A Constructability Methodology to Integrate Planning and Design for Workers' Safety in Construction Management

Dissertation

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*) Either the German or the Italian form of the title may be used.

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DEDICATION

This work is dedicated to my father and mother who taught me the value of education, and I am grateful for their love, care, and sacrifices. In spite of the cruel war which forced me to stay away from them for five years, they have my everlasting thanks and unimpeachable loyalty; I hope that I can one day repay them for such love and support. I do not know if I will be able to see them or my death will wait for me on my way to them.

My deep gratitude goes to my husband for his limitless love, support, encouragement, and sacrifices along with me during these years. A lot of thanks go to my little daughter Liana for granting hope and optimism, as well as a desire to continue life and patience with me since her early childhood travel with study and mobility difficulties.

To my brother Tarek wherever he is, I hope that God will keep him for us, to my sister Nada Rasha, and my brother Eyad. I also want to let them know that they are not far, they are in my heart.

To remember my uncle and relatives who were killed in the war, and my cousins who were lost.

To my friends in Syria, to those who were killed or died in this war, or were forced to immigrate. To remember of my friend Nisren (Mermaid) how she died at sea during travel.

To the University of Damascus and the University of Aleppo and to all my colleagues who died in the incident of universities.

With deep pain I greet my wounded homeland, Syria, the holy land blessed by God, the place where the death life meet without borders, where you leave your home and cannot know if will go back.

To the remains of its cities and pieces of bodies and blood blended with its land, to those who died without a grave and ended at sea.

ABSTRACT

A CONSTRUCTABILITY METHODOLOGY TO INTEGRATE PLANNING AND DESIGN FOR WORKERS' SAFETY IN CONSTRUCTION MANAGEMENT

There are two important reasons for accidents resulting in injuries and fatalities on construction sites, i.e. the interference of different activities and the fact that aspects of workers' safety are considered to be only a concern of the construction phase. The main objective of this research was to incorporate a new workers' safety model into the existing critical path method (CPM) which is used as a supplemented tool in the planning and design phases to identify, remove or minimise the risk of accidents.

In a first task the WSiCPM framework (integrating **W**orkers' **S**afety **i**nto **CPM**) was developed. A matrix in the database was automated to analyse all interfering activities and to evaluate potential hazards. Besides the usual qualitative risk assessment based on expert judgment, the probability of an accident is calculated for each pair of interfering activities using new equations depending on parameters such as overlapping duration, overlapping working area, number of workers and type of hazard. The severity of an accident is estimated analogously to the compensation of casualties by insurance companies and is transformed to a monetary value representing the accident cost. In addition, the framework makes suggestions to eliminate or minimise the risk, e.g. by separating the activities spatially or temporally, modifying the path or re-scheduling the activities.

In a second task the concept of 'schedule for safety' was introduced by linking building design for safety (BDS) with CPM. The supplemented BDS can be applied in both the construction and control phases. New safety indicators were derived to assess the level of an accident and the impact on the project cost.

The WSiCPM framework can help to overcome existing deficiencies of workers' safety through the link between schedule and design and between temporal and spatial attributes, and by considering the safety issues in all phases of the project. The example application demonstrates that this can lead to significant improvements in health and safety on construction sites.

Keywords: construction management, design, schedule, workers safety, CPM, BDS, constructability, space-time-conflict, safety indicators.

SOMMARIO

UNA METODOLOGIA DI COSTRUIBILITÀ PER INTEGRARE LA PROGETTAZIONE E LA PIANIFICAZIONE PER LA SICUREZZA DEI LAVORATORI NELLA GESTIONE DELLA COSTRUZIONE

Ci sono due cause importanti di incidente che determinano infortuni, anche mortali, nei cantieri : l'interferenza tra attività diverse e il fatto che gli aspetti della sicurezza dei lavoratori considerati solo nella fase costruttiva. Il principale obiettivo di questa ricerca è di integrare un nuovo modello di sicurezza dei lavoratori all'interno del Critical Path Method (CPM) che è utilizzato come uno strumento supplementare nella programmazione e nella progettazione per identificare e rimuovere o minimizzare il rischio di infortuni. Nel primo stadio è stato sviluppato il framework WSiCPM (integrare la sicurezza dei lavoratori nel CPM). Nel database è stata automatizzata una matrice per analizzare tutte le attività interferenti e per valutare i possibili pericoli. Oltre all'usuale valutazione qualitativa basata sul giudizio degli esperti, nel WSiCPM sono calcolate le probabilità di un accidente per ogni paio di attività interferenti usando equazioni di nuova formulazione. Queste dipendono da parametri quali: la durata di sovrapposizione delle attività, la sovrapposizione di aree di lavoro, il numero di lavoratori ed il tipo di pericolo. La gravità dell'accidente è stimata analogamente alla compensazione adottata dalle compagnie di assicurazione per gli incidentie si trasforma in un valore monetario che rappresenta il costo del incidente. Inoltre, il framework suggerisce soluzioni possibili per eliminare o minimizzare il rischio (e.g. la separazione di attività interferenti temporalmente o spazialmente, la modifica dei percorsi, la riprogrammazione delle attività) . Nel secondo stadio della ricerca viene introdotto il concetto di "programmazione per la sicurezza" collegando il Building Design for Safety (BDS) con il CPM . Sono stati progettati nuovi indicatori di sicurezza per valutare il livello di infortuni e l'impatto di essi sui costi di progetto. Dall'applicazione al caso studio è emerso che il framework WSiCPM può aiutare a superare le criticità della

sicurezza dei lavoratori in cantiere collegando programmazione e progettazione, connettendo caratteristiche spaziali e temporali delle attività e considerando la sicurezza in tutti le fasi del progetto.
Parole chiave: construction management, progetto, programmazione, sicurezza dei lavoratori, CPM, BDS, costruibilità, conflitti spaziali e temporali, indicatori di sicurezza.

ZUSAMMENFASSUNG

EINE BAUBARKEITSMETHODIK ZUR INTEGRATION VON PLANUNG UND ENTWURF FÜR DIE SICHERHEIT DER ARBEITER IM BAUMANAGEMENT

Es gibt zwei wichtige Gründe für Unfälle mit Verletzten und Toten auf Baustellen, das Zusammentreffen verschiedener Arbeiten und die Tatsache, dass Belange der Arbeitssicherheit nur in der Bauphase betrachtet werden. Primäres Ziel dieser Forschungsarbeit war es, ein neues Modell für die Sicherheit der Arbeiter in die vorhandene Kritische-Pfad-Methode (CPM) zu integrieren und dieses erweiterte Werkzeug in der Planungs- und Entwurfsphase zu nutzen, um ein Unfallrisiko zu erkennen und zu beseitigen oder zu minimieren.

In einem ersten Teilvorhaben wurde das WSiCPM System (Integrieren der Sicherheit der Arbeiter in CPM) entwickelt. Eine Matrix in der Datenbasis wurde automatisiert, um überlappende Aktivitäten zu analysieren und potenzielle Gefahren zu ermitteln. Neben der üblichen qualitativen Risikoeinstufung durch Expertenschätzung wird die Wahrscheinlichkeit eines Unfalls bei überlappenden Arbeiten in Abhängigkeit von Parametern wie Überlappungsdauer, Überlappungsbereich, Anzahl der Arbeiter sowie Art der Gefahr berechnet. Die Schwere eines Unfalls wird analog zum Schadenersatz für Todesfälle durch Versicherungen abgeschätzt und in einen Geldbetrag als Maß für die Unfallkosten transformiert. Zusätzlich macht das System Vorschläge zur Beseitigung oder Minimierung des Risikos, z. B. durch räumliche oder zeitliche Trennung, geänderte Abfolge oder neue Terminierung der Arbeiten.

In einem zweiten Teilvorhaben wurde das Konzept des ‘Terminplans für Sicherheit’ durch Verknüpfung von Bauwerksentwurf für Sicherheit (BDS) und Kritische-Pfad-Methode (CPM) eingeführt. Durch Einsatz der ergänzten BDS Software bei der Bauausführung und –überwachung können anhand abgeleiteter Sicherheitsindikatoren die Schwere eines Unfalls und die Auswirkung auf die Projektkosten bewertet werden.

Das WSiCPM System kann helfen, bestehende Defizite bei der Sicherheit der Arbeiter zu überwinden, indem Terminplan und Entwurf sowie zeitliche und räumliche Aspekte verknüpft und Sicherheitsaspekte in allen Projektphasen berücksichtigt werden. Die exemplarische Anwendung des Systems zeigt, dass damit erhebliche Verbesserungen der Gesundheit und Sicherheit auf Baustellen möglich sind.
Stichworte: Baumanagement, Entwurf, Terminplan, Arbeitssicherheit, CPM, BDS, Baubarkeit, Zeit-Raum-Konflikt, Sicherheitsindikator.

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LIST OF ABBREVIATIONS

CPM: Critical Path Method

BDS: Building Design for Safety

PPE: Personal Protective Equipment

BDSiCPM: Observation tool developed in this research

WSiCPM: The framework developed in this research integrating Workers' Safety into

PERT: Program Evaluation Review Technique

VBA: Visual Basic Application

IDEF0: The Integration Definition language 0 for Function Modelling

WBS: Work Breakdown Structure

HSE: Health and Safety Executive

RIDDOR: Reporting of Injuries, Diseases and Dangerous Occurrences Regulations

DEV: Ratio of accident cost to the earned value

DCV: The accident role in the cost variance

PWC: the percentage of work completed

PMBOK: Project Management Body of Knowledge

BCWP: Budgeted cost of work performed or

EV: earned value

BCWS: Budgeted cost of work scheduled

PV: planned value

ACWP: Actual cost of work performed

AC: Actual cost

SV: Schedule variance

CV: Cost variance

CHAPTER 1

INTRODUCTION

1.1 Work related injuries and ill health

The construction industry is globally recognized as one of the most dangerous industries, due to the number of fatalities and serious injuries it directly accounts for. Despite strict legislative control, as well as the attention and caution focused on safety measures, there yet remain a worryingly high number of industry-related accidents on construction sites.

Several charts can provide such numbers, highlighting the extent to which such injuries occur at work sites. These are useful in presenting the dilemma in a simple way highlighting the main concerns.

Due to the significance of such an issue, it is not difficult to find statistical studies on this particular area.

The figures below present some examples of these statistics.

Figure 1-1 shows that in 2013 the standardized rate of incidents at the work place for the building sector is the highest in the industrial sector, according to data from Eurostat (Statistical Office of European Communities).

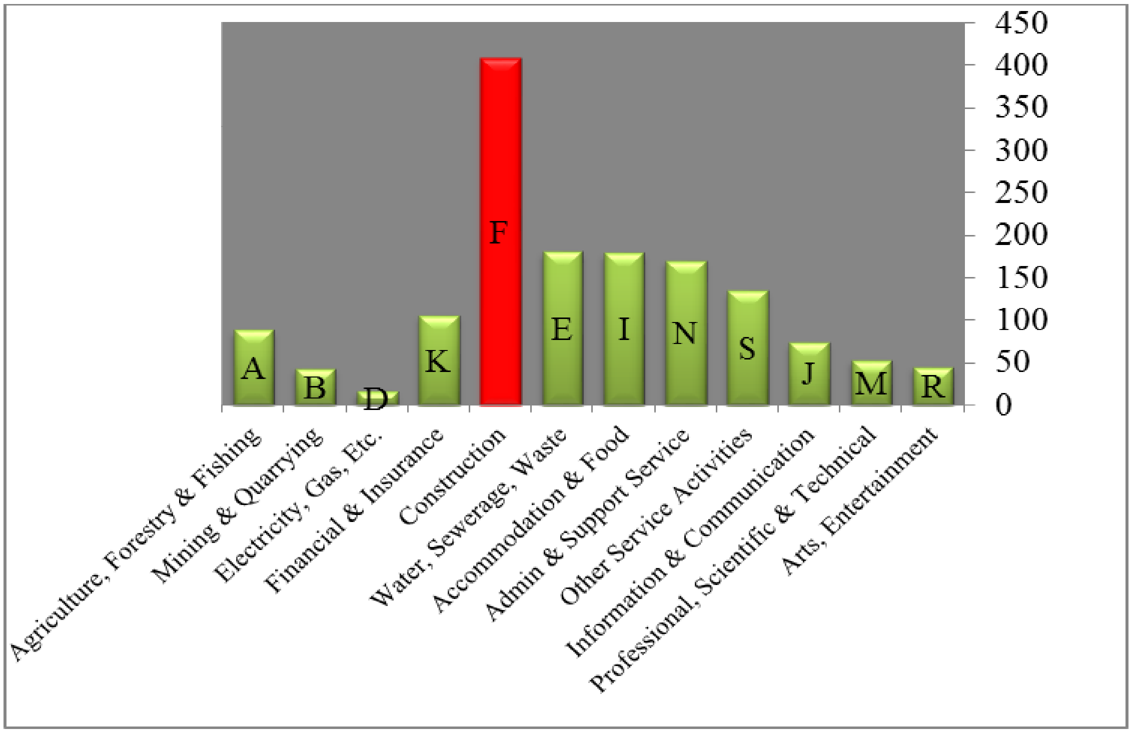


Figure 1-1 Standardized incidence rate of workplace accidents in terms of economic activity injuries reported by economic sector 2013 (HSA), European Union Source: Eurostat

Through choosing the construction industry, figures from Eurostat in 2012 show the number of the accidents in the Figure 1-2 below.

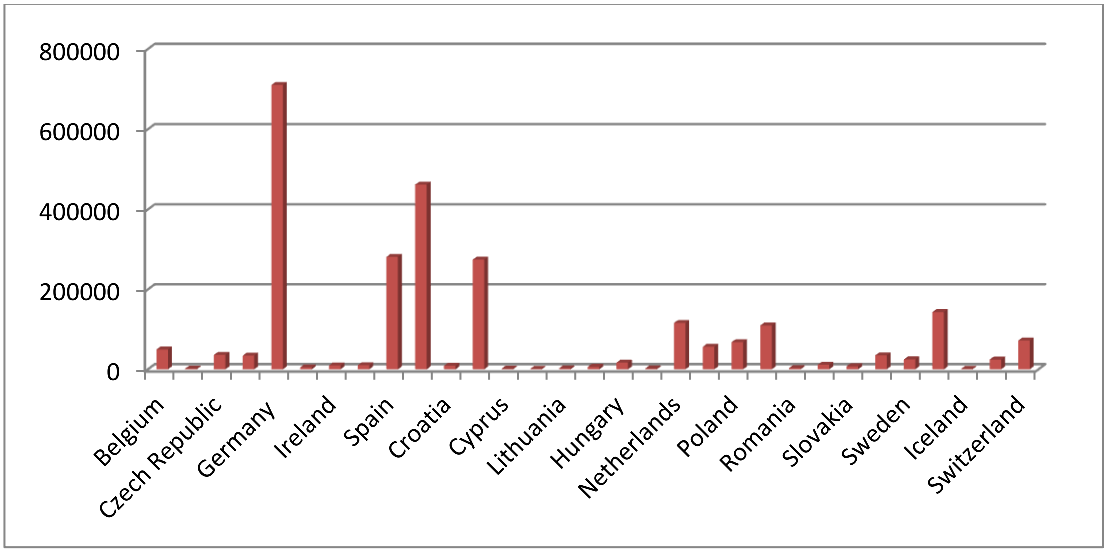


Figure 1-2 Accidents at work by economic activity and type of injury in Europe 2012; Source: Eurostat

In UK, it is highly perceived that there has been a reduction in the number and rates of injuries over the years. However, the construction industry remains the most unsafe industry, see Figure 1-3.

