range of score can be referred to Chapter 5 section 5.4.1, as follows: most likely safe has range of likelihood score of 1 – 0.750, fairly safe has range of likelihood score of 0.251 – 0.749, and most likely unsafe has range of likelihood score of 0 – 0.250. By using these classification ranges of score, every activity can be observed and classified. The results of activity-based safety trend test are as follows:

a. Access Scaffolding

Access scaffolding is an activity, which is consisting of two basis activities of working at height and scaffolding erection and connection. This means the likelihood score (B score) is depends on safety practice of those two basis activities. After being calculated (see Appendix 3), the likelihood scores for access scaffolding activity from three projects are showed in table 7.14 below and plotted in Figure 7.31.

Table 7.14. Access Scaffolding Likelihood Scores

Score	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	Project
B	1	1	1	0.8335	1	1	0.8335	1	0.8335	0.8335	0.9445	1	1	1	Leach
B	0.4445	1	1	0.4723	0.4723	0.5	0.9334	1	1	1	1	0.889	1		City
B	0.9445	0.9445	1	1	0.8335	0.8668	1	1							Espl

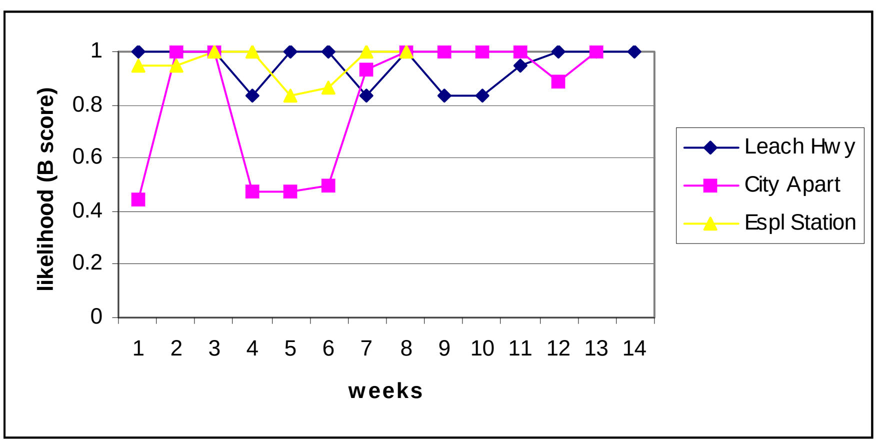


Figure 7.31. Access Scaffolding Safety Trend Tests

It can be seen from Table 7.14 or Figure 7.31 that from 35 test only four tests (11.4%) has score less than 0.75 and in range between 0.251 – 0.749. These four tests classified as fairly safe. The remaining test or 31 tests (88.6%) has score more than 0.75 and classified as most likely safe. From this result, it can be concluded that access scaffolding activity has common likelihood score above the 0.75 line, and thus classified as most likely safe. However, more safety practice improvement needs to be performed to achieve better result in future.

b. Concreting

Concreting is an activity, which is composting of two basis activities of steel reinforcing and form working. This means the likelihood score (B score) is depends on safety practice of those two basis activities. After being calculated (see Appendix 3), the likelihood scores for concreting activity from two projects are shown in Table 7.15 and plotted in Figure 7.32.

Table 7.15. Concreting Likelihood Scores

Score	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	Project
B	1	0.5	0.5	0.6665	0.6665	0.3335	0.3335	0.5	Espl
B	0.2221	0.667	0.667	0.6665	0.3335	0.3335	0.5		Curtin

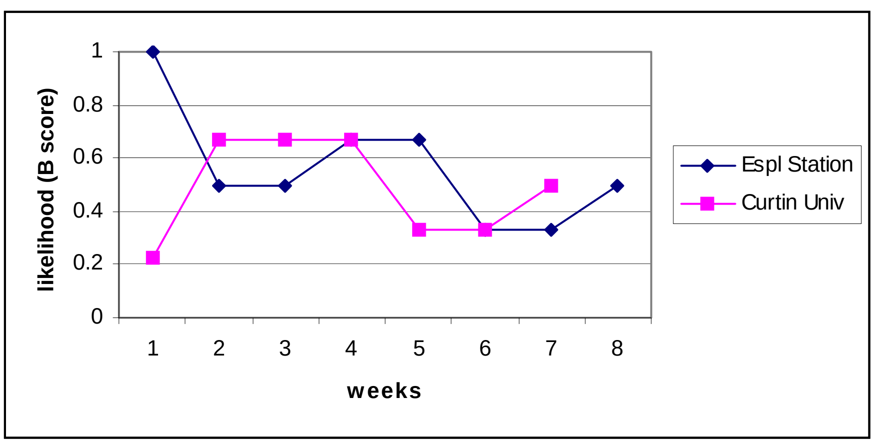


Figure 7.32. Concreting Safety Trend Tests

It can be seen from Table 7.15 or Figure 7.32 that from 15 test only one test (6.7%) has score above 0.75 and classified as most likely safe, nine tests (60%) has score in range of 0.251 – 0.749 and classified as fairly safe, and five tests (33.3%) has score less than 0.25 and classified as most likely unsafe. From this result, it can be accomplished that concreting activity has common likelihood score between 0.251 – 0.749 lines and classified as fairly safe. This result shows that safe concreting activity on project's site need to be improved so safer workplace will achieve

c. Lifting

Lifting in this study is an activity, which is basically made of lifted and moved object using crane. This means the likelihood score (B score) for lifting activity is depends on safety practice of lifted and moved object using crane. After being calculated (see Appendix 3), the likelihood scores for lifting activity from two projects are shown in Table 7.16 below and plotted in Figure 7.33.