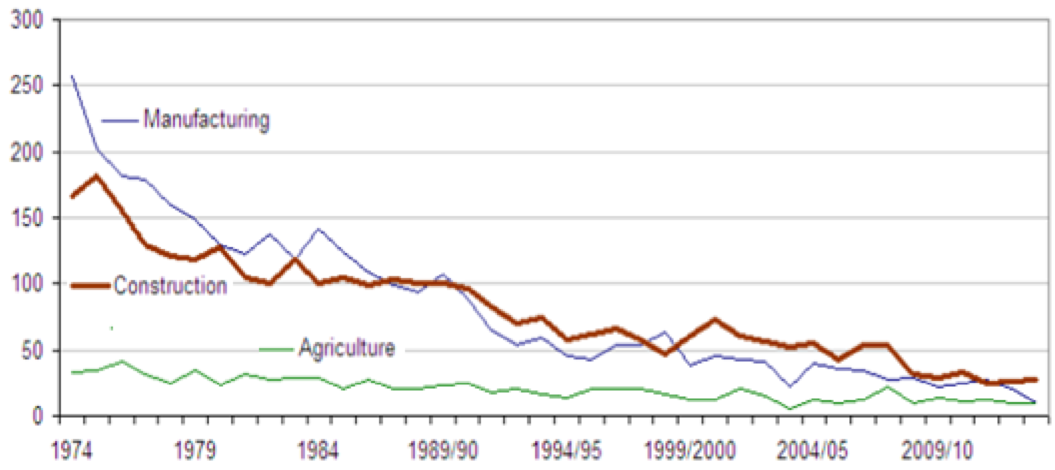


Figure 1-3 Numbers of fatal injuries to employees (RIDDOR) 1974 to 2013/14p

The following statistics are available online at

http://www.hse.gov.uk/statistics/industry/construction/

In the USA, the fatality and injury rates can be seen in Figure 1-4, on an average from 1951-2008.

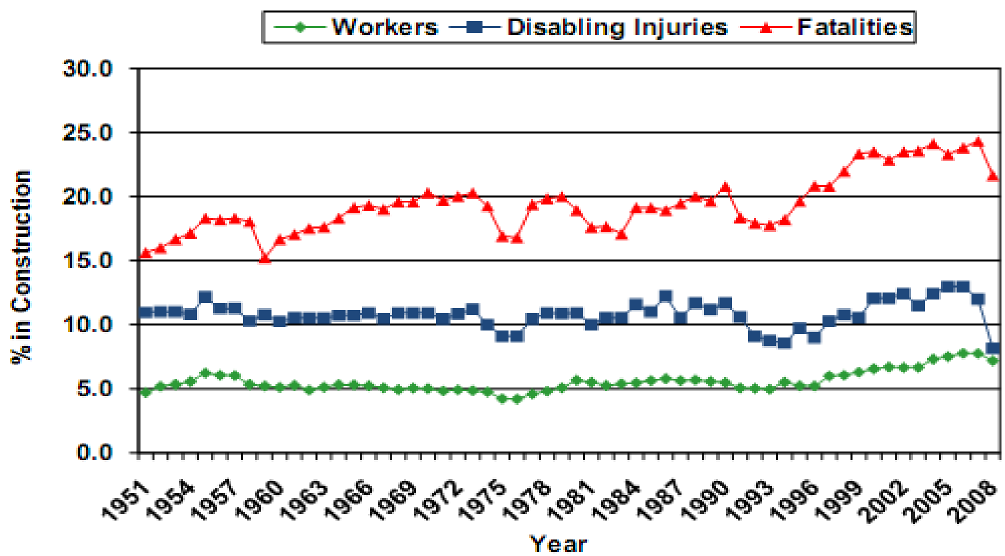


Figure 1-4 Construction workers fatalities, and disabling injuries as a percentage of total U.S. Workforces (Source: "Injury Facts", National Safety Council, 1952-2010)

It seems evident that implementing strict legal control on the matter is not sufficient to eliminate the risk of accidents. The Figures above show that the safety of workers is neither improved drastically nor fully guaranteed through the imposition of such legal measures.

Personal experience in Syria as a project manager in the construction industry presented a first-hand account of such an incidence. A sad recalling of what has occurred was that a paint worker's clothing had suddenly caught fire, resulting in severe burns. The cause of this was that the worker had been working with flammable material while electrical works were running nearby. What made the situation more shocking was that the burns were left untreated. This incident was the main instigator of my personal incentive to resolve the time-space-conflict through research.

One of the main problems through personal experience concerns the safety drawings. These were ordinarily completed in the design phase of a project before the construction phase, yet they were not updated. Consequently, the changes and adjustments during implementation were not taken into account. To add, the as built drawings were not drawn until completion, for the purpose of maintenance and building safety, not for the sake of workers' safety.

This research attempts to guarantee workers' safety on construction sites by improving project management, which in turn refines and deal with safety issues in scheduling, planning, and design.

1.2 The problem of the research

It seems evident from research studies that the workers' safety issues are not well- considered in design, planning, and scheduling. They are often believed to be the concern of the site and contracts, not the planners and designers.

Many researchers emphasize that the lack of space and overcrowding are the most significant causes of accidents on construction sites. The schedule is a vital factor affecting the safety on construction sites, but they are still as 'after-the-fact approach' researches.

It is apparent from research studies that there is a lack of integration in both temporal and spatial attributes in the safety of design tools, since common analysis approaches ignore the temporal attributes.

Another valid point to note is that we can find many researches in design for safety, nevertheless the concept of scheduling for safety is a rare topic of research.

1.3 The objective of the research

The key objective of this research is to eliminate or significantly reduce safety risks on construction sites. This can be achieved through improving the project management, while also considering the safety in design, planning, and scheduling phases. In other words, to develop an integrated framework that involves the measures of workers' safety into the plan, design, and all other project phases.

The main objective of the research is

- To develop a framework to integrate the workers' safety concept into the Critical Path Method (CPM).

The main objective can be achieved through the following sub objectives:

- Automate a framework to determine the space-time overlay hazard, which also has the potential to suggest a solution for each space-time-conflict.
    - Create a simple database allowing information transfer between the schedule and safety in design tools, as shown in
    - Figure 1-6,Detect the space-time-conflicts that affect the workers' safety,
    - Evaluate the probability and severity of expected accidents, qualitatively and quantitatively, while assessing risks in the overall project,
    - Suggest a reasonable solution for each space-time-conflict hazardous situation,
- Improve safety in schedule and in design.
    - Schedule for safety (baseline schedule),
    - Improve the schedule - design tools to implement safety control throughout the project, as well as reviewing safety measures on construction sites,
    - Implement safety tracking in CPM throughout the project by developing several safety indicators, which depend on the cost of the accident, delay in time, etc.,
    - Use these indicators to evaluate the failure of safety measures on construction site and in safety design.

An algorithm has been established to achieve the objectives mentioned above; the processes are defined through the construction process modelling (IDEF0).

MS Project, MS Access, and VBA (Visual Basic Application) are used to implement this framework; MS Project is used as a scheduling tool. Using MS Project allows the schedule analysis function to thoroughly integrate with other Office programs and purposes. MS Access is used to create the database. The VBA in the environment of MS Access and MS Project is used to implement the schedule analysis and cost calculation modules and to integrate the different components of the framework.

1.4 Main subjects related to the scope of the research

Main subjects related to the scope of the research are listed below:

1. Buildability as a construction knowledge tool,
2. Safety in design tools,
3. Relationship between safety, planning, scheduling, and project management,
4. Relationship between (time –space) planning and design,
5. The impact of congestions, overlaps, and space- time conflicts on attaining workers' safety,
6. Construction process modelling.

This research is faced with four difficulties, which are generally deemed separate:

- The lack of integration of safety into scheduling,
- The lack of integration of design into scheduling,
- The lack of integration of safety into the design phase and construction process,
- The lack of integration of constructability with the fields above.

1.5 Research methodology

1.5.1 *The steps of the research*

The research methodology is made up of seven main steps:

- ❑ *STEP 1: Existing safety in design constructability tools, scheduling techniques,* and analysing methodologies

  The purpose of this literature review is to clarify the fundamental concepts used in existing safety design constructability tools and scheduling techniques. Also, assessing how these tools and techniques could be incorporated for a more feasible design, planning and schedule for the purpose of achieving workers' safety on construction sites.

  The literature review is in regards to the following fields:

  - Buildability and constructability,

- Safety on construction sites,
- Safety in design tools,
- Construction management and planning,
- Scheduling techniques,

❑ *STEP 2: Gaps in planning and safety in design tools*

- Investigating any current gaps in planning techniques,
- Investigating any current gaps in the existing safety measure in design tools,

❑ *STEP 3: Analysing and studying issues*

- Study the project operation and the relationship between scheduling and workers' safety,
- Analysing potential space-time-conflicts,
- Analysing the exchange of information between the safety in design tool and schedule, as shown in
- Figure 1-6.

❑ *STEP 4: Development of the WSiCPM (addressing workers' safety into CPM* method) framework as it can be seen in the next paragraph Figure 1-5

❑ *STEP 5: Integration of safety in scheduling and BDS tools*

- Safety within the schedule (baseline schedule),
- (BDS a CPM) safety control tool,
- Safety tracking,
- Safety indicators,

❑ *STEP 6: Examples of applying the method*

❑ *STEP 7: Conclusion and recommendations*

1.5.2 ***The structure of the proposed framework on addressing safety in CPM***

In Figure 1-5 a diagram explaining the structure of the proposed framework is depicted while in Figure 1-6 the model of the database is shown.

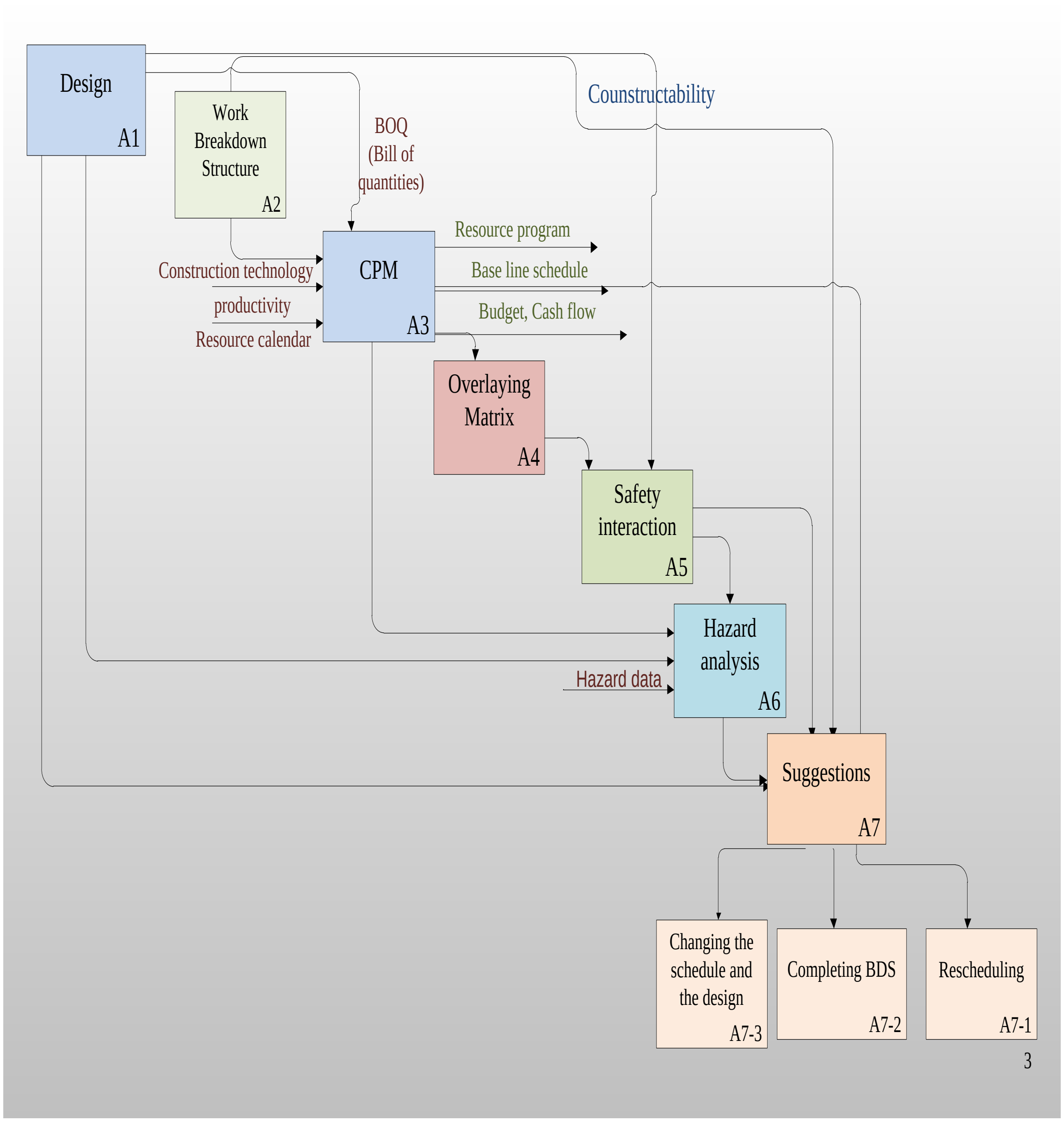


Figure 1-5 Proposed framework for the integration of a workers' safety concept into CPM (described by IDEF0)

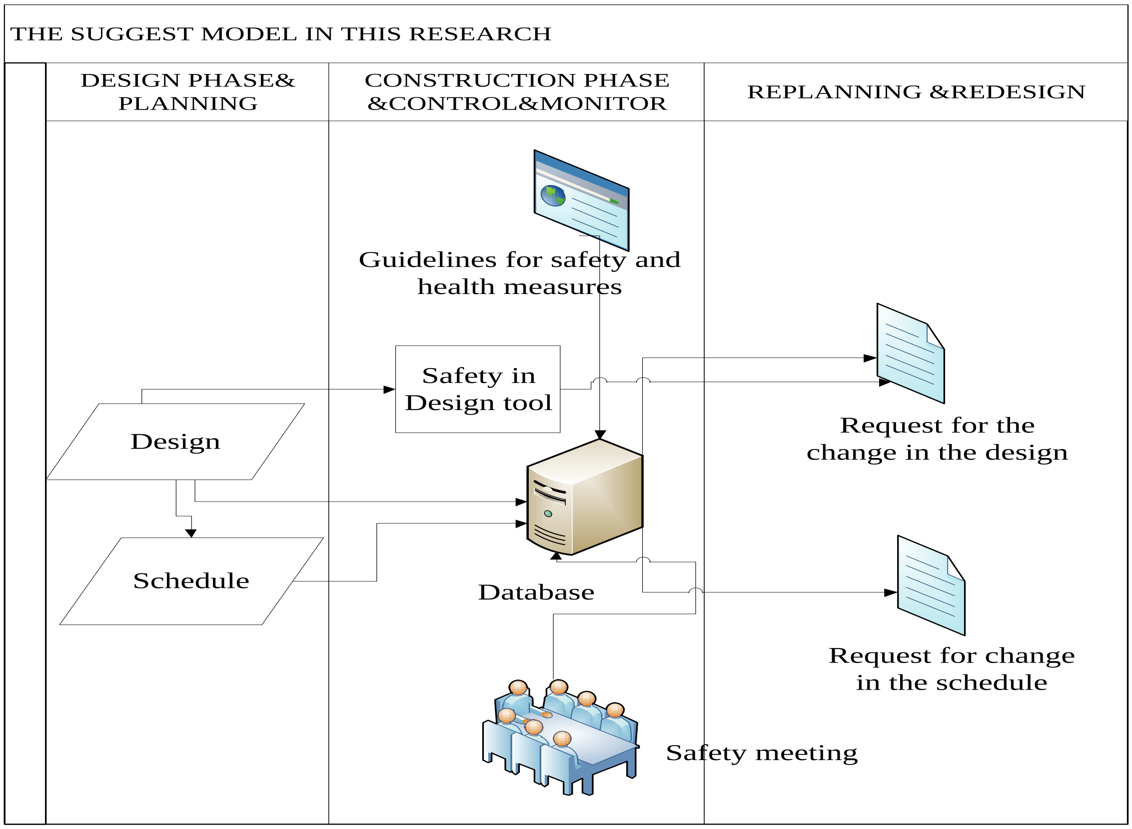


Figure 1-6 Proposed model of the database

1.6 Guide to the research

This thesis has been divided into 7 Chapters covering the seven phases of the research.

Chapter 1 provides a general introduction to the research, while presenting the aims and objectives of the work. It also defines the methodology applied in this research and presents a guide to the thesis.

Chapter 2 begins with a review of definitions, concepts and principles of buildability and constructability while providing a review of health and safety research in construction. It continues on to examine and analyse the existing safety in design tools, providing a close assessment of such tools. Key points for the improvement of the research through the integration of the design with construction planning are discussed, also the ability of these tools are dissected and incorporated with the schedule. Thus, the idea of a framework to consider workers' safety in the design and schedule is proposed.

Chapter 3 initially presents a review of existing planning techniques, as well as providing an in-depth investigation of current practice and problems in construction planning, while analysing these techniques in depth, and their ability to cover the issues of worker safety. Therefore, the CPM (Critical Path Method) technique is found to be the most suitable technique in achieving the objectives of this research. A review of existing planning process models and modelling techniques is presented, IDEF0 is defined to identify the appropriate modelling technique for demonstrating the construction planning process for the purpose of this research.

Chapter 4 introduces the WSiCPM framework, clarifying its methodology then presents general steps of the CPM method. The probability and severity of predicted accidents have been discussed qualitatively and quantitatively, introducing a new theory to calculate the probability and severity of the predicted accidents. In addition, a method is proposed to help the planner to decide where changes are necessary.

Chapter 5 presents important rules for baseline scheduling of safety. It covers the important gap of integrating the design with the schedule by linking BDS graphic method with the schedule. Thereby giving the method its ability to be scheduled, tracked, and controlled. It then presents an integration of short time planning-design method (BDSiCPM) to control the safety progress and the BDS performance in the site. This allows an observation of BDS, then it suggests some indicators to control safety in the site, such indicators could also be used to review the failure in safety measures and safety in design

Chapter 6 introduces the application of the generic model through an example, aiming to prove that it is fully functional, and then the advantage of this model compared to the previous methods is discussed.

Chapter 7 concludes the thesis, summarizing its research contributions, and describing its limitations. Suggestions for future researches are also given in this chapter.

CHAPTER 2

SAFETY IN DESIGN EXISTING TOOLS

2.1 Buildability and constructability

2.1.1 *Definitions of buildability*

Buildability is a large area of study in the field of construction technology in the construction industry which involves a lot of researchers and organizations. Thus, several definitions of buildability have been introduced. However, the commonly used definition derives from the Construction Industry Research and Information Association (CIRIA), which states that "*buildability is the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building*".

Other definitions of buildability are listed below:

Ferguson (1989) stated that buildability is *"the ability to construct a building efficiently, economically and to agreed quality levels from its constituent materials, components and sub-assemblies"*.

Chen et al., 1991 referred to buildability as *"the extent to which decisions are made during the whole building procurement process, in response to factors influencing the project and other project goals, ultimately facilitating the ease of construction and the quality of the completed project"*.

Several researches detected that all of the definitions of buildability share the three common themes:

- Designing for ease of construction,
- A holistic view of the building
- Building performance over time is directly related to user and environment requirements.

The general concept of buildability is described by several researches shown in Figure 2-1. This figure reflects the importance of taking buildability into consideration at an early stage in the total construction process, since the ability to influence the project triangle (time, cost, quality) and safety is greater at an early phase of the project.

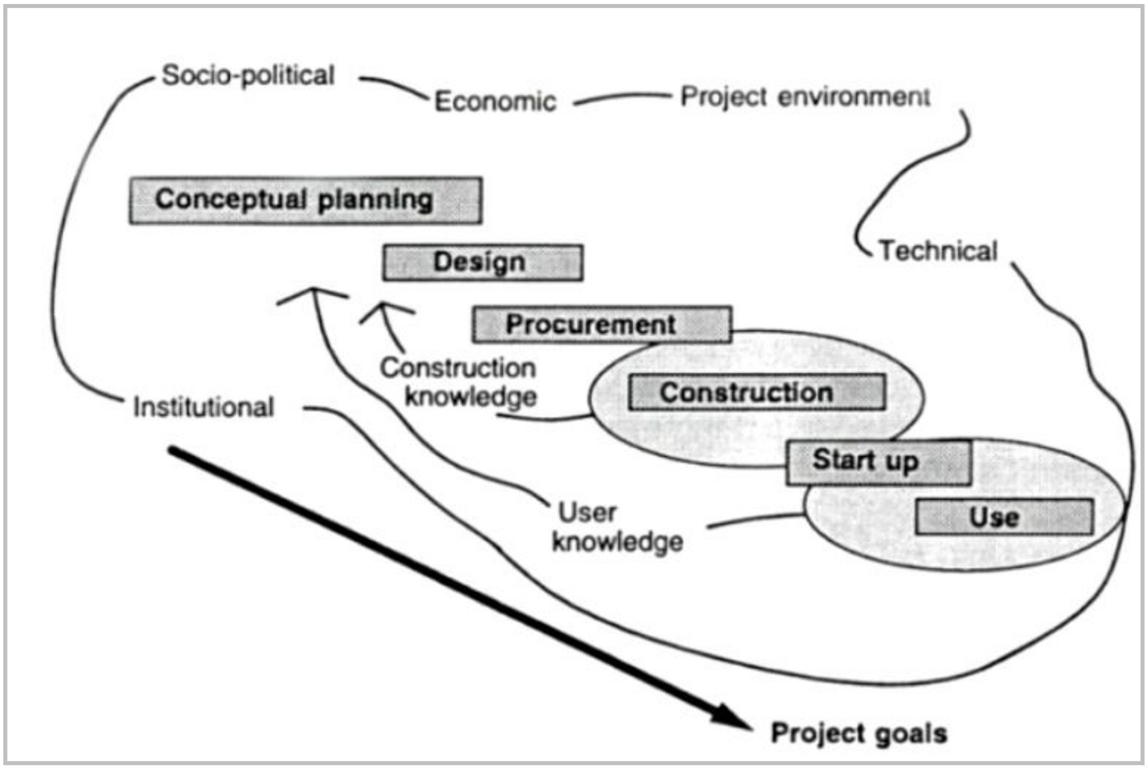


Figure 2-1 Buildability in a wider framework (International Journal of Sustainable Construction Engineering & Technology, June 2011)

2.1.2 *Definitions of constructability*

Constructability has been defined in various ways, the most common of which was established by the Constructability Task Force of the CII in (1986) and defined as follows: *"constructability is the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives"*.

Another important definition was introduced by the Construction Industry Institute in Australia CII Australia (1996) which described it as "*the integration of construction knowledge in the project delivery process and balancing the various project and environmental constraints to achieve the project goals and building performance at an optimum level*".

This was later modified by Griffith and Sidwell (1997) as *"a system for achieving optimum integration of construction knowledge in the building process, and balancing the various project and environmental constraints to achieve maximization of project goals and building performance".*

Arditi (2002) referred to constructability as *"programs aimed at integrating engineering, construction, operation knowledge, and experience to better achieve project objectives."*

2.1.3 *The difference between buildability and constructability*

Buildability is a design concept while constructability is a concept for the whole project process. Although constructability and buildability are interchangeable, many researchers believed that the two concepts are identical, except that buildability is typically used in the UK while constructability is usually used in the USA.

However, we follow researchers who consider constructability as significantly different from buildability in terms of its substantially wider boundaries, (Griffith and Sidwell, 1997).

- Buildability refers to the extent to which a building design facilitates the ease of construction, whilst clients' requirements are met. It therefore focuses on the design of a building
- Constructability, which embraces both design and management functions, is concerned with a wider scope than 'buildability'. It deals with the project

management systems which optimally use construction knowledge and experience to enhance efficiency of project delivery.

We can express the difference in a simpler way: buildability is a design concept while constructability is a concept for the whole process of a project.

2.1.4 *Comparison of the attributes in the studies of buildability in various countries*

We can recognize in Table 2:1, that the workers' safety concept is essentially ignored, even if it was implicitly stated in several ways, e.g. the attribute "less work underground" leads to safer work. Also, the effective site layout, simple installations and maximizing prefabrication have a positive impact on workers' safety.

In addition, it is mentioned that in high-rise buildings, the designers should study the impact of the design solution on the workers' safety during the delivery of materials.

This table also emphasizes the idea that the construction industry is known for its lack of integration of the design, planning and construction phase, as we have previously mentioned.

Table 2-1 Comparison of buildability attributes in different countries, modified from (Patrick T. I. Lam et al., 2005)

Studies on Buildability in various countries															
Comparison of buildability attributes as identified by researchers in different countries															
Attributes	**CIRIA 1983**	**CIRIA 1985**	**Adam 1989**	**Fergu- 1989**	**CII 1986**	**CII Concept**	**Hon 1988**	**CII Australia**	**Moore 1998**	**Singa- BDAS 2000**	**CIRC Report**	**NIAM 2001**	**TAM 2007**	**Ganah 2000**	**LAM et al 2006**
Less Work Below Ground			√	√											
Provide Clear and Complete Design Information															√
Construction Methods					√	√	√								
Simple Detailing			√	√			√								
Allow Flexibility		√				√	√								
Optimize Labour/Skills Usage			√	√		√	√	√							
Optimize Materials Usage	√	√	√	√		√	√	√							
Optimize Equipment Usage			√	√		√		√							
Maximize Prefabrication						√				√	√		√		
Maximize Standardization	√		√			√	√		√	√	√				
Consider workers Safety															
Consider Construction Sequence	√	√	√	√		√									√
Simple Installation	√	√		√		√	√		√	√	√				√
Effective Site Layout	√		√	√	√	√						√			√
Sufficient Tolerance	√	√	√				√								
Consider Construction Methods					√	√									
Consider Impact of Weath- er			√												
Employ Visualization Tools														√	
Encourage Sustainable Construction													√		
Minimize/Avoid Return Visit															
Consider Innova- tive/efficient					√	√									
Provide Clear &Complete Design Information															√
Integration							√			√					

2.1.5 *Buildability principles*

Every researcher and organization has determined their own principles of build-ability from a subjective point of view. Although they rely on the findings of their own research approach, the main concepts of these principles remain fundamentally similar.

CIRIA pinpointed seven principles of buildability:

- Carry out thorough investigation and design,
- Plan for essential site production requirements,
- Plan for a practical sequence of building operations and early enclosure,
- Plan for simplicity of assembly and logical trade sequences,
- Detail for maximum repetition and standardization,
- Detail for achievable tolerances,
- Specify robust and suitable materials.

John A. Gambatese, et al. (2005) have introduced these principles in a simple manner:

- Integration,
- Construction knowledge,
- Team skills,
- Corporate objectives,
- Available resources,
- External factors,
- Programmer,
- Construction methodology,
- Accessibility,
- Specifications,
- Construction innovation,
- Feedback.

2.1.6 *Constructability concepts and attributes*

The Construction Industry Institute (CII CIRIA, 1983; Tatum, 1987; Adams, 1989; CII, 1993; CIIA, 1993; Nima et al., 1999), and finally Nima (2001) have developed 23 constructability concepts:

2.1.6.1 Constructability enhancement concepts during conceptual planning phases of the project C1 to C7

Concept C1: The project of the constructability program should be discussed and documented within the project execution plan, as well as the participation of all the project team members.

Concept C2: A project team that includes a representation of the owner, the engineer, and the contractor should be formulated and maintained to consider the constructability issue from the outset of the project, and through its other phases.

Concept C3: Individuals possessing knowledge and experience of modern construction should achieve the early project planning so that any interference between design and construction can be avoided.

Concept C4: The construction methods should be taken into consideration when choosing the type and the number of contracts required for executing the project.

Concept C5: The master project schedule and the construction completion date should be construction-sensitive and be assigned as early as possible.

Concept C6*:* In order to accomplish the field operations easily and efficiently, major construction methods should be discussed and analysed in-depth as early as possible to direct the design according to such methods.

Concept C7: Site layout should be studied carefully to allow construction, operation and maintenance to be performed efficiently, and avoid interference between the activities performed during these phases

2.1.6.2 Constructability enhancement concepts during design and procurement phases of the project C8 to C15:

Concept C8: Design and procurement schedules should be dictated through the construction sequence. Thus, the construction schedule must be discussed and developed prior to the design development and procurement schedule.

Concept C9: Advanced information technologies are essential to any field, including the construction industry. Hence, the use of those technologies will overcome the problem of fragmentation into specialized roles in the field, and enhance constructability.

Concept C10: Designing through design simplification, and design review by a qualified construction personnel must be configured to enable efficient construction.

Concept C11: Project elements should be standardized to an extent that prevents any costs from being negatively affected.

Concept C12: The project's technical specifications should be simplified and configured to achieve efficient construction, without reducing the level or efficiency of the project performance.

Concept C13: The implementation of modularization and preassembly of project elements should be taken into consideration and studied carefully. Modularization and preassembly design should be equipped to facilitate fabrication, transportation, and installations.

Concept C14: Project design should consider the accessibility of construction personnel, materials, and equipment to the allocated position inside the site.

Concept C15: Design should facilitate construction during adverse weather conditions. Efforts should also be made to plan for the construction of the project under suitable weather conditions. Otherwise, the designer must increase the project elements that could be fabricated in workshops.

2.1.6.3 Constructability enhancement during field operation phases of the project C16– C23

Concept C16: Field task sequencing should be configured in order to minimize damages or rework some project elements, while also minimizing scaffolding needs, formwork used or congestion of construction personnel, material, and equipment.

Concept C17: Innovation in temporary construction materials/systems, or implementing innovative ways of using available temporary construction materials/systems that have not been defined or limited by the design drawings and technical specifications. Such actions will deliver a positive contribution to the enhancement of constructability.

Concept C18: Incorporating new methods of innovation through the use of off-the-shelf hand tools or modifying available tools. Furthermore, the introduction of new hand tools can reduce labour intensity, increase mobility, safety or accessibility which will consequently enhance constructability at the construction phase.

Concept C19: The introduction of innovative methods for using or modifying the available equipment to increase their productivity will lead to improved constructability.

Concept C20: To increase productivity you must reduce the need for scaffolding, or improve the project constructability under adverse weather conditions, while constructors should be encouraged to use any optional preassembly.

Concept C21: Constructability will be enhanced by encouraging the constructor to carry out the innovation of temporary facilities.

Concept C22: Good contractors, based on quality and time of their work should be documented. Subsequently, future contracts for construction work would not solely be awarded based on low bids, but also by considering other attributes, i.e. quality and time.

Concept C23: Evaluation, documentation and feedback of the issues of constructability concepts should be maintained throughout the project and used in later projects as learned lessons.

2.1.7 *Advantages of improving buildability*

Many benefits of improving buildability on the time, cost, quality, and safety of the project have been emphasized by numerous studies all over the world. Some of these benefits are summarized in Table 2-2.

Table 2-2 Advantages of improving buildability in the literature review

	The advantage of improving buildability	References
Design	Get better design; enable the use of the open building system, and the use modular design.	CIRIA 1983;Hon 1988; Adams 1989; Francis, et al. (1999); Jergeas and Put (2001); Trigun-arsyah (2004).
Cost	Reduce the cost; get a greater saving in the cost of the changes; get a great saving in the cost of construction bids.	Francis, et al. (1999); Jergeas (2001); Law (2001).
Safety	Reduce the risks, and enhance building safety.	Adams 1989 ;Francis, et al. (1999); Low and Abeyegoonasekera (2001);
Workers safety	It is mentioned in other attrib-utes, like less work underground	
Quality	Improve the quality of the project performance.	CIRIA 1983; Hon 1988; Francis, et al. (1999); Low and Abeyegoonasekera (2001); Trigunarsyah (2004).
Team	Enhance the cooperation among the project team, improve the work relationship, and increase job satisfaction.	Francis, et al. (1999); Low (2001).
Communication	Improve the communication in the project	Low (2001); Eldin (1999).
Management	Improve site management, and enable a success management	Low (2001); Trigunarsyah (2004).
Planning	Get better construction plan-ning and better resource utilization.	Chan (1999); Eldin (1999); Francis, et al. (1999); Low (2001).
Feedback	Provide a feedback for upcom-ing projects.	Chan (1999).
Productivity	Get better productivity levels.	Chan (1999); Eldin (1999); Francis, et al. (1999); Low (2001).