Table 7.16. Lifting Likelihood Scores

Score	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W10	Project
B	0.667	0.667	1	1	1	0.333	0.4449	0.667	1	1	Espl
B	0.4449	0.667	1	1	1	1	0.667	0.667	0.667		City

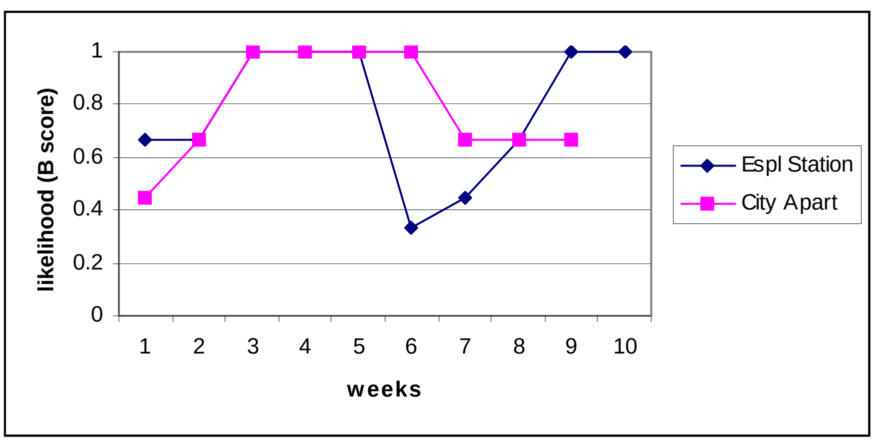


Figure 7.33. Lifting Safety Trend Tests

It can be seen from Table 7.16 or Figure 7.33 that from 19 tests, nine tests (47.4%) has score above 0.75 and classified as most likely safe, ten tests (52.6%) has score in range of 0.251 – 0.749 and classified as fairly safe. From this result, it can be outlined that lifting activity has two common likelihood scores, which are above the 0.75 line and in between 0.251 – 0.749 line. But since the likelihood score of above 0.75 line has less percentage than in between 0.251 – 0.749 line, then it can be stated that lifting activity in common has likelihood score in between 0.251 – 0.749 line and classified as fairly safe. Therefore it needs to improve lifting safety practice and by this way safer lifting practice will achieve.

7.7.3. Prediction Test

The prediction test has a goal to predict a safe practice being performed in construction project. In this research, a prediction test is using project-based trend test results which is based on correlation between time and likelihood score (see section 7.4). It is possible to use correlation test result to make a prediction. If two variables are related in some systematic way, it is possible to use one variable to make prediction about the other (Gravetter and Wallnau, 2007).

The results from trend test in section 7.4.1 show there are three types of correlation, positive (see Figures 7.27, 7.28, 7.29), negative (see Figures 7.24, 7.26, 7.30) and horizontal (see Figure 7.25). Positive correlation means that two variables tend to move in the same direction, as the value of *X*-axis (time) increase, the value of *Y*-axis (likelihood score) also tends to increase. Negative correlation tend to go in opposite direction, if the value of *X*-axis (time) increase, the value of *Y*-axis (likelihood score) is tends to decrease. Horizontal correlation occur when the value of *X*-axis (time) increase, but *Y*-axis (likelihood score) not. By using positive correlation, it can be predicted that as the value of *X*-axis (time) increase, the value of *Y*-axis (likelihood score) tends to increase. Likewise, for negative correlation it can be predicted that as the value of *X*-axis (time) increase, the value of *Y*-axis (likelihood score) tends to decrease. Whereas for horizontal correlation it can be predicted no change or a little bit change for likelihood scores in future.

The prediction test is used trend test's result and as the trend test is conducted using a likelihood score which obtain from uncertain interpretation, therefore it is reasonable only to say words, e.g. improving, stable, decline.

In this research, there are three possibilities for project's future safety prediction (refer to results in section 7.7.2). First possibility is a safe practice being performed in a future will remain a same with recent safe performance. This is based on the horizontal trend line (see Figure 7.25). The horizontal line means that the following weeks will have a same likelihood score. The meaning of horizontal trend line can be good but can be bad as well. If the recent likelihood score reach the highest score, which is 1.0, this is the best because if the flat line is in likelihood score equal 1.0 it means that throughout the construction period a contractor performed the perfect safe practice.

Second possibility is a safe practice being performed in a future is better than before. This is obtained from the trend line with positive correlation (see Figure 7.27, 7.28, 7.29) and a good one as it means the following weeks will have a better safety likelihood score which is get from better safety practice being performed. The slope of trend line sharper is better and it means that in the following weeks a contractor will perform safe practice much better than the previous week.

Third possibility is a safe practice being performed in a future is worse than the recent safe performance. This founded from the trend line with negative correlation (see Figure 7.24, 7.26, 7.30). Counter wise with positive correlation, this is a bad one as it means the following weeks will have a worse safety likelihood score which is get from worse safety practice being performed. The slope of trend line sharper is worse and it means that in the following weeks a contractor will perform safe practice worse than the previous week and corrective action should take immediately as it can be predicted that in future the possibility of accidents to occur is bigger.

7.7.4. Discussion of The Use of The Safety Assessment Results

The safety assessment process describes in section 7.3 reveals its results, *P(H/E)* which indicates the likelihood of safe construction practice being used (Hypothesis) given information in the image that safe particular activities are occurred (Evidence) and *P(E/H)* which indicates the prior likelihood of safe construction practice being used for particular activity based on observed attributes.

The demonstration of application of the system is using image data collected from four project covered three different construction activities. The results verify that the system is fast, practical, effective and efficient way to assess safety in construction project. It can be summarised from the application that the safety assessment result can be used for:

a. Project-Based Safety Trend Test

The use of results in this research is for safety trend tests (sections 7.7.1 and 7.7.2). A trend test is initially based on correlation between two variables and in this research a safety trend test is a test to correlate data collection time on weekly basis (*X*-axis) and likelihood scores (*Y*-axis) obtained from each week. Results of the trend tests are provided in sections 7.7.1 and revealed that no obvious pattern is showed from point distribution so a trend line is added (see Figures 7.24 to 7.30). A trend line is drawn through the middle of the data points. Thus, after a trend line is added, the line helps make a safety pattern in each project more obvious.

b. Activity-Based Safety Trend Test

Another safety trend test which described in section 7.7.2 is a activity safety trend test. The goal of activity-based safety trend test is to observe the likelihood of safety practice being used for particular activity. From three activities as the examples, an access scaffolding activity has common likelihood score above the 0.75 line (see Figure 7.31). This indicated that three construction projects perform most likely safe access scaffolding activity in their project.