2.2 Construction health and safety

2.2.1 *Research in construction health and safety*

The safety in construction is one of the most significant concerns in the construction industry. This has been made clear by numerous research publications, and law papers. We attempt to review some of them which examine the factors related to the fundamental problems.

2.2.2 *Causes and factors of the accidents*

Many researchers confirm that multiple reasons would create an accident, in other words, the accident is unplanned and occurs when several factors concur simultaneously in a specific way.

Through studying Figure 2-2 (introduced by Health and Safety Executive 2003) we can see that an accident could occur because of an unplanned interaction. This interaction would be between two or more factors occurring at the same space-time, or a failure in other factors. These factors could be the materials, equipment, workplace, design, or the workers themselves etc., while failure could be in the personal protection equipment, or in the design, etc.

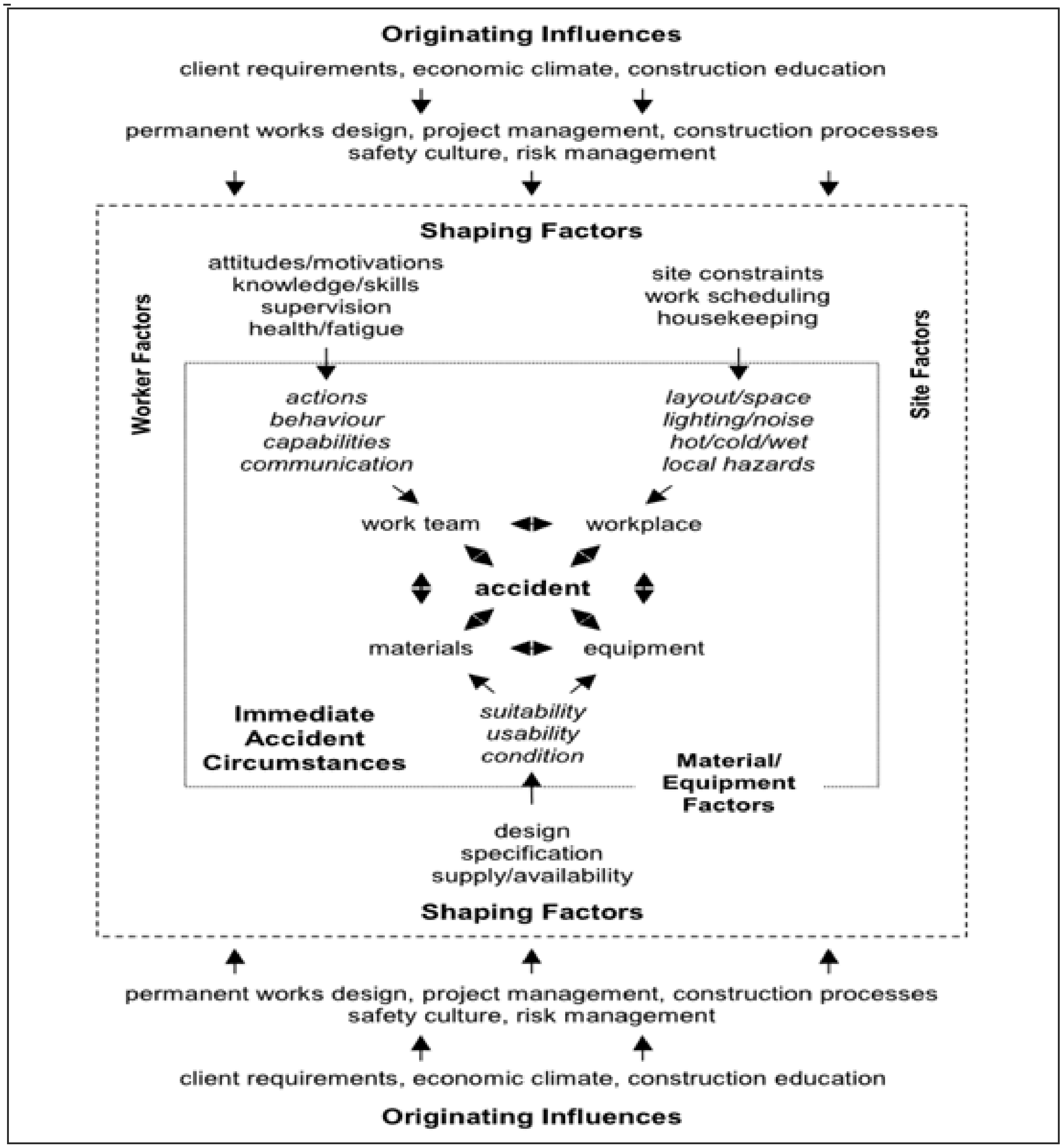


Figure 2-2 Hierarchy of influences in construction accidents, after R. A. Haslam, et al. (2003)

In this figure, we can also clearly see that overcrowding at the workplace could potentially lead to an accident, even if the accident had not occurred due to a quick reaction.
In 2003, Health and Safety Executive research report number 156 prepared by Loughborough University and UMIST, states that conflicts within the workplace are the leading instigator and cause of accidents.

2.2.3 *Most frequent causes of death in construction industry*

After examining numerous reports, articles, researches we can conclude that the most common cause of deaths in construction industry are:

- Fall from height – roof,
- Fall from step ladder,
- Fall from height roof lights,
- Falling through fragile roofs and roof lights,
- Fall from height scaffold,
- Fall from height - moveable platform,
- Falling into the digging,
- Falling at the same level,
- Contact with falling objects,
- Being struck by moving vehicle,
- Being struck by excavators, lift tricks or dumpers,
- Lifting forks,
- Digging works,
- Being crushed by collapsing structures,
- In the vehicle with loss of control,
- Overturning vehicles,
- Contact with electricity,
- Cut by an equipment,
- Cut with knife, cutting board,
- Contact with hanging objects,
- Diving in liquid,
- Chemicals materials,
- Flammable materials,
- Contact with moving parts of machine,
- Fire,
- Buried by bulk mass.

2.2.4 *Interrelationship among the variables that affect the safety management on the construction site*

John P. Spillane, et al. 2011 examined several case studies and individual interviews, after which they determined three principal issues which are the primary factors affecting workers' health and safety on construction sites:

- Lack of space,
- Problem of coordination and management of site personnel,
- Overcrowding of workplace.

The causal loops diagram presented in Figure 2-4 clarifies the various variables they found.

This confirms the idea that the lack of space and overcrowding are the leading causes of accidents on construction site, which stresses the importance of this type of research.

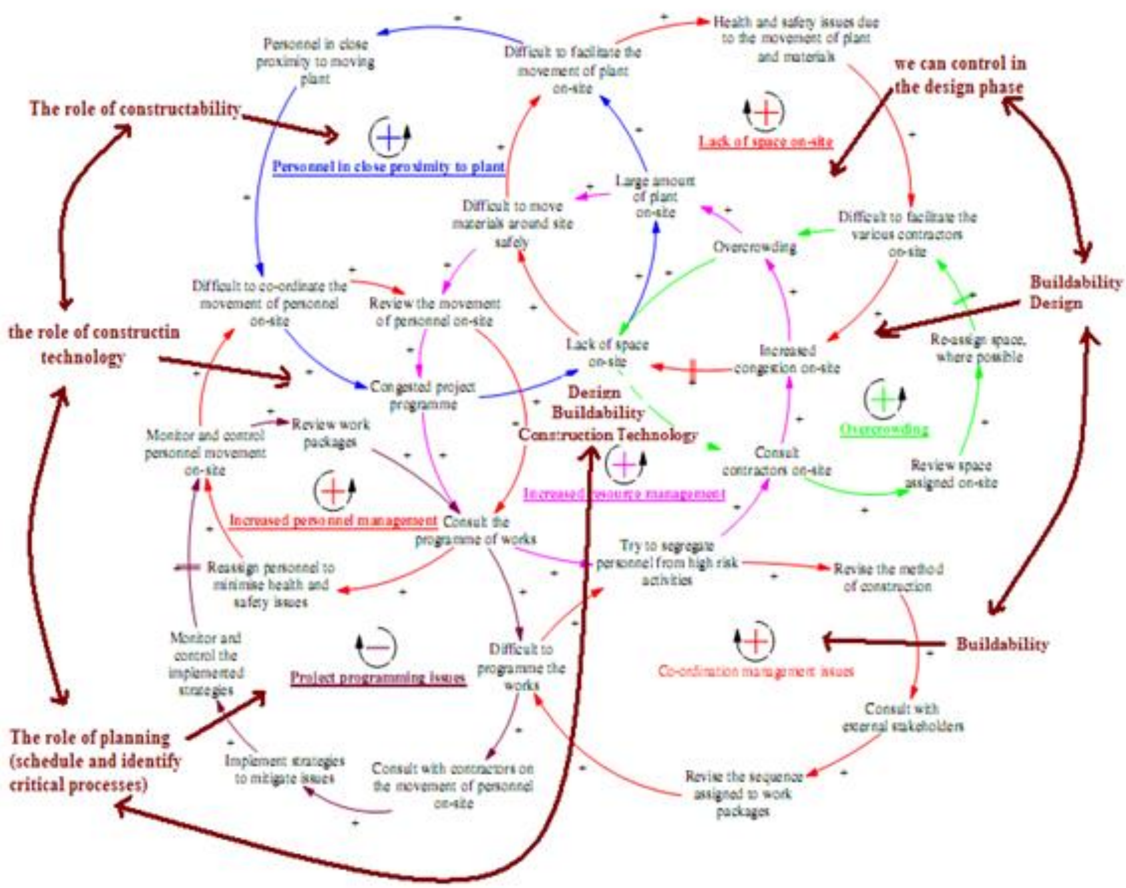


Figure 2-4 Modified Causal Loop Diagram, showing interrelationships among the variables, based on John P. Spillane, et al.

This figure has been modified to represent the relationship with the key principles of this research, and to confirm the three issues causing accidents.

2.3 Review of some existing safety in design tools

After collecting the data and analysing the tools which have been used in the literature, some of these tools have been extracted below:

Prevention through Design (PtD): Prevention through design (PtD) is a process or concept used to control and to prevent occupational injuries, illnesses, and fatalities. It is also used to reduce work-place safety risks and reduce workers' reliance on personal protective equipment. (NIOSH, the National Institute for Safety and Health)

Safety through design (StD): Safety through design (StD) is identified as the integration of hazard identification and risk assessment methods early in the design process. This is used to eliminate or minimize the risks of injury throughout the life of the product being designed. It encompasses all the design including facilities, hardware, systems, equipment, products, tooling, materials, energy controls, layout, and configuration.

Design for Safety (DfS): (Manuele, 1997) expressed that *"designing for construction safety as an intervention is supported by the hierarchy of controls common to the safety and health professions which identifies designing to eliminate or avoid hazards as the preferable means for reducing risk*".

CHPtD: Construction hazard prevention through design (CHPtD) is identified as "*a process in which the architectures and engineers take into account the safety of workers in construction sites during the design phase*", (Gambatese J., and Toole. T. M., 2008).

Construction Design Management (CDM): Construction design management (CDM) is a set of regulations established by the United Kingdom in the EU Directive 92/57/EEC (OJ L245, 26.8.92). These regulations allocate specific duties on designers, clients, and contractors. These duties were established to ensure that all individuals involved in the construction project recognized their responsibility to health and safety.

Design for Safety-Process (DFSP): The design for safety process (DFSP) tool uses three-dimensional building models. It applies virtual reality and database technologies that assist users in identifying potential construction safety risks in the design during the construction stage. These models allow all project members to walk through the construction stage as it is being virtually built.

Computer-Aided Design (CAD): Design visualization by computer-aided design (CAD) is a helpful tool for addressing workers' safety in the design phase of the project. The CAD software simplifies visualizing the design in the three dimensions to highlight the design, conflicts, and space issues. Following the activities in the CAD drawings, it is vital to determine the impact of construction activities on the workers' safety, (Gambatese, 2004).

3D modelling*:* Bergsten (2001) illustrated that *"3D model is a static model, built in the computer for representing the building. However it is a problem when it comes to health and safety management at the design phase, 3D is not a model where workers and sub-contractors could contribute optimally as the 3D model does not allow the visualization of a dynamic construction workplace".*

4D modelling: 4D CAD is a technology depending on the integration of the 3D CAD model with the schedule.

BIM: Building Information Modelling (BIM) is a 3-dimensional model, which allows a design of the complete building with all its details.

Virtual reality (VR): Hadikusumo and Rowlinsson (2002) and Rowlinsson (2003) suggest the use of VR to assist safety analysis.

ToolSHeD: The ToolSHed system uses health and safety regulations for risk analysis.

CIB: A manual code used earlier in 1997.

2.4 Discussion of existing safety in design tools which could be linked to the framework of this research

2.4.1 *Construction Hazard Assessment Implication Review (CHAIR)*

2.4.1.1 CHAIR definition

CHAIR was identified as a tool to enable better safety awareness and solutions. This tool is used to improve safety and construction through identifying potential hazards in a coordinated approach by all stakeholders.

2.4.1.2 The CHAIR process

CHAIR study aims to achieve workability, aesthetic, economic, and maintainability, as well as the safety and constructability in the final design.

The CHAIR process is completed through three steps (Behm et al. 2008):

- CHAIR 1: review of design concept,
- CHAIR 2: review of design details,
- CHAIR 3: review of design of the maintenance.

CHAIR 2 must be defined since it could potentially be linked to the framework produced in this research, therefore it must be done in the pre-planning stage.

2.4.1.3 The CHAIR 2 design review

This review aims to determine potential safety hazards in the design. This may require design modifications or additional measures.

2.4.1.4 A CHAIR 2 methodology

The main points of the CHAIR 2 methodology as they have been presented in the same reference are:

- The construction sequence has to be divided into logical steps to facilitate its analysis.
- For each step, the sources and factors of the risks have to be identified.
- The risks and their controls have to be assessed to improve the design and choose a suitable construction method.

2.4.2 *CII Design for Construction Safety Toolbox*

The Design for Construction Safety Toolbox is a versatile software package developed by CII. This software contains a database with several proposed safety measures in design, which could be implemented during the pre-planning and design phases of the project.

This tool could be an additional source of the proposed safety measures of the change request of the design, and an important source for identifying the hazardous area for every activity, as it focuses on the safety dimensions.

2.4.3 *Design for Construction Safety (DfCS)*

2.4.3.1 Definition

DfCS is defined as "*the deliberate consideration of construction site safety in the design phase of a construction project, with the goal of reducing inherent risk to construction workers*". (Toole, 2007)

2.4.3.2 Designing for construction process

DfCS Designing for construction safety ensures the constructability review, safety measures of the project, and reassures that the design decisions take health and safety of the workers into consideration, in addition to other objectives.