Other construction activity is concreting. From example projects, all those projects perform fairly safe concreting activity. This is not a good indication. It suggests that project management should take corrective action to improve their safety practice. The last activity of example activities is lifting. The result from activity safety trend test for lifting is interesting. From 19 tests, nine test has score above 0.75 and ten test has score in between 0.251 – 0.749. It can be seen from both projects that they sometimes perform most likely safe practice and sometimes they perform fairly safe practice. However, not a single datum shows that they perform most likely unsafe safety practice. It can be assumed that the safety management was applied in those projects but not in tight control.

c. Prediction Test

Using the results from project-based trend tests for prediction test (section 7.7.3), it can be seen there are three trend line directions obtained: horizontal, tend upward, and tend downward (see Figures 7.24 to 7.30). Tend upward has a positive indication as it can be taken as an indication that a high level of safety was being achieved and that the level of safety will continue increasing. This increases will of course, be limited to the achievement of the highest level of performance or $P(E/H)$ = 1 but would still need to be monitored. Counter wise, tend downward has negative indication as it can be taken as an indication that a low level of safety was being achieved and decreasing. If one project has trend line tends downward, the project management should take immediate correction action to provide a safer work environment.

Horizontal line in trend line has meaning that a following time has a same likelihood score with a previous one. If a likelihood score reach the high score (likelihood score $\geq$ 0.75, or even the highest score =1), it can be taken as an indication that a high level of safety was being achieved (see Figure 7.24 as an example). But, if a likelihood score reach the score < 0.75, it can be taken as indication that a low-level of safety was being achieved, and a corrective action should be taken immediately by project management.

Regarding the use of a safety assessment system, the demonstration in Chapter 7 only used very limited image data, which is collected on weekly basis. It assumed that the result would be more comprehensive if the data for trend test are bigger. A bigger data can be collected from more time of data collection, not only weekly basis but daily basis, and not only one spot every datum taken but several spots around construction sites. The use of a video surveillance camera or remote CCTV camera is considered. This idea is a strong suggestion for future research in developed safety assessment system.

Beside the idea of using video surveillance camera or remote CCTV, as the system has been developed in Web-based system, the use of mobile phone that has features of camera and internet access for taking photos and accessing safety assessment system is considered for fast assessment action. Hence, results of the assessment and identified hazards could be retrieved in relatively short time period, to provide the best solution to prevent accidents from happening. This idea is also strongly considered for future research in developed safety assessment system.

7.8. Utilizing The Safety Assessment System

The safety assessment system, its results and use of result were demonstrated in sections 7.2 to 7.7 and reveals that it is advantage to utilize construction images to assess safety and use the assessment results to obtain common likelihood of construction practice's safety and to predict project's safety in future.

Further, the safety assessment system which then build in Web-based system become more benefit for anyone, including safety administrator and construction engineers. Following sections will explain the use of the assessment system on construction project.

7.8.1. The Safety Assessment System for Monitoring and Controlling Project Safety

Control as one of a management basic function is a process that has a purpose to determine whether everything is going in accordance with the policies developed through the planning process. The control process involves three steps (refer to section 2.4.1):

- **Step 1. Establish Standards**.

Control begins by setting standards. A standard establishment is usually done in earliest stage of construction phase. Standards establishment include designing safe construction method and setting performance values. In this research, a safety system has two standards of performance values for construction practice shown from an image.

An establishment of safe construction method standard in early stage of a project was using a case-based reasoning method. A case-based reasoning is an approach that used previous information (problems or cases and its solutions) from previous events to solve the problems for following events (see section 4.5). It is a chance to learn from previous project(s) about their successes and failures to make a better performance for following project(s). A brief demonstration of establishment standard using case-based reasoning will be given in section 7.8.2.

Next, there are two steps to set performance values. First, standard to define a construction practice showed in an image into two definitions: high-level of safety and low-level of safety (refer to section 5.3.1). Each definition has its likelihood score of safety *P(H/E)*, 0 means low-level of safety and 1 means high-level of safety. Second, standard to classify high-level of safety of construction practice showed in an image into three classifications: most likely unsafe, fairly safe, and most likely safe (refer to section 5.4.1). Each classification has its likelihood score *P(E/H)*, which are less or equal with 0.25 for most likely unsafe, in between 0.25 and 0.75 for fairly safe, and more or equal with 0.75 for most likely safe. These standards were included in developed computer program. The results of assessment process, represents by B score and Z score (see Figure 7.6), will then arrive automatically to definition and classification information in the same interface. Based on those standards, safe construction practice has a standard of *P(H/E)* = 1.0 (high-level of safety) and *P(E/H)* = 1.0 (most likely safe). The next step of measure actual performance against standards is then referred to these scores.

- **Step 2. Measure Actual Performance against Standards**.

The second step involves measuring actual performance against standard. To measure an actual performance two methods has selected and discussed in chapter three. The measuring actual performance has demonstrated in section 7.4. The measurement result is in form of likelihood score. This score then will compare with the standards. Safe construction practice has a standard of *P(H/E)* = 1.0 (high-level of safety) and *P(E/H)* = 1.0 (most likely safe).

- **Step 3. Identify Deviations (from Standard) and Take Corrective Action**.

Once compared actual with planned performance, and the actual one does not match the planned performance, the next step is to identify important deviations, and take corrective action. In this research, an identification of deviation recognized as a hazard identification and a corrective action recognized as a solution (see Figure 7.6). These features can be used as a tool for controlling a project safety as well as a tool for designing a project safety.

Inadequate performance is usually just a symptom, and so it is important to clearly identify the central problem. Hence by establishing standard, measuring the actual performance against standard and identifying deviation from standard, then the control decision of corrective action can be taken.

Control is a process to determine whether everything is going in accordance with the policies developed through the planning process (see section 2.4.1). Control involves setting a target, measuring performance, and taking corrective action. All control systems collect, store, and transmit information on profit, sales, quality, safety, and some other factor. Control also requires that targets, standards, or goals be set. To manage construction project, in addition construction safety, the safety management process should be involved throughout the construction phases (refer to section 2.4.1). A safety assessment system in this research can be used as a tool of project safety monitor and control as a part of project management process.

The example in section 7.4 demonstrates the way to use a safety assessment system for project safety monitor and control. Refer to statement about control in section 2.4.1, it involves setting a target, measuring performance or monitoring, and taking corrective action. In safety, the main purpose is to reduce, ideally to zero, the number of accidents (see section 2.2). This purpose can be set as a target for project safety control. In order to achieve that target, a control process has three steps: 1. Establish standards, 2. Measure actual performance against standards in monitoring process, and 3. Identify deviations (from Standard) and take corrective action in control process.

This safety assessment system has established standards (in this research only for three construction activities). Those standards are in form of safety checklist (see Tables 5.1, 7.1 and 7.2). The probability approach to calculate safety likelihood score established in this research is a tool to measure safety performance. The hazard identification and solution feature provided in a Web-based database is a device to identify deviations from standard and take corrective action. It can be accomplished that the safety assessment system can be used for project safety control.