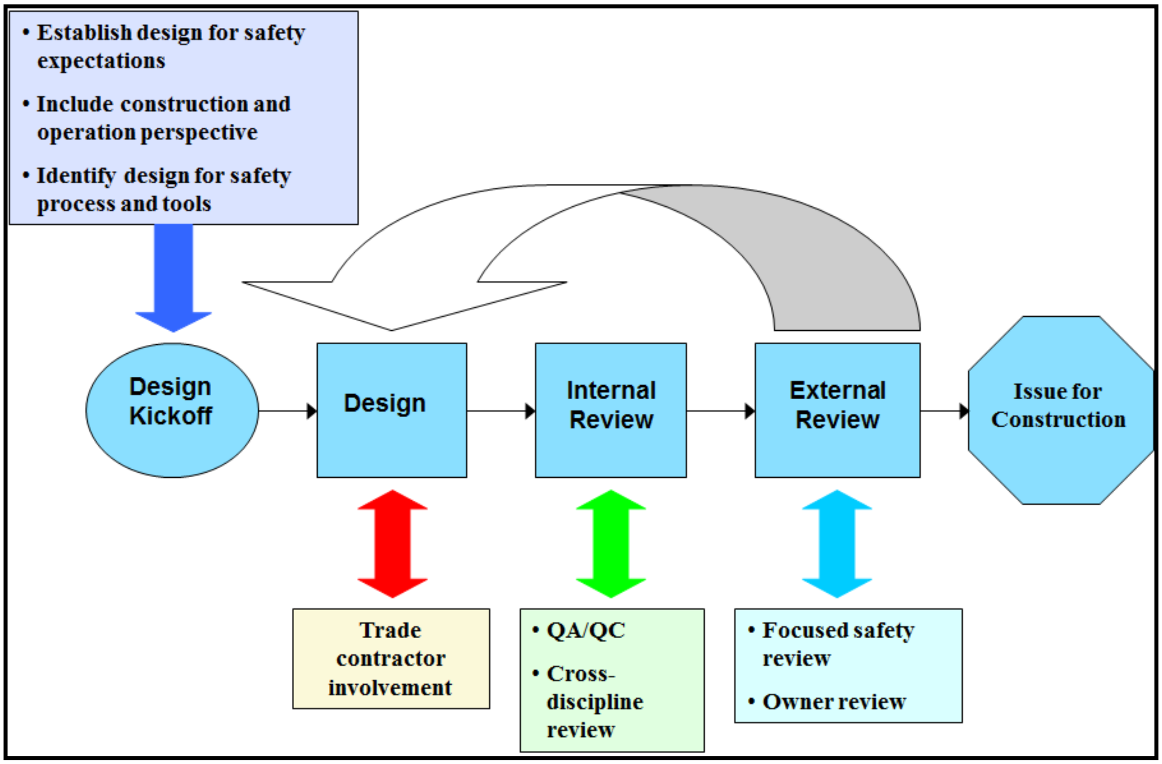


Figure 2-5 Design for Construction Safety Process, Gambatese and Hinze (2003) and Toole (2009)

Figure 2-5 shows that external tools must be used to review and change the design, while the framework presented in this research could be the external review tool and the external data source which react with DfCS.

It is stated in the literature review that the lack of knowledge of the construction process and tools are the most imperative barriers to DfCS, which increases the significance of this research as an input source of knowledge.

Thereby, this tool has the potential to exchange the information with the framework presented in this research.

Throughout the safety in design reviews, the DfCS process uses a risk assessment matrix, **Figure 2-6**. This matrix aids in estimating the probability and severity of potential hazards, which affect workers' safety. This matrix has been used in a significant amount of research on safety.

Probability	Severe	Serious	Moderate	Slight
	Severity			
High	High	High	Medium	Low
Medium	High	Medium	Low	Low
Moderate	Medium	Low	Low	Negligible
Low	Low	Low	Negligible	Negligible

Figure 2-6 Risk assessment matrix, from Toole (2009)

This research uses the matrix as a ranking scale to indicate a qualitative measure of the potential hazard and as a reference indicator to compare the results calculated in this framework with it.

2.4.4 *Graphic of Standard Operating Procedure Documents (SOPD)*

SOPD is a manual tool which provides a chronological list on how each task should be carried out. Moreover, it clarifies the precautions to be taken, such as the movement of materials and the preparations before each task commences. Mourgues, for resolving the failure in the traditional drawings and verbal communication, developed a work instruction template based on several criteria for good communication: clear, error-free, meaningful, concise, relevant, complete, accurate, and timely. **Figure 2-7** shows the layout developed by Mourgues containing four main sections:

- Drawing section (red): contains design information, locations, dimensions, and materials, etc. and is subdivided into four views:
    - Model view,
    - Detail view,
    - Key plan which expresses the work area,
    - Colour coding legend which explains the colour used in the model view.
- Instructions (yellow) contain construction steps with several considerations.
- BOM (Bill of Materials) (Green); lists of required materials to perform the work.

- Equipment and Tools (blue) contains required tools and equipment to perform the work.

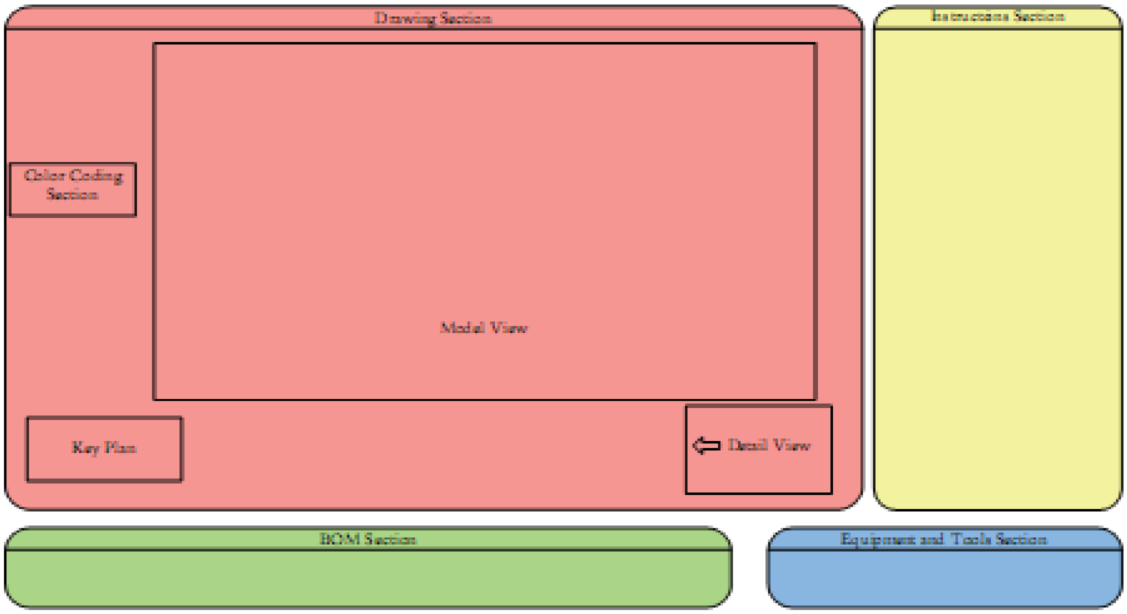


Figure 2-7 Activity (Action-Resource-Object-Work area), from Mourgues (2008)

This tool was later used by many researchers for different purposes.

This research finds it essential to be further developed, as it could prove beneficial in improving safety, and become a part of our framework.

2.4.5 ***Building Design for Safety (BDS)***

Building Design for Safety (BDS) is a method of graphic representation of safety in construction management, experimented by Capone (2013).

The main principles of the graphic BDS are:

- Greater adherence with the specific project executive,
- More detailed analysis of specific processes and consequent increases in detail of the policies, procedures and PPE to be carried out,
- Better readability.

One of the most important new features of this method is the combination of graphic tables that follow the phases of construction of the work step by step. These clarify the position of workers, the possible use of machinery, the risks that arise from specific processing and suitable countermeasures to be taken.

The whole project has to be split in process and sub-process, in other words, we have to define the WBS (Work Breakdown Structure). There are one or more tables for each part of work. The diagram of the following plates is shown in **Figure 2-8**.

- A: title of the described plate,
- B: number of the described plate,
- C: the first main part which presents the design step of the described process,
- D: title of the phase of sub-step, described with the addition of notes and operational requirements,
- E: the second main part which shows the type of manpower, machinery and equipment used in the described step and assesses the associated risks,
- F: shows in the form of symbols the collective protection devices, relating to the current phase,
- G: the third main part which shows the relationship between manpower, machinery and equipment used in the described step, the risks, and individual or collective safety requirements and safety regulations,
- H: title of the case study and common information to all boards.

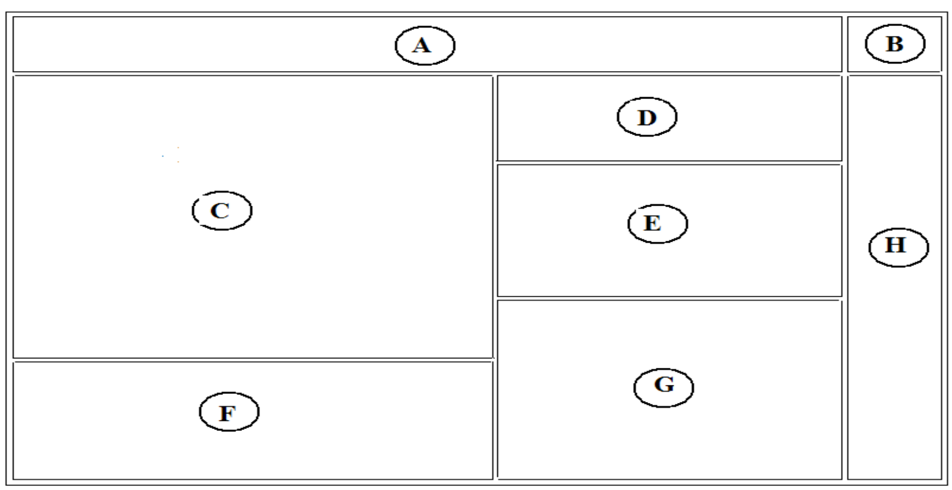


Figure 2-8 Scheme of graphic plates of BDS

The research in this method continues to integrate the constructability with safety in the design. (Capone, 2013) states "*Constructability and safety can be joined by design: this* *is the reason why it is interesting to work directly on design drawings. The proposed method can be defined as a Construction Management approach supported by a design tool directly based on design drawings*".

This tool has two key attributes which makes it suitable to be linked with the framework of this research:

- First, it depends on WBS that gives it the ability to be linked with the database and exchange the information with the framework developed in this research. In addition, the WBS makes it suitable to achieve the change design request when the same WBS is accomplished in both the schedule and design. On the other hand, this link adds the time dimension to BDS.
- Second, this method considers constructability, therefore it supports the knowledge exchange.

2.5 **Conclusion**

The first section of this chapter provided a comprehensive literature review on buildability and constructability. This included the definitions, concepts, developments in different countries and the advantages of buildability developments which have been summarized.

The second section discusses safety on construction sites; it refers to the large number of research studies and reports in this field which reflect the growing worldwide interest on the matter. The factors leading to accidents have been discussed, while the relationship between these factors and other fields of this research has been clarified. It was then concluded that the lack of space and overcrowding are the most common causes of accidents on construction sites.

The third section includes more than 65 studies offering tools to improve safety in the design phase by using buildability or constructability, which have been collected and discussed. All these tools have then been extracted, some of which could become a part of this research's the framework in this research (as an input resource of the information, output of the result, or a tool for re-design request). They have been examined with their potential features which enable this link, as well as being demonstrated. Hence, the BDS tool is most suitable to be used in this framework.

Much of the research around the world has focused on the growing issue of safety, which is complicated and involves various fields of this research.

The importance of this research is affirmed as it uses the schedule technique and construction technology to address safety at the planning and design phases.

Furthermore, it considers the temporal attributes, conflictions, and time-space-coordination, which were not fully considered in previous studies.

We hope that the study of tools could prove useful for the designers, researchers and for further studies. The results of the desk study provide background information, and knowledge for this study as well as further examinations.

Finally, a clear understanding of the concept is required before any strategies can commence. As we mentioned above, the issue of workers' safety is complicated and involves many other fields. Therefore, a deeper study of the relationship between safety and the fields of this research is required. Figure 2-9 shows that the workers' safety can be affected by planning, performed organization, design, and the used technology. We can determine that the scheduling as well as the design and buildability are fundamental and challenging to manage for improving workers' safety.

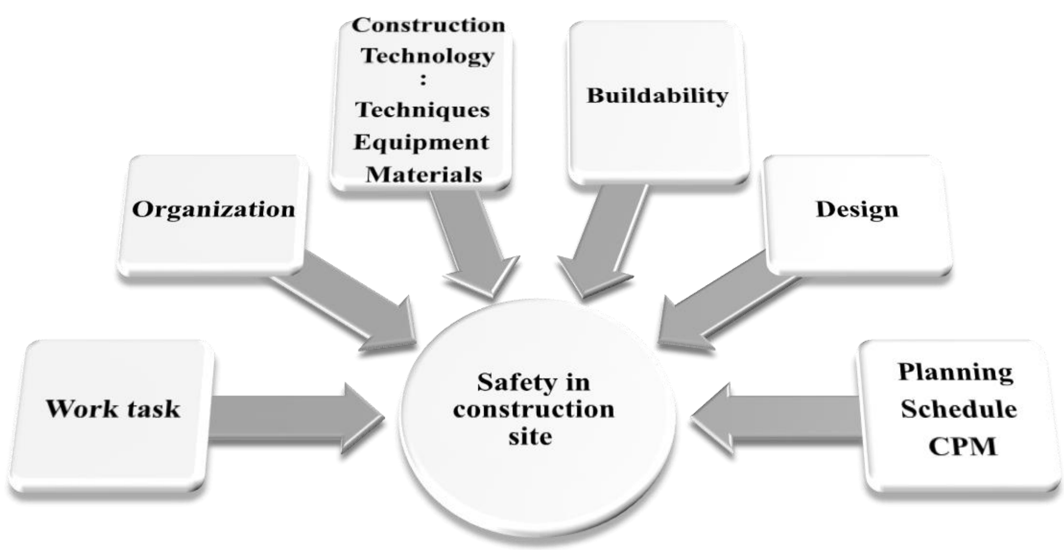


Figure 2-9 Aspects which affect the safety

CHAPTER 3

THE EXISTING TECHNIQUES IN CONSTRUCTION PLANNING

3.1 Introduction

Generally, there are three types of companies working in civil engineering projects:

- The design company, which is involved in the design and delivers all of the design details. It is responsible for providing the buildable design, which achieves the goal of the project.
- The contracting company, which is involved in the construction, and finalizes other subcontracts (inside contracts).
- The construction management company which has the most vital role. It is involved in the project at an early stage (the moment in which it is an idea). It works with the owner to transfer it from an idea to a project. It also plans and manages the project, as well as coordinates all the project participants. Therefore, declaring that its work begins with the contracting company is untrue, since the role of project management is also essential in the design phase.

It is often believed that the issues of workers' safety are the concern of the contracting company. Yet, the preceding chapters confirm that the role of the design company is crucial to the workers' safety. Furthermore, we can see that this work cannot be completed by the designers alone, as they need the information and experience from the site.

Here, the role of the construction management arises in addition to its important role in planning for safety and achieving it throughout the project.

Therefore, this thesis addresses workers' safety in the project management, so it ensures it at the earlier stages of the project and all others, while it also considers the safety to all participants. Hence, this research includes all the workers' safety conditions in the plan phase, while considering the limitations related to safety issues in the first schedule of the project, taking into account the integration between design and schedule, as well as the integration between the spatial and temporal attribute. Consequently, re-scheduling is required when it is necessary to ensure workers' safety. Thus, the fundamental aim is to limit or reduce the hazard on construction sites.

3.1.1 *Project management and construction planning*

The concept of project management is considered wider than the concept of planning, even though the planning concept is at times used to refer to a wide part of the project management more than a process.

3.1.1.1 Definition of project management

Project management is known as 'the art of directing and coordinating human and material resources through the life of a project by using modern management techniques to achieve predetermined goals of scope, cost, time, quality, and participant satisfaction'.

3.1.1.2 Definition of construction planning

Planning is *"a decision-making process performed in advance of action which endeavours to design a desired future and effective ways of bringing it about", (Laufer and Tucker, 1987).*

Planning is *"the production of budgets, schedules, and other detailed specification of the steps to be followed and the constraints to be obeyed in project execution", (Ballard, 2000).*

Construction planning is a fundamental and challenging activity in the management and execution of construction projects. It involves the choice of technology, the definition of work tasks, the estimation of the required resources and durations for individual tasks, and the identification of any interactions among the different work tasks.

A good construction plan is the basis for developing the budget and schedule for work. Developing the construction plan is a vital task in the construction management. In addition, it may also be necessary to make organizational decisions about the relationships between project participants and organizations to include in a project (Hendrickson, 2000).

It seems clear that the role of construction planning is not just in the construction work. It is crucial during the design phase as well as the construction and closing phases, including where there are problems during construction which require re-planning.

Construction planning originates from the fundamental idea of the project; it grows as the project progresses, and continues after the project has ended. The planning requires experience in building construction, as well as estimating the required equipment and resources at the early design phase. This knowledge and experience is useful to create the schedule, plan, as well as derivative plans such as resources and cash flow.

3.1.2 *The objectives of construction planning*

Many researchers have determined the objectives of construction planning in different ways, yet with similar foundations.

Neale and Neale (1989) stated that the objectives of planning are:

- Analyse how the job is to be done, in what order and with what resources;
- Anticipate potential difficulties;
- Schedule resources to make the optimum use of the available and most economic resources;
- Provide a basis for co-ordination in the work of the parties and contractors participating in the project, as well as the prediction and control of the time and cost needed;
- Produce data necessary for the preparation of future plans.

Faniran et al. (2005) declared, "*The typical objective in planning construction projects is the completion of a prescribed amount of work within a fixed time, at a previously estimated cost, and to specified standards of quality*".

Generally, most projects have similar objectives, scope, time, and cost. These are considered the most important objectives, especially for the owner and costumer, Figure 3-1.

This research attempts to focus on an alternative yet crucial objective of the project, which is the performance of the project without accident and injuries of workers (workers' safety).

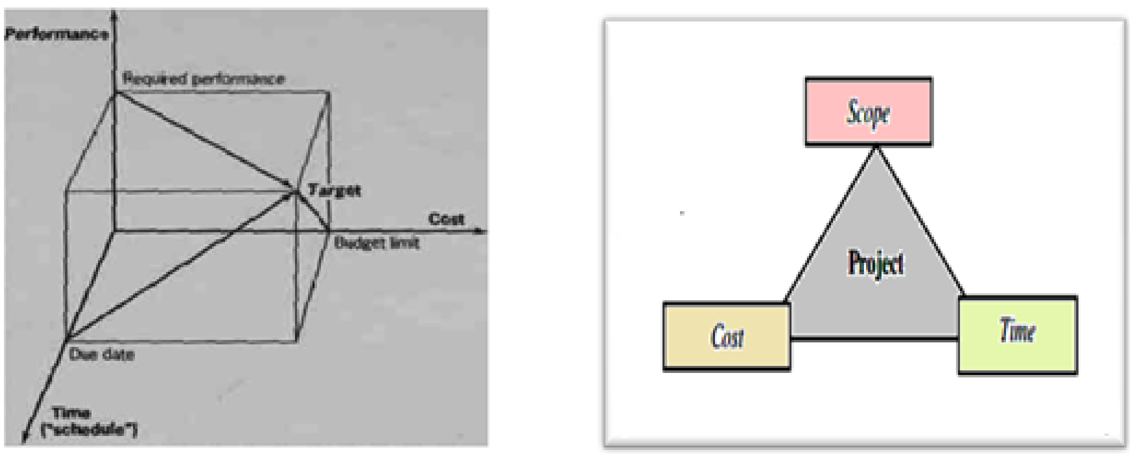


Figure 3-1 Iron Triangle from (Atkinson, 1999)

3.2 Review of the PMBOK, the first and most important school of thought in construction management

This approach is largely used by the Project Management Institute's (PMI) Project Management Body of Knowledge (PMBOK) (PMI, 1996; Winch, 2006), for that it is also known as "PM theory/approach" (Koskela and Ballard, 2006).

PMBOK identified the project management as "*the project management is the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements*".

Project management processes in PMBOK School, as is known traditionally, is comprised of five process groups:

– Initiating,
– Planning,
– Executing,
– Monitoring and Controlling,
– Closing.

We can see that the concept of management in PMBOK School is larger than the concept of planning, which is a group of the management process. These groups form a loop as we can see in Figure 3-2

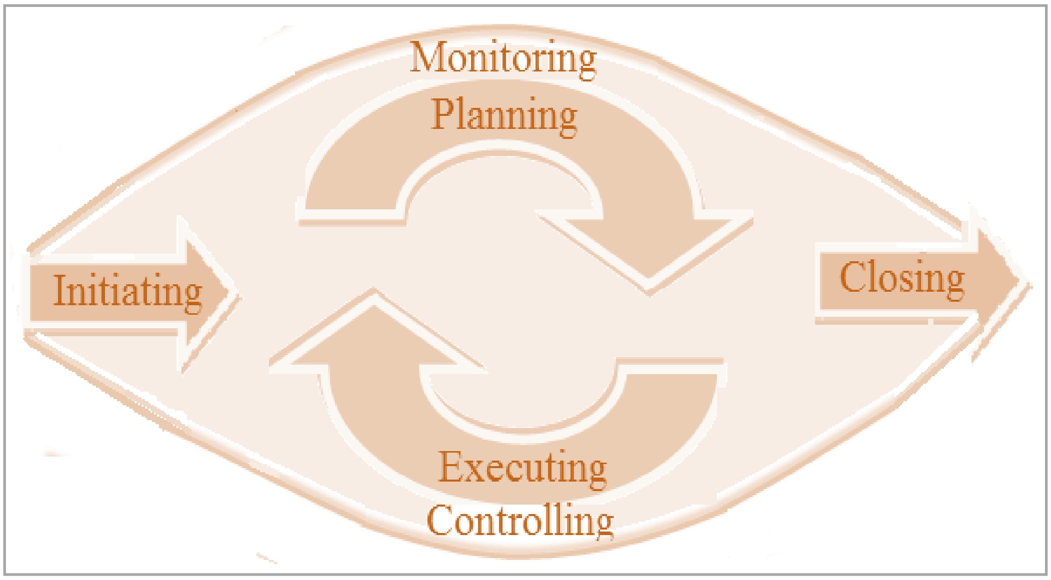


Figure 3-2 Management process (PMI, 2004)

Managing a project, according to the theory of PMBOK School includes:

– Identifying requirements,
– Addressing the various needs, concerns, and expectations of the project,
– Balancing the project constraints which basically includes at least:
  - Scope,
  - Quality,
  - Schedule,
  - Budget,
  - Resources,
  - Risk.

This school specifically takes it as an approach to the Critical Path Method (CPM) and the Work Breakdown Structure (WBS) to achieve the project management, and stated that ”*much of the knowledge to manage projects is unique or nearly unique to project management”*, (Choo, 2003).

3.3 **Evolution of planning techniques**

3.3.1 ***Bar chart today, milestone chart, linked bar chart, and network analysis:***

Bar chart techniques developed by Henry Gantt in the USA in the early 1900s, are considered as the basis of all planning techniques (Spice, 2003).

The milestone chart is similar to the bar chart, however it shows the start day of an activity and other relevant information.

The linked bar chart, in addition to the start date, end date and estimated duration shows the links between the activity, as well as the preceding and succeeding ones. It is also useful for calculating the required resources for accomplishing an activity.

Today, the bar is still commonly used, as it is the simplest and has intelligible readability.

3.3.2 ***Network analysis***

The network diagram presents the activities and the logical relationship between them, as it could be done manually or through the use of a software.

The network diagram is the result of the following steps:

- Complete the list of the activities,
- Determine the logical relationship between activities,
- Assess the duration of each activity, to determine the start and end date of each activity and the obtainable float,
- Assess the required resources.

There are two popular forms of network analysis:

- Activity-on-the-node (precedence diagrams) that it is also known as PDM,
- Activity-on-the-arrow.

3.3.3 *Activity-based schedule critical path method - CPM and PERT*

The critical path method (CPM) is applied in the majority of today's construction projects, as it is essentially the most common technique used for construction planning and scheduling. It has been proven to be a very potential technique for planning, scheduling, and controlling projects. Existing software products, such as Primavera and Microsoft Project use this technique for project scheduling, making it widely spread (Hessom, 2004).

CPM schedules the project depending on the duration of activities and the relationship among them, as well as analysing how they are correlated. CPM presents a graphical view of the project and calculates the time required to complete it.

It offers a visual and mathematical method to analyse, schedule, plan, control and monitor construction project activities.

The basic principle of this technique is that a sequence of activities control the duration of the entire project. This sequence is called the critical path, it is the longest path in the project and therefore determines and controls the duration of the whole project. If this sequence is studied carefully, and resources are managed properly, the entire project will be well-controlled.

This gives more flexibility to the non-critical activities, which can be moved without affecting the end of the project, and their resources allocated flexibly.

The network of CPM is displayed through the use of a bar char, which is called Gantt chart and presents the schedule of the project.

Currently, the availability of computing technology makes the mathematical functions used in planning with PERT (Program Evaluation Review Technique) much easier than before. PERT depends on the possibility that the time and cost of an activity are indefinite, which is reasonable since construction projects' time and cost overruns are not uncommon. For that, PERT uses three values for an activity - optimistic duration (do), most likely duration (dm), pessimistic duration (dp) – to calculate the probable duration.

The CPM and PERT merged due to the evolution of the computer programs and the available software, such as MS Project, to support both techniques.

In these activity-based schedules, a common problem is that the space is not well-considered.

3.3.4 *Location-based scheduling and the problem of space-time buffers, and lack of work-space*

The attention to the location-based scheduling dates back to 1940s when a lot of research had been carried out on this matter. In the literature, we can find several techniques of location-based scheduling, such as ‘Disturbance Scheduling’, ‘Vertical Production Method’, ‘Time-Location Matrix Model’, ‘Construction Planning Technique’, and ‘Horizontal as well as Vertical Scheduling Logic for Multi-storey Projects’ (Harris 1998; Kenley 2004), but the most famous two are ‘Line-of-Balance’ and ‘Flow line’.

The location-based scheduling method is a challenging task. It involves the design of space and time buffers among the activities, which is considered the most common problem of location-based techniques. The second most important problem is resource allocation, this is due to the basis of these techniques allocating the resource to each activity without the interference of other activities. Finally, the absence of software packages that support location-based planning makes it limited and unusable.

3.3.5 *Development techniques*

3.3.5.1 Simulation and expert system

Construction simulation techniques have been developed to optimize the resources and improve the productivity (Sriprasert, 2004). Modelling, planning and analysing the detailed construction operations have achieved their purpose (Martinez, 1999).

However, whilst the simulation is suitable to the systems composed of repeated activities, these techniques are still limited in construction projects, since the operations are unique.

3.3.5.2 4D techniques

Although 4D techniques would be helpful in construction management, since they improve communication, constructability addressing and understanding, Webb et al. (2004) used simulations in 4D to clarify the sequence of the project and its progress, yet these various 4D techniques are not feasible to schedule and manage the project activities, since they are not planning techniques. In fact, they are 3D designs with time dimension, in other words they are a 3D CAD model linked with the schedule.

3.3.5.3 Last Planner System

The Last Planner System was specifically developed to implement lean thinking in construction industry projects. It aims to improve the reliability of processes through structured predictive and collaborative planning with the inclusion of the last planners (Ballard, Glenn, 2002).

3.3.5.4 Dependency Structure Matrix and ADePT

Dependency Structure Matrix (DSM) technique was developed to resolve the problem of loops in dependency. A dependency loop occurs when an activity depends on information from a successive activity, which in its role requires information from the first one. Traditionally, this can be resolved by estimating the information and later checking it, however this results in errors of estimation and a significant amount of rework later.

In order to reduce these loops, DSM use “partitioning” to reorder the activities sequence within this matrix that could be achieved using the genetic algorithm or expert system.

Austin et al. (1999) adopted the DSM conception and developed the Analytical Design Planning Technique (ADePT) for planning the detailed building design process.

However, follow the opinion of most researchers in believing that these development techniques are still limited. Since they are expensive, building a model requires a lot of time, in addition to the time necessary to be taught and trained. We can also add that they are difficult to read and understand by everyone. The cost and time are the main reasons to be refused by the owners, they’re therefore not used widely.

3.4 The reasons of choosing CPM in this research

After this discussion, we concentrate in the framework of the CPM technique for the following reasons:

- It is the most logical one and its process allows mathematical function;
- It is the most common one and is already applied in almost every project;
- It is readable by everybody and therefore it will make the framework a helpful tool for achieving workers' safety.

We have used MS Project as software as it is easily linked with other MS Office applications and has the ability to be programmed and developed by visual basic applications.

3.5 Construction project process modeling

It is apparent that process modelling has the potential to improve the management of the construction planning process.

3.5.1 *History of project planning process model*

A first project planning process model was determined by the Project Management Institution, (PMBOK Guide, 1996). Several other models of construction planning process have been developed since 1996, some of which are generic while others are designed for specific purposes.

Some of these construction project process modelling are demonstrated through:

- Flow charts,
- Data flow diagramming,
- Entity-relationship diagrams (ER-Diagram),
- Higraphs,
- The structured analysis and design technique (SADT),
- Graphic presentation model IDEF0,
- Hierarchy plus input-process-output (HIPO) diagrams,

- Jackson diagrams,
- Petri nets (PNs).

Until now, many of the construction process models have been developed and are used above all for the integration of project phases design, planning and construction, as well as for the review of constructability. This is because these models provide a clear graphic presentation which makes the understanding of a complex process easy and readable.

This research used IDEF0 models to clarify the process since they allow the top-down analysis.

3.5.2 ***IDEF0***

The Integration Definition language 0 for Function Modelling (IDEF0) is a methodology and process modelling language. It is a functional modelling method designed to model the decisions, actions, and activities of an organization or system. It was derived from the established graphic modelling language Structured Analysis and Design Technique (SADT) developed by Douglas T. Ross and SofTech.

In its original form, IDEF0 includes both a definition of a graphical modelling language (syntax and semantics) and a description of a comprehensive methodology for developing models. (NISTI, DEF0, 1993)

IDEF0 was defined as a "*a compound acronym (Icam DEFinition for Function Modelling, where 'ICAM' is an acronym for Integrated Computer Aided Manufacturing) is a function modelling methodology for describing manufacturing functions, which offers a functional modelling language for the analysis, development, reengineering, and integration of information systems; business processes; or software engineering analysis*" (Systems Engineering Fundamentals,2001)

Recently, Integration Definition for Function Modelling (IDEF0) was widely used to model a construction process in all its phases, design, planning, and scheduling.

Each activity in the IDEF0 model is described by a verb-based label placed in a box. Inputs are shown as arrows entering the left side of the activity box, while outputs are shown as exiting arrows on the right side of the box. Controls are displayed as arrows entering the top of the box, and mechanisms are displayed as arrows entering from the bottom of the box. Inputs, controls, outputs, and mechanisms are all referred to as concepts.

The basic building block of the IDEF0 modelling is the ICOM (Input, Control, Output, Mechanisms) shown in Table 3-1.

The presentation of the IDEF0 diagrams is hierarchical, although in lower levels we can find more details as we can see in Figure 3-3.

This model is completed with MS Visio, which is a graphic presentation software program.