Nevertheless, as hazard identification in this system was done manually, and exclusively depends on user safety knowledge and carefulness, it assumes that provide automated hazard identification will improve the safety assessment system and avoid mistake such as unidentified hazard because of user's careless. It suggests that automation in hazard recognition and identification is strongly recommended for future research.

7.8.2. The Safety Assessment System for Case-Based Reasoning

This research has been developed a computer-based database to store construction images as a part of a Web-based safety assessment system. The development of the Web-based safety assessment system has been described in Chapter 6. The database under Web-based safety assessment system then named as "Image Description for Case Library" (see Figure 7.6).

The Web-based safety assessment system was built based on the aim of this research which is to investigate the usefulness of descriptive database of construction methods for construction safety assessment and the objectives of this research (refer to section 1.3). Hence, the overall model of safety assessment system consists of the assessment function, case-search function and image database. In particular, the stored cases with its description including hazard identification and solution could be used to provide information for any reasoning method, e.g. case-based reasoning.

As an example how to use information in database which is a part of a safety assessment system for reasoning process, the following example will be given using case-based reasoning. The theory of case-based reasoning has been given in section 4.5.

An example of the use of assessment system for case-based reasoning

In order to fulfill the need of case-based reasoning to search prior cases then a case-search function feature is provided by Web-based safety assessment system. This research only used one class of case-based reasoning that interpretive case-based reasoning (see section 5.6). The four steps of interpretive case-based reasoning are as follows: proposed, justification, criticism and evaluation, store. A use of case library for case-based reasoning can be explained using the following example:

One new construction project will construct a multi level building. Construction equipments are provided. One of those equipments is system scaffold. A project manager wants that his project perform high-level of safety with most likely safe classification. He wants to retrieve a case or cases that can assist him to decide what kind of construction practice he should use for access scaffold. Then, he use "Image Description for Case Library" to do that.

a. Proposed

According to an interpretive case-based reasoning step, first the project manager should assess a situation (step 1: proposed). He chose to use the most specific information that most likely safe. Then he types "most likely safe" in Case-List Search field (see Figure 7.34).

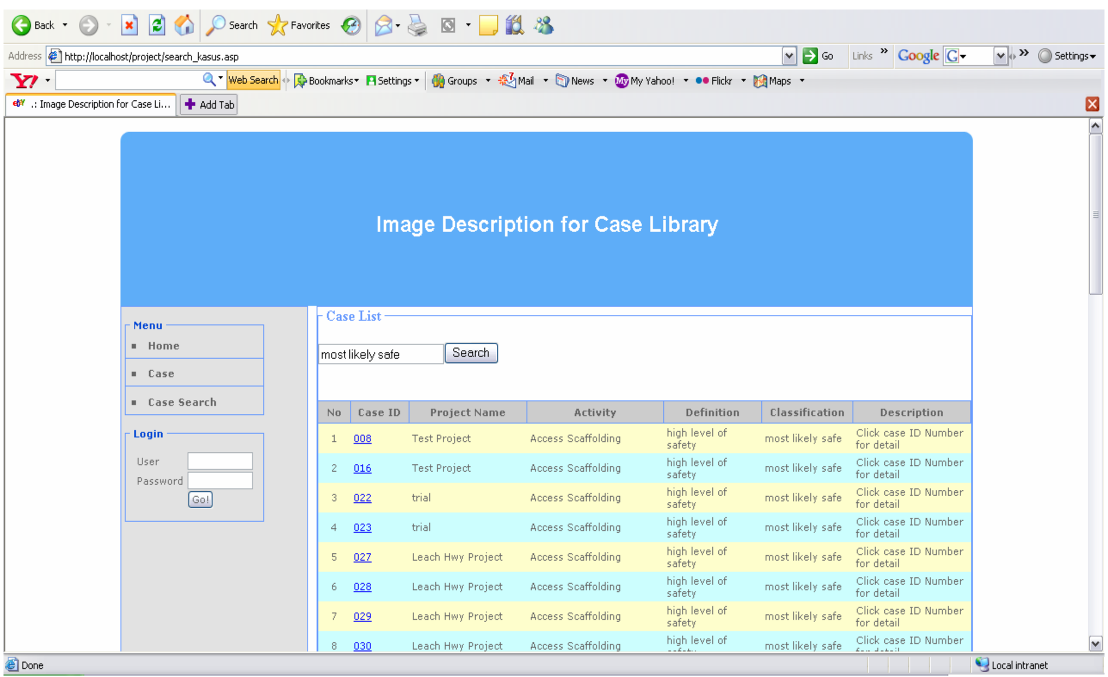


Figure 7.34. A Case List Search User Interface Template

b. Justification

Next step he should separate retrieved cases (step 2: justification). As he needs information of access scaffolding, then he only open stored cases that have access scaffolding activity from activity column (see Figure 7.34).

c. Criticism and evaluate

Following this, he should compare the new situation (multi storey building with system scaffold) with the old situation (step 3: criticism and evaluate). The result of this step is the answer of the question: "what kind of construction practice he should use for access scaffold?" The information of selected cases will include how to erect safe access scaffold, how to secure the scaffold connection, how to prevent falling hazard, etc. and hazard identification for such activity and its solution as well.

d. Store

Then, the project manager chooses the closest case and derived solution from that case to provide better safety performance for access scaffolding. Finally, the image of the current situation and its description is then stored into case library (step 4: store).

Summary the use of assessment system for case-based reasoning

Using case-based reasoning method as explained above, the project manager will be able to make plan and design for safe construction practice using whatever resource he has for his new project based on the previous experiences with similar situation. The benefit of this system is that the safe construction practice plan and design can be done from the earliest stage of construction phase.

Yet, as the safety assessment system at this moment only has feature of one field of case search function, the system can only retrieve stored case a user ask for without ability to retrieve the most relevant case. As case-based reasoning process will give better result, which is closest relevant with current case, it assumes that add more features, such as advance search function, provide more than one field of case search function, will improve a safety assessment system. It suggests taking into account this need for future research.

7.9. Conclusion of A Safety Assessment System (SAFE AS)

This chapter has presented the data used in this research. Data in this research are photographic images that have been taken from four different construction sites surrounding Perth metropolitan area covered three different activities. These data were taken in weekly basis. From these sample sites, 189 images had been collected and only 69 images can be used for safety assessment process.

This chapter also demonstrated a safety assessment system, and the interpretation of the result derived from the safety assessment system. A step-by-step safety assessment process has been presented and began with image observation. The result of image observation is information and for this research the information is limited for safety practice being performed. Then, based on safety attributes and sub attributes from safety checklist, the safe practice being performed scored. After calculated, the result of safety assessment is likelihood scores, *P(H/E)* and *P(E/H)*. The meaning of both likelihood and the use of the likelihood scores have been obtainable.

One test in this research for studying a use of safety assessment system is trend test. Revealed from literatures, a trend test basically is a correlation test between two variables. Thus, in this research a trend test was conduct to correlate time and a safety practiced being performed using likelihood scores. The trend test result and an interpretation of the trend test result have been offered.

Another tests for utilizing safety assessment result is a prediction test. A prediction test was performed to predict the safety likelihood in future based on a trend test result. Another benefit of a safety assessment system developed is as a tool for project safety control. As the data were collected throughout construction phase then the project safety control can be implemented throughout construction phase as a part of project management.

The demonstration of safety assessment system, its result and the use of the result have been illustrated in Chapter 7. It can be concluded that construction images can be used as a source of information, the safety assessment system can be used to assess safety, and the result of safety assessment system can be used to control safety in construction project and to predict the safety performance in future.

Chapter 8

CONCLUSIONS AND RECOMMENDATIONS

8.1. Introduction

This thesis has addressed a research carried out to investigate the usefulness of a descriptive database of construction methods for safety assessment. In addition, it investigates the possibility of utilizing construction images as sources of safety-related information. To achieve it, four objectives had been set out. Following sections will describe the overall conclusions and outcomes, also recommendations for future research.

8.2. Conclusions of the Use of Construction Images to Assess Safety

This section reviews the overall conclusions and outcomes after research and how the objectives have been met.

1. The investigation of the potential used of construction images as data to assess safety (first objective)

a. The use of construction images

Construction information in the form of photographic images is increasingly being used as a source of information in the study and control of construction practices. In particular, images have been used to provide information concerning the construction methods, progress, damage, and the condition of sites themselves, as they are likely to be the original sources of construction-related information. The natural capability of a photographic image to capture an event at any point of time suggests that it can be used to represent actual situations on construction sites.

b. Reviewed studies findings

The reviewed studies on construction safety reveal that to provide a safe work environment in construction project, it is necessary to implement a safety program from the early stages of a project. Safety and health hazards must be identified as early as possible as prevention is always better than cure. However, from the reported studies that have been done, no single study has developed a safety control program based on actual situations on construction sites.

c. Preliminary investigation

The omission of the potential assessment of on site safety thus became the basic inspiration of this research, to use construction images as data to assess safety. A preliminary investigation was undertaken to investigate the possibility of using construction images as data for on site safety. Sets of images from construction projects were taken and shown to several construction practitioners who were questioned about the construction practices safety observed from the images.

d. Findings

As a result of this trial it was decided that: 1. A construction image can be used as a source of information, 2. There are agreements about common information provided by an image, and 3. There are some disagreements about safety justification from images because of lack of construction practice experiences and/or uncertain interpretation of observed images. Following from this new problem then arose: 1. How to use past experience, either personal or from other persons for particular construction methods? And 2. How to make a relatively similar judgment about safe construction practices being performed based on the interpretation of the information from construction images?

From this brief explanation, it can be concluded that construction images can be used as data to assess safety, however problems arose concerning the reuse of past experience and safety assessments based on image interpretation.

2. The development of a safety assessment system using information observed from construction image (second objective)

a. Problems that arise from preliminary investigation

Process of utilizing construction image used in the preliminary investigation stages does not present a systematic way or method to deal with arisen problems. This research, then, went on to develop a safety assessment system that consists of safety assessment method and image database. Safety assessment method assumed as the answer of problem of providing a relatively similar judgment about safe construction method being used. Image database assumed as the answer of problem related with reuse past experience.

b. Safe construction activity checklist provided

Disagreement about safety judgment came about as a result of a lack of safety guidelines to use construction image for safety assessment and uncertain interpretation of information from images. To solve this problem, a construction activity checklist was required and it will use to assess safety based on interpretation of information from images.

This research provided three safety checklists derived from the Occupational Safety and Health Administration safety regulations to use as guidelines to assess construction practices safety. An assessment begins by answering questions on the checklists based on the interpretation of information observed from an image. As this is usually qualitative with terms such as likely safe, mostly unsafe, etc, it needed to be treated quantitatively to obtain a safety score to make assessment easier and have result in exact numbers.

c. Development of manual mathematical method of assessment

The quality or detail of construction images sometimes cannot be accurately interpreted. To deal with uncertain interpretation, one problem-solving tool comes from Artificial Intelligence, a probability, is proposed. Probability is a quantitative way to deal with uncertainty. Two formulas from Bayes' theorem and fuzzy logic theory have used to calculate the probabilities of a hypothesis based on evidence observed from an image. Hypothesis in this research means a safe construction practice being used, whereas evidence means information about construction practice in an image expressed by safety scores. Calculations were done manually using MS Excel spreadsheet. The result of this process is construction practice definition and classification.

d. Development of image database

Construction images and its description which are construction project name, activity, construction practice definition and classification, hazard identification, and solution then need to be stored in a database. The database is developed as a computer-based database using a Structure Query Language (SQL) Server database. This database enables users to retrieve the stored data as past experience. Hence, if someone has not had prior experience of a particular activity or several activities, experience from someone else can be used as basic knowledge to arrive at a safety judgment.

e. Problem with manual assessment method

The application of the safety assessment system using a limited number of images demonstrates that the system provided a practical way of assessing construction practice safety. However, manual safety assessment process, updating a database and retrieving data to reuse them as past experience which done separately found to be time-consuming. To solve these problems, the safety assessment system needed to be built in the form of a Web-based system.