Table 3-1 ICOM (Input, Control, Output, Mechanisms) of IDEF0

Input	That which will be transformed by the activity or process. Data needed to perform the activity.
Control	Describes the conditions or rules, those elements related to the activity that constrain or govern how the activity will be conducted
Output	The results of the activity. This is the input after its transformation by the activity.
Means	The way the activity is undertaken. Those things that do or support the activity. This may be people, systems, facilities or equipment. For example, a specific job role, a machine, device and/or a software application such as CAD

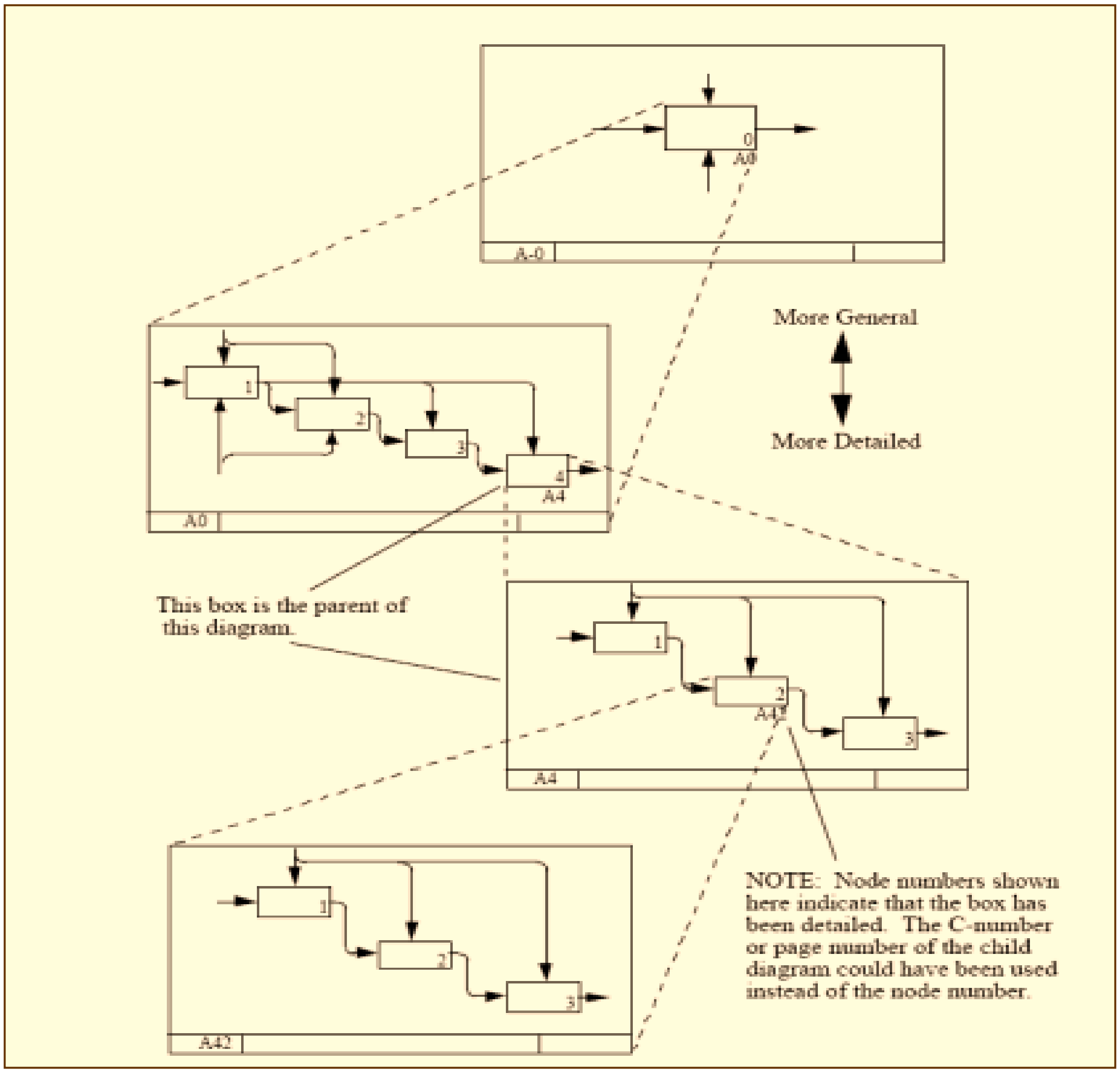


Figure 3-3 IDEF0 diagram-linking system (hierarchical) (Wikipedia)

3.6 Conclusion

This chapter has identified the concept of project management, construction planning and presented a review of the project management objectives, and then displayed (PMBOK) as the most important school in construction management. It became apparent that the research in construction planning has concentrated on achieving the project triangle (time, cost, and quality), since the developed techniques and processes have paid little attention to the workers' safety. Today, as more research is being conducted, the importance of workers' safety is becoming a greater topic of discussion.

The planning techniques were then discussed and analysed. Therefore it was concluded that the CPM, which is an (activity-based) scheduling tool, is the most common technique used in practice for construction planning and scheduling. The existence of software programs such as Primavera and Microsoft Project makes it easier, yet similarly to the other (activity-based) scheduling tools, it does take space into consideration.

Moreover, it was found that the (location-based) scheduling tools have a gap in the way that the resource distribution is done, and they are not common. Other techniques such as 4D and simulation are not used in practice due to cost, time, and difficulty.

For all the reasons mentioned above, and programming ability, its wide spread and its readability for everybody on construction sites, CPM is deemed to be used in this framework.

The construction process model was then presented, while the IDEF0 as construction process functional model was explained.

The upcoming chapters will present the framework to bring the concept of workers' safety into CPM.

CHAPTER 4

THE WSiCPM FRAMEWORK TOWARDS RESOLVING SPACE-TIME-CONFLICTS

4.1 Introduction

As seen in the second chapter of this research, see 2.2, overcrowding is the core issue affecting workers' safety on construction sites.

In fact, many researchers confirmed that overcrowding, especially combined with chemicals, other dangerous agents, or machineries, cause accidents and decrease productivity.

Robinson (2009) confirmed that overcrowding in the workplace is a risk factor, particularly if the work program is accelerated or pressed. Loosemore (2003) has cautioned the use of dangerous machinery within an overworking environment.

These researches generally study the impact of overcrowding on health and safety, yet analyse the issue from a cause-effect viewpoint and fail to offer a solution.

In this research, we found that there are some risky machines, vehicles, and activities, which need certain dimensional requirements, while implementing other works in the same place can be dangerous. In other words, overlapping activities could cause hazard situations.

This chapter will introduce the WSiCPM framework (integrating Workers' Safety into CPM) to resolve the space-time-conflict by changing the time or place for one of the two conflicting operations, taking in account the critical path and the logical sequence of operations.

4.2 The WSiCPM framework

In Figure 4-1 the methodology following in the WSiCPM framework is shown.

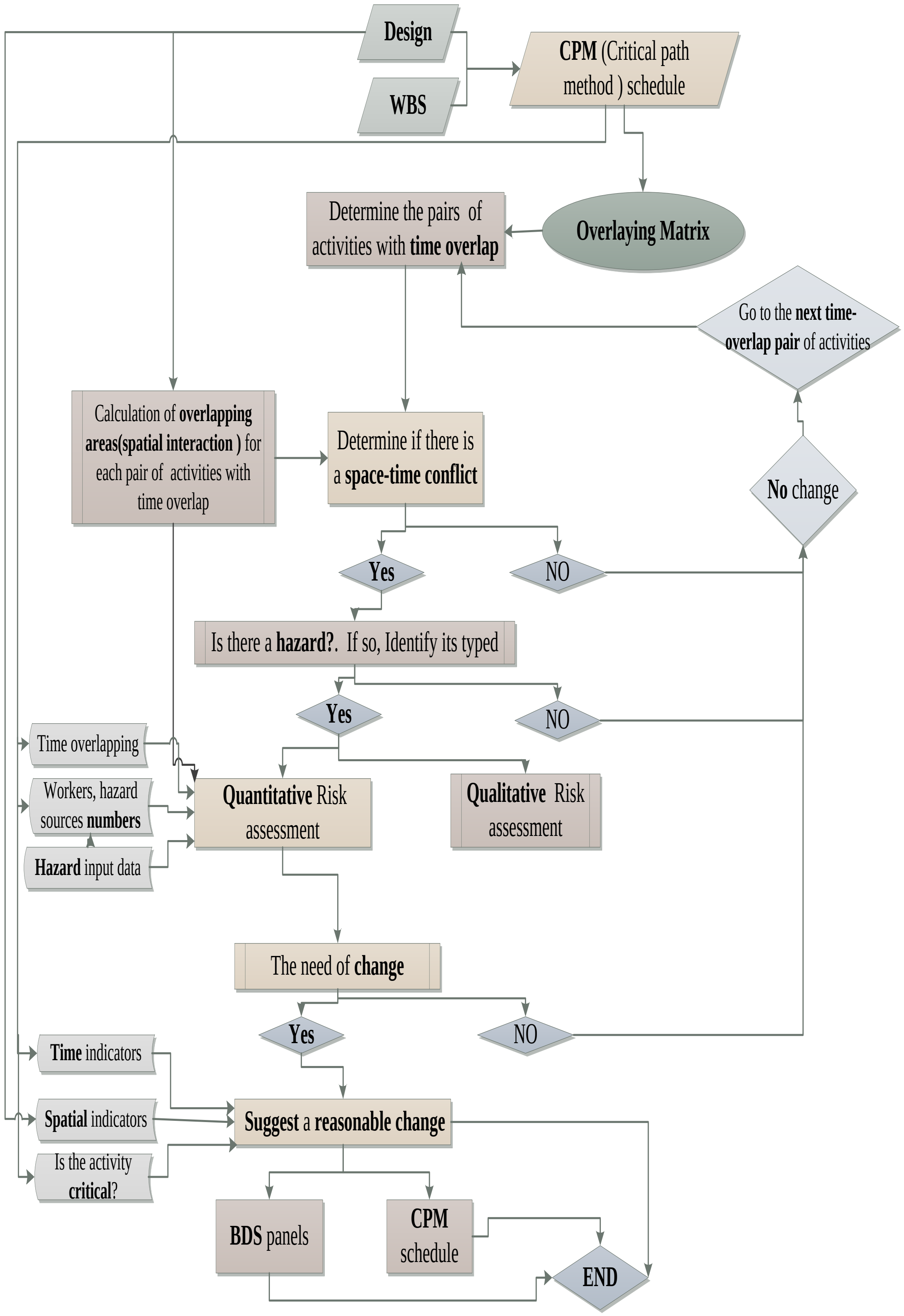


Figure 4-1 Methodology of the WSiCPM framework (described by using IDEF0)

We have integrated workers' safety into CPM through the following steps:

- Complete the CPM,
- Create the database to link the information from design, schedule, and safety measures,
- Create a matrix to determine the time-overlaying activities,
- For each time the overlaying pair of activities determine the spatial interaction to find out space-time-conflict activities that requires determining the required area for each activity (work, hazard, and path),
- Analyse the hazard level that is created by the conflict qualitatively and quantitatively,
- Decide if there is a change; if yes, suggest a solution either in the schedule or in the design.

4.3 The stages of construction planning completing

4.3.1 *Work tasks definition*

Tasks in the construction planning approach are also called activities; they are the items of the project work.

"The definition of appropriate work tasks can be a long and a tedious process, yet it represents the necessary information for application of formal scheduling procedures. Since construction projects can involve thousands of individual work tasks; this definition phase can also be expensive and time consuming". (Hendrickson, 2000)

The set of tasks defined for a project should include all the work involved. Usually, the definition of tasks depends on the design and project definition, while each element in the design has one or more linked activities. This operation is crucial in accomplishing the schedule, the more accurate the activity's definition is the more successful the scheduling is.

4.3.2 *Creating the work breakdown structure*

The work breakdown structure (WBS) is a set of arranged project activities. It divides the project into a hierarchical structure of items or work-packages. This structure enables project management and planning at different levels. It also facilitates resource loading of schedules and cost estimation. It is also used to identify parts of the project that can be sub-contracted.

Since the WBS established a common frame of reference for a construction project, it will be used in this research as a reference to link the different parts of the framework, and as an essential field in the database, meaning the design must be performed in the same WBS.

4.3.3 *Defining precedence relationships among activities and creating the flow diagram*

After the work activities have been defined, the relationships among them can be determined. For each activity, the previous and successive ones must be identified.

The flow diagram is the order of activities in the project phases. It identifies the sequencing of activities within the WBS. While some activities do not depend on others, they can run in parallel ways. Other activities require a chronological order and depend on others, meaning the start of one is dependent upon to the start or finish of another. This relationship may take four forms, as shown below.

Generally, there are four dependence types:

- Start to start (SS): the second activity cannot start before the first one is starting.
- Finish to start (FS): the second activity cannot start before the first one is finishing.
- Start to finish (SF): the second activity cannot finish before the first one is starting.
- Finish to finish (FF): the second activity cannot finish before the first one is finishing.

These four types can be modified by the lags or leads. PMBOK defines lag as *"the amount of time whereby a successor activity will be delayed with respect to a predeces-*

sor activity", leads as *"the amount of time whereby a successor activity can be advanced with respect to a predecessor activity"*.

We can practically consider the lags and leads as one concept by giving the former positive numbers, and negative numbers to the latter.

4.3.4 *Bill of quantities, duration estimate, cost estimate of the operation*

Depending on the primary designs, the bill of quantities or amount of work can be calculated and used in the time and cost estimates.

Duration estimates have to be completed in the planning process. These estimates reflect the amount of time required to complete each activity within the WBS. Once the estimates are mapped on the flow diagram, the accurate estimate can then be calculated.

The cost estimate can be calculated in several ways and must include the direct costs, which are the resources, materials, equipment, and cost of use, etc. and also indirect costs, those being the project management, software license, portion of the project from administration staff salaries, licenses, etc...

The duration and cost of the project can therefore be calculated using the code of productivity estimation (work unit / day), code of unit price through resource (price of day) or material (price of unit):

- The duration estimate by day = amount of work / productivity,
- The duration of the operation = the duration estimate by day / number of workers,
- The cost of operation = resource cost + material cost + equipment cost,
- Material cost = quantity* price of the unit,
- Resource cost = duration * price of the day,
- Equipment cost = cost of the use + (duration*price of the day).

4.3.5 *Creating the project schedule*

The project schedule relies on the WBS, the precedence relationships among activities, and the availability of the resources (resources, project team, equipment, facilities, and other required resources). In various instances, the project must be scheduled within the agreed deadline, therefore all activities must be carefully scheduled from the start date to its end, as to ensure the project is completed on-time.

4.3.6 *Resources*

To allocate a suitable and sufficient amount of resources (human resources, machines, and equipment) for basic activities is imperative in planning, as to ensure the project is completed on time and within its budget. Such procedure is determined by various factors:

- The required time to accomplish each activity,
- The priority of critical or especial activities,
- The additional cost of reducing the duration of the activity,
- The possibility of prolonging some activities,
- The productivity of the workers or the equipment,
- Resources shared by other activities or other project,
- Overlap of resources,
- Resource restraints.

4.3.7 *Discovering the critical path*

Critical path (longest-duration path through the project) analysis is an essential operation in project planning.

The critical path refers to the chain of activities that cannot be delayed, without consequently affecting the project end date. There can be more than one critical path, while it is possible that the critical path can change along with work progression.

The critical path can be established by calculating the following values for each activity:

Earliest Start Time (ES): the earliest time at which the activity can start, taking in account that all predecessor activities have ended.

Earliest Finish Time (EF): the earliest start time for the activity, plus the duration of the activity

Latest Finish Time (LF): the latest time at which the activity can be completed without delaying the project.

Latest Start Time (LS): the latest finish time minus the duration of the activity.

The float for an activity is the time between its earliest and latest start time, or between its earliest and latest finish time.

Therefore, the float is the length time in which a task can be delayed without affecting the end date of the project. If the earliest and latest end times are similar, then the task is critical.

The critical path is the series of activities which link the start of the project with the end, in which none of these activities have float, ES=LS and EF=LF for all its activities. The delay of one of these activities in the series of the critical path delays the whole project.

In addition to the possibility of finding more than one critical path, it is possible to find links between the start of the project and its end, these have slight differences in their duration from critical path, meaning they are paths with small float; also known as semi-critical paths.

Reducing the period of the project can be achieved by reducing the length of critical activities (e.g. add resource to some of these activities). However, other critical paths may appear prior to semi-critical paths, which depends on the difference of the duration among these paths.