3. The development of a Web-based safety assessment system (third objective)

a. Proposed method to replace manual assessment with a Web based system

For effective construction safety management, the manager needs up-to-dated safety information for effective decision-making which can access from anywhere. Sooner construction hazards identified, sooner accidents can be prevented. With regard to the need, a Web-based safety assessment system is developed. This system enables users to assessing construction practice safety, updating and retrieving safety information automatically.

b. Development automated assessment system in Web-based platform

The Web-based safety assessment system was developed using an Active Server Pages (ASP), an Internet Server Application Programming Interface (ISAPI) application that allows several operations to be performed and the three most important operations are: make *If...Then* decisions, process information from clients, and access databases and files. In this way, the program can thus perform safety assessment calculations, store data into database and retrieve data from database, in one comprehensive system. As ASP is an application based on the Internet, anyone can access the system from anywhere if the user knows the Uniform Resource Locator (URL) such as: http://localhost/project.asp of the database server.

c. Uses of Web-based system

The safety assessment system has two settings of Web program based on two kinds of user: A safety administrator and a construction engineer. While a safety administrator has authorization to undertake safety assessment and update the database, a construction engineer can only access and retrieve stored data. For this need the system has these features: username, password and case search function. Anyone can use the case search function without logging in into the system (typing username and password). This feature is merely for security reasons and acts like a portal for the database. Without correct username and password, no one can manipulate data in the database.

d. Web-based safety assessment system test

The Web-based safety assessment system was tested using the same images as those for the manual system and revealed the same results thus confirming it was ready to be used as data analysis tool for research data.

4. The application and use of the safety assessment system (fourth objective)

a. Research data collection

The safety assessment system was tested using limited data verifying it could be used for larger amounts of data. Research data, 69 construction images, from four project sites covered three construction sample activities were analysed. They were collected on a weekly basis and each image was given its identification called an image ID.

b. Research data storage

Each image was analysed using the system and was stored in a database called "Image Description for Case Library". Each image depicted more than one activity could be used more than once, therefore storing was not based on image ID but based on case ID which identified project name and construction activity. The cases were stored in time order.

c. Demonstration of the safety assessment system

The safety system was successfully applied to analyse data so that every case could be defined and classified. As the definition refers to a likelihood score of *P(H/E)* and classification to a likelihood score of *P(E/H)*, every case had both scores. From the definition process, the score of *P(H/E)* of 69 images was the same thus all images defined as high-level of safety no matter their case ID yet, each case had different *P(E/H)* score.

d. The use of assessment results

As mentioned earlier, every case and its *P(E/H)* score had been stored in a time order so that two variables could be correlated, time and *P(E/H)* score. Correlation is a statistical technique that is used to measure and describe a relationship between two variables. To represent this relationship, there needs to be a score for each variable, usually identified as X and Y. In this research, the Y-axis represents *P(E/H)* score and the X-axis time. These pairs of scores were presented graphically in a scatter plot and a trend line was added to indicate the trend of the data. As the time is on weekly basis so the correlation process showed the weekly safety trend.

The trend line indicates whether construction safety practice tends to be positive where there is an improvement in safety practice, or negative where the safety practice deteriorate, and horizontal when the safety practice remains the same.

The safety trends produced in this research can thus be used to predict future construction safety practice and also to monitor and control project safety. The trend refers to results from a safety assessing process which can be done at any time during construction phase thus the accident prevention can be done at anytime.

e. The use of safety assessment system for case-based reasoning

An additional advantage of the case library is it contains experience from previous projects which can be used in future for reasoning process to solve problems such as providing solutions of identified hazards that might occur in subsequent projects in a similar situation. Construction engineers will thus be able to benefit from the success and failure of previous projects in the hope that safest practice will perform for following projects.

f. Summary of the safety assessment system

An application of the safety assessment system, including its refinement and the use of the result have demonstrated it is a useful fast, practical, effective and efficient way to assess, monitor, and control construction project safety, therefore it can be concluded that a safety assessment system developed in this research can make significant contributions to construction safety research.

8.3. Recommendations for Future Research on the Use of Construction Images for Safety Assessment

Over all achievements and outcomes, for improvement of the safety assessment system, the following recommendations are suggested:

1. This research has used digital camera and computer separately, that means it needs time to upload image from camera into computer. The use of mobile phone that has built in camera and Internet access is strongly recommended as an alternative device to get safety assessment result faster. If corrective action needs to be taken to prevent accident, it can be done in relatively short time.
2. This research has used very limited data only 69 images from four construction sites. Collecting more images, especially those showing more detail, from larger numbers of construction sites is strongly recommended for future research to obtain more comprehensive results. The use of CCTV camera that can record image continuously is considered.
3. This research only surveyed three construction activities. Enlarger the numbers of construction activities are strongly recommended for future research to verify the applicability of the safety assessment system.
4. Data for this research was collected on a weekly basis from a single spot per datum. In future research, it strongly recommended collecting data more frequently and from several spots per datum. In this way, more obvious trends will be obtained.
5. The use of Case-Based Reasoning only investigated in a limited way. Regarding utilizing the system for CBR, it only provided a single field case search function

that was able to retrieve very common cases. This does not satisfy the requirements of CBR which should show relevance previous cases in similar situations to reuse previous cases for subsequent one. It strongly recommended for future research to provide advanced search function to narrow the search and be able to retrieve closer relevant cases.

6. Manual hazard recognition and identification by viewing construction images that resulted with unrecognised and unidentified hazard because of carelessness can increase the occurrence of accidents. To avoid this risk, automated hazard recognition and identification is strongly recommended for future research to enhance the safety assessment system. However this requires computer-based object recognition that is beyond the scope of this research and the techniques commercially available.

8.4. Summary of The Safety Assessment System

The present research has demonstrated the development of a safety assessment system using construction images as sources of safety-related information. The safety assessment results have provided a fast, practical, effective and efficient way to assess safety on construction sites. The system has the potential to be used to identify safety trends and hence predict future safety performance. It can be used as a tool for construction safety monitoring and control.

The image database with its safety information has the benefit of providing information from prior project experience for use as a basis for reasoning process to identify better safety practice. The overall outcome of the research is the system for improving construction site safety and reducing, ideally to zero, the occurrence of construction accidents.

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Appendix 1
Results of The Use of Preliminary Investigation Image Data for Calibrating Automated Assessment Results

Safety Scores from Automated Assessment System Using Images in Figure 5.4 (Preliminary Investigation Image Data)

Image #	Work ID 111	Work ID 112	Work ID 121	Work ID 122	Work ID 123	Work ID 124	Work ID 125	Work ID 126	Work ID 131	Work ID 132	Work ID 141	Work ID 142	Work ID 143	Work ID 144	Work ID 151	Work ID 152	Work ID 153	Work ID 154	Work ID 155	Work ID 161
1	N/A	1.000	1.000	1.000	1.000	0.670	0.670	0.670	1.000	0.670	1.000	1.000	0.670	1.000	N/A	N/A	N/A	1.000	1.000	1.000
2	1.000	0.670	0.670	0.670	0.670	0.670	0.670	0.670	N/A	N/A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
3	N/A	0.670	0.670	0.330	0.670	0.330	0.670	0.330	N/A	N/A	0.000	0.000	0.000	0.000	0.000	0.330	0.330	N/A	N/A	1.000
4	0.670	0.670	0.670	0.000	0.000	0.000	0.670	0.670	0.000	N/A	0.000	0.000	0.000	0.000	N/A	N/A	N/A	0.00	N/A	0.000
5	0.670	0.670	1.000	0.670	1.000	0.670	0.670	0.670	N/A	N/A	1.000	0.670	0.670	1.000	0.670	0.670	1.000	0.670	1.000	1.000
6	0.670	0.670	0.670	1.000	1.000	0.670	0.670	0.670	N/A	N/A	1.000	1.000	0.670	N/A	1.000	N/A	1.000	1.000	1.000	1.000
7	N/A	0.670	0.670	1.000	1.000	1.000	1.000	1.000	1.000	N/A	1.000	1.000	0.330	1.000	1.000	N/A	1.000	1.000	1.000	1.000
8	1.000	1.000	0.670	1.000	0.670	1.000	1.000	1.000	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9	N/A	0.670	0.670	1.000	0.670	N/A	N/A	N/A	N/A	N/A	0.000	0.000	0.000	0.000	N/A	N/A	N/A	N/A	0.000	1.000
10	1.000	0.670	0.330	0.000	0.330	0.670	0.670	0.670	N/A	N/A	0.000	0.000	0.000	0.000	0.670	N/A	0.670	0.000	0.000	1.000
11	N/A	0.670	0.670	0.670	0.330	0.330	0.670	0.670	N/A	N/A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
12	N/A	0.330	0.670	1.000	1.000	0.670	N/A	0.670	N/A	N/A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
13	N/A	0.670	0.670	0.000	0.000	0.000	0.670	0.670	N/A	N/A	0.000	0.000	0.000	0.000	N/A	N/A	1.000	0.00	0.00	0.330
14	N/A	0.670	0.670	0.330	0.670	0.670	0.670	0.670	N/A	N/A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
15	N/A	N/A	0.670	0.330	0.670	0.670	0.670	0.000	N/A	N/A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
16	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.670	N/A	N/A	1.000	1.000	0.670	1.000	1.000	1.000	1.000	1.000	1.000	1.000
17	N/A	0.670	1.000	1.000	1.000	1.000	0.670	0.670	N/A	N/A	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
18	N/A	0.670	1.000	1.000	0.670	0.670	0.670	0.670	0.670	N/A	1.000	1.000	0.670	1.000	1.000	0.670	0.670	0.330	1.000	1.000
19	N/A	0.670	0.670	0.330	0.000	0.330	0.670	0.670	N/A	N/A	0.000	0.000	0.000	0.000	0.330	0.330	0.330	0.00	0.00	1.000
20	1.000	0.670	1.000	0.670	0.670	0.670	0.670	0.330	N/A	N/A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

Results of Automated Assessment Using Preliminary Investigation Image Data (see Figure 5.4)

Image Number 1

A	5.58375
B	0.6368866226875
C	0.00006103515625
D	0
E	0.99993896484375
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Image Number 2

A	2.5005
B	0
C	0.000244140625
D	0
E	0.999755859375
Z	0
Definition	Low Level of Safety
Classification	Unsafe

Image Number 3

A	2.389
B	0
C	0.000244140625
D	0
E	0.999755859375
Z	0
Definition	Low Level of Safety
Classification	Unsafe

Image Number 4

A	1.0005
B	0
C	0.00006103515625
D	0.2219445
E	0.99993896484375
Z	0
Definition	Low Level of Safety
Classification	Unsafe

Image Number 5

A	4.0787
B	0.3461063617642
C	0.000244140625
D	0
E	0.999755859375
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Image Number 6

A	4.334
B	0.461325214
C	0.000244140625
D	0
E	0.999755859375
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Image Number 7

A	5.44475
B	0.524932084875
C	0.00006103515625
D	0
E	0.99993896484375
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Image Number 8

A	1.889
B	0.889
C	0.015625
D	0
E	0.984375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Image Number 9

A	2.445
B	0
C	0.000244140625
D	0
E	0.999755859375
Z	0
Definition	Low Level of Safety
Classification	Unsafe

Image Number 10

A	2.6115
B	0
C	0.000244140625
D	0
E	0.999755859375
Z	0
Definition	Low Level of Safety
Classification	Unsafe

Image Number 11

A	2.55616666666667
B	0
C	0.000244140625
D	0
E	0.999755859375
Z	0
Definition	Low Level of Safety
Classification	Unsafe

Image Number 12

A	2.1332
B	0
C	0.000244140625
D	0
E	0.999755859375
Z	0
Definition	Low Level of Safety
Classification	Unsafe

Image Number 13

A	1.66683333333333
B	0
C	0.000244140625
D	0.098691321
E	0.999755859375
Z	0
Definition	Low Level of Safety
Classification	Unsafe

Image Number 14

A	2.61166666666667
B	0
C	0.000244140625
D	0
E	0.999755859375
Z	0
Definition	Low Level of Safety
Classification	Unsafe

Image Number 15

A	1.50016666666667
B	0
C	0.0009765625
D	0
E	0.9990234375
Z	0
Definition	Low Level of Safety
Classification	Unsafe

Image Number 16

A	4.86125
B	0.865870375
C	0.000244140625
D	0
E	0.999755859375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Image Number 17

A	4.556
B	0.592963
C	0.000244140625
D	0
E	0.999755859375
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Image Number 18

A	4.76215
B	0.232714309712487
C	0.00006103515625
D	0
E	0.99993896484375
Z	1
Definition	High Level of Safety
Classification	Most Likely Unsafe

Image Number 19

A	2.3113
B	0
C	0.000244140625
D	0
E	0.999755859375
Z	0
Definition	Low Level of Safety
Classification	Unsafe

Image Number 20

A	2.50033333333333
B	0
C	0.000244140625
D	0
E	0.999755859375
Z	0
Definition	Low Level of Safety
Classification	Unsafe

Appendix 2

    

    

   

    

    

  

    



































Appendix 3
The Leach Highway Project
Access Scaffolding

Week1

A	6
B	1
C	0.00006103515625
D	0
E	0.99993896484375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week2

A	5
B	1
C	0.000244140625
D	0
E	0.999755859375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week3

A	5
B	1
C	0.000244140625
D	0
E	0.999755859375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week4

A	5.8335
B	0.8335
C	0.00006103515625
D	0
E	0.99993896484375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week5

A	5
B	1
C	0.000244140625
D	0
E	0.999755859375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week6

A	5
B	1
C	0.000244140625
D	0
E	0.999755859375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week7

A	4.8335
B	0.8335
C	0.000244140625
D	0
E	0.999755859375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week8

A	4
B	1
C	0.0009765625
D	0
E	0.9990234375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week9

A	4.8335
B	0.8335
C	0.000244140625
D	0
E	0.999755859375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week10

A	5.8335
B	0.8335
C	0.00006103515625
D	0
E	0.99993896484375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week11

A	3.9445
B	0.9445
C	0.0009765625
D	0
E	0.9990234375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week12

A	6
B	1
C	0.00006103515625
D	0
E	0.99993896484375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week13

A	5
B	1
C	0.000244140625
D	0
E	0.999755859375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week14

A	4
B	1
C	0.0009765625
D	0
E	0.9990234375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

The Esplanade Train Station Project
Access Scaffolding
Week1

A	4.9445
B	0.9445
C	0.000244140625
D	0
E	0.999755859375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week2

A	4.9445
B	0.9445
C	0.000244140625
D	0
E	0.999755859375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week3

A	4
B	1
C	0.0009765625
D	0
E	0.9990234375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week4

A	3
B	1
C	0.00390625
D	0
E	0.99609375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week5

A	4.8335
B	0.8335
C	0.000244140625
D	0
E	0.999755859375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week6

A	3.8668
B	0.8668
C	0.0009765625
D	0
E	0.9990234375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week7

A	3
B	1
C	0.00390625
D	0
E	0.99609375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week8

A	4
B	1
C	0.0009765625
D	0
E	0.9990234375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Concreting

Week1

A	4
B	1
C	0.0009765625
D	0
E	0.9990234375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week2

A	2.5
B	0.5
C	0.00390625
D	0
E	0.99609375
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week3

A	3.5
B	0.5
C	0.0009765625
D	0
E	0.9990234375
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week4

A	3.6665
B	0.6665
C	0.0009765625
D	0
E	0.9990234375
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week5

A	3.6665
B	0.6665
C	0.0009765625
D	0
E	0.9990234375
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week6

A	3.3335
B	0.3335
C	0.0009765625
D	0
E	0.9990234375
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week7

A	3.3335
B	0.3335
C	0.0009765625
D	0
E	0.9990234375
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week8

A	3.5
B	0.5
C	0.0009765625
D	0
E	0.9990234375
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Lifting

Week1

A	3.667
B	0.667
C	0.0009765625
D	0
E	0.9990234375
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week2

A	3.667
B	0.667
C	0.0009765625
D	0
E	0.9990234375
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week3

A	3
B	1
C	0.00390625
D	0
E	0.99609375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week4

A	3
B	1
C	0.00390625
D	0
E	0.99609375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week5

A	4
B	1
C	0.0009765625
D	0
E	0.9990234375
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week6

A	2.333
B	0.333
C	0.00390625
D	0
E	0.99609375
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week7

A	2.334
B	0.444889
C	0.00390625
D	0
E	0.99609375
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

The City Apartment Project
Access Scaffolding
Week1

A	4.389
B	0.4445
C	0.000244140625
D	0
E	0.000732421875
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week2

A	4
B	1
C	0.0009765625
D	0
E	0.0029296875
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week3

A	4
B	1
C	0.0009765625
D	0
E	0.0029296875
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week4

A	4.4445
B	0.47225
C	0.000244140625
D	0
E	0.000732421875
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week5

A	4.4445
B	0.47225
C	0.000244140625
D	0
E	0.000732421875
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week6

A	4.5
B	0.5
C	0.000244140625
D	0
E	0.000732421875
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week7

A	3.9334
B	0.9334
C	0.0009765625
D	0
E	0.0029296875
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week8

A	4
B	1
C	0.0009765625
D	0
E	0.0029296875
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week9

A	5
B	1
C	0.000244140625
D	0
E	0.000732421875
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week10

A	4
B	1
C	0.0009765625
D	0
E	0.0029296875
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week11

A	4
B	1
C	0.0009765625
D	0
E	0.0029296875
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week12

A	3.889
B	0.889
C	0.0009765625
D	0
E	0.0029296875
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week13

A	4
B	1
C	0.0009765625
D	0
E	0.0029296875
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Lifting

Week1

A	3.334
B	0.444889
C	0.0009765625
D	0
E	0.0029296875
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week2

A	3.667
B	0.667
C	0.0009765625
D	0
E	0.0029296875
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week3

A	4
B	1
C	0.0009765625
D	0
E	0.0029296875
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week4

A	3
B	1
C	0.00390625
D	0
E	0.01171875
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week5

A	4
B	1
C	0.0009765625
D	0
E	0.0029296875
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week6

A	2
B	1
C	0.015625
D	0
E	0.046875
Z	1
Definition	High Level of Safety
Classification	Most Likely Safe

Week7

A	3.667
B	0.667
C	0.0009765625
D	0
E	0.0029296875
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week8

A	2.667
B	0.667
C	0.00390625
D	0
E	0.01171875
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week9

A	3.667
B	0.667
C	0.0009765625
D	0
E	0.0029296875
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

The Curtin University Project

Concreting

Week1

A	2
B	0.222111
C	0.00390625
D	0
E	0.01171875
Z	1
Definition	High Level of Safety
Classification	Most Likely Unsafe

Week2

A	2.667
B	0.667
C	0.00390625
D	0
E	0.01171875
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week3

A	2.667
B	0.667
C	0.00390625
D	0
E	0.01171875
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week4

A	1.6665
B	0.6665
C	0.015625
D	0
E	0.046875
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week5

A	2.3335
B	0.3335
C	0.00390625
D	0
E	0.01171875
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week6

A	2.3335
B	0.3335
C	0.00390625
D	0
E	0.01171875
Z	1
Definition	High Level of Safety
Classification	Fairly Safe

Week7

A	1.5
B	0.5
C	0.015625
D	0
E	0.046875
Z	1
Definition	High Level of Safety
Classification	Fairly Safe