4.3.8 *Completing the project budget and cash flow*

The project budget is the cost of the project including resources, materials, and costs of the use. It must cover the cost of the team's time, facilities, and all foreseeable expenses. Cash flow is the distribution of this cost on the time of the project, it is essential to notify management when funds must be available to allow the project to continue.

4.3.9 *Milestones*

Milestones are points in the flow diagram and scheduling as an operation without time, resources, and cost. They take a different shape and are used for several purposes such as determining the start and finish of the project, or an important phase such as getting an approval.

Safety milestone will be discussed in details in the coming chapters.

4.3.10 *Scheduling according to safety conditions*

In this research, we find that the project schedule must be modified to ensure workers' safety. The upcoming chapter will discuss the communication for safety plan in the general communications plan, choosing the technology for a safer work environment, cost of accidents and safety, as well as the role of safety documentation.

4.3.11 *The resulting schedule*

The resulting schedule indicates the activities' starting and finishing dates as well as resources and the relationship between them. It builds up in different levels in the hierarchy of the Gantt charts. Figure 4-2 shows a general example of the scheduling with CPM method by MS Project (the network diagram) the activities in red presents the critical path, While Figure 4-3 shows the same example presented as Gantt-Chart in CPM method also by MS Project the activities in red as previous are the critical path, while the activities in black are the key activities referred to the hierarchy of the Gantt charts.

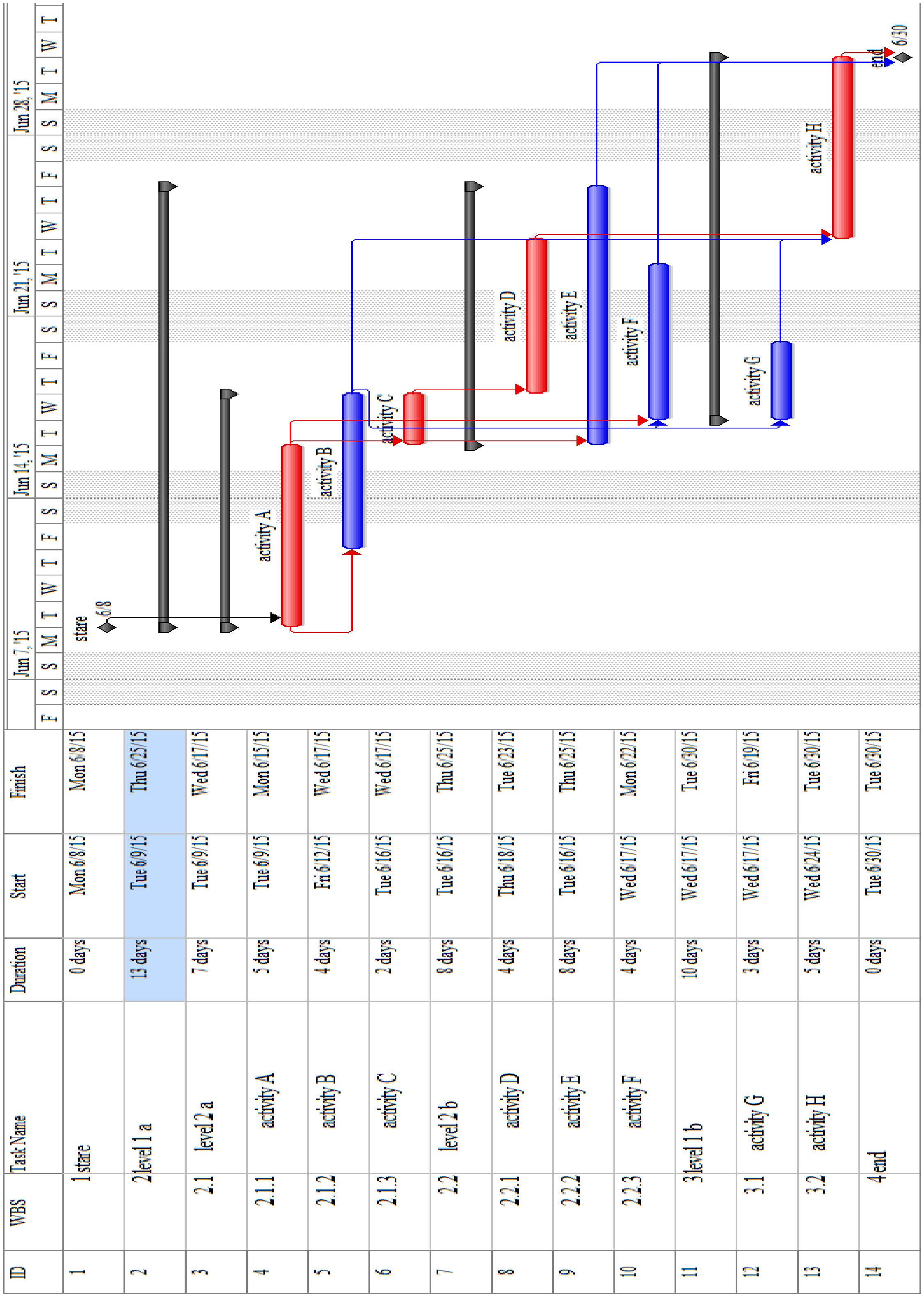


Figure 4-2 CPM method example (network-diagram)

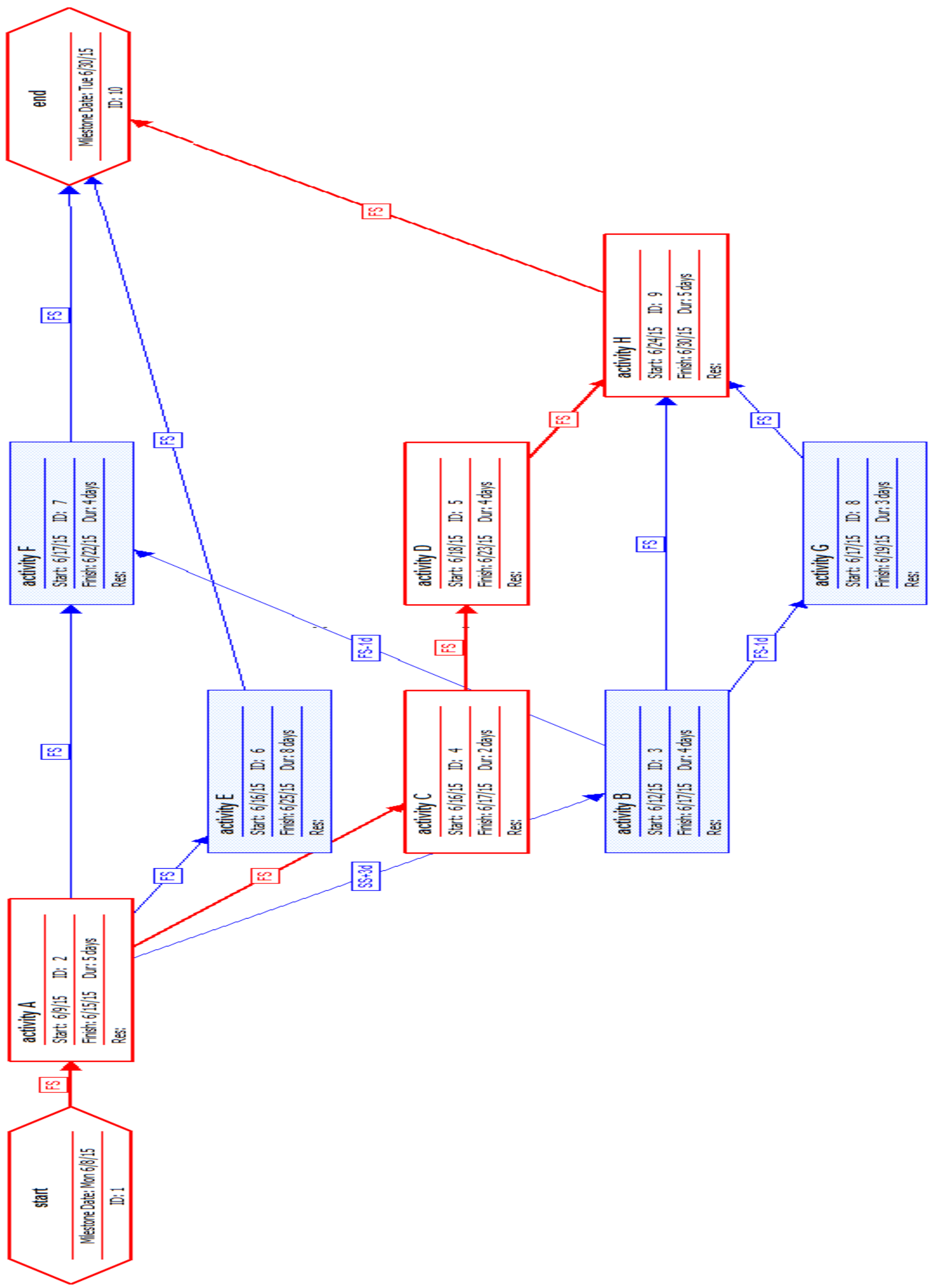


Figure 4-3 CPM method example

4.4 Finding activities with space-time-conflict

4.4.1 *Matrix of overlapping*

To determine overlapping activities, using the approach of 4D along with other approaches, they are sorted by weekly activities. Since the duration of the project is subdivided into weeks, the activities that run in the same week create a single group.

For the purpose of this research, it is not enough to determine the groups of activities that run simultaneously or are overlaying. We must determine the time-overlapping activities in a way to achieve the following.

- Sorting the interfering activities into pairs, to discuss the interrelationship between them,
- Applying the mathematical concept of non-analogue relationship between the two activities of each pair,
- Calculating the overlapping duration of each interfering pair of activities.

To achieve that, we must create a matrix that allows us to access information on every pair of activities, while distinguishing the impact of the first activity on the second, and vice versa. This could be accomplished using the following steps:

- Exporting information about the tasks from the baseline schedule (CPM) to the database as input data, practically from MS Project to MS Access. This includes the activities (name, duration, start, finish, dependencies, etc.) and their resources (name, cost, cost of use, and amount).
- Creating a matrix in the database to determine the tasks within the overlapping time; e.g. the matrix of overlapping of the schedule in Figure 4-3 will be as shown in Table 4:1.

Table 4-1 Time-overlapping matrix

	A	B	C	D	E	F	G	H
A		Time interfer-ence	No conflict	No conflict	No conflict	No conflict	No conflict	No conflict
B	Time interfer-ence		Time interfer-ence	No conflict	Time interfer-ence	Time interfer-ence	Time interfer-ence	No conflict
C	No conflict	Time interfer-ence		No conflict	Time interfer-ence	Time interfer-ence	Time interfer-ence	No conflict
D	No conflict	No conflict	No conflict		Time interfer-ence	Time interfer-ence	Time interfer-ence	No conflict
E	No conflict	Time interfer-ence	Time interfer-ence	Time interfer-ence		Time interfer-ence	Time interfer-ence	Time interfer-ence
F	No conflict	Time interfer-ence	Time interfer-ence	Time interfer-ence	Time interfer-ence		Time interfer-ence	No conflict
G	No conflict	Time interfer-ence	Time interfer-ence	Time interfer-ence	Time interfer-ence	Time interfer-ence		No conflict
H	No conflict	No conflict	No conflict	No conflict	Time interfer-ence	No conflict	No conflict	

4.4.2 *The required space for the activity*

For each activity in overlaying pairs the adumbration and lineation of the required space has to be identified. This includes work area, temporary storage, path space, and hazard space which will be used to determine the space conflict.

The hazard area is determined through the safety dimensions, by experience, or by the help of safety in design tool (CII Design for Construction Safety Toolbox), see2.4.2. Figure 4-4 shows how the area requirements of an activity can be identified.

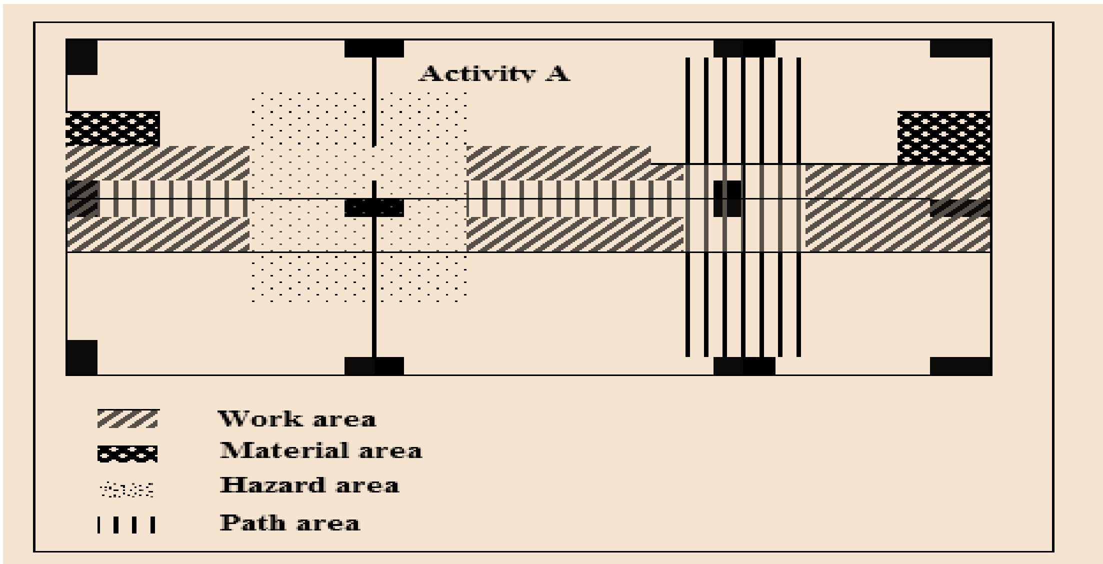


Figure 4-4 Example of area requirements of an activity

4.4.3 *Space conflict types*

Researches using the 4D approach show that the interfering between activities produces numerous complications such as loss of productivity, damage, congestion, and hazard. Table 4-2 shows the type of area conflicts mentioned in the researches of 4D, as well as in the scope of this research.

Table 4-2 Types of area conflict modified from research in 4D to show the scope of this research

			TASK A								
							This research scope				
							Hazard	Work area		Path	
			Building area	Temporary building	Temporary storage	Protection area	Hazard area	Human resource	Equipment area	Path area	Dead area
TASK B		Building area	Design problem	Design problem	Design problem	No impact	Design problem	Design problem	Design problem	Design problem	No impact
		Temporary building	Design problem	Design problem	Congestion	Damage	Design problem	Congestion	Design problem	Congestion	No impact
		Temporary storage	Design problem	Congestion	Design problem	Damage	Design problem	Congestion	Congestion	Damage	No impact
		Protection area	No impact	dam-age	Damage	No impact	Damage	No impact	Damage	Damage	No impact
This research scope	hazard	Hazard area	Design problem	Design problem	Design problem	Damage	No impact	Safety hazard	Safety hazard	Safety hazard	No impact
	Work area	Human resource	Design problem	Congestion	Congestion	No impact	Safety hazard	Congestion	Congestion	Congestion	No impact
		Equipment	Design problem	Design problem	Congestion	Damage	Safety hazard	Congestion	Congestion	Congestion	No impact
	Path	Path area	Design problem	Congestion	Damage	Damage	Safety hazard	Congestion	Congestion	Congestion	No impact
		Dead area	No impact	No impact	No impact	No impact	No impact	No impact	No impact	No impact	No impact

4.5 Determine the type of hazard

After determining the space-time-conflicts, we have to acknowledge whether a hazard has been created by each space-time-conflict pair of activities. If so, the type of hazard has to be identified relying on the type of the two activities that run simultaneously.

A visualization of the hazard can be achieved through the experience, logical analysis, or the help of safety in design tools like (CII Design for Construction Safety Toolbox), see 2.4.2, or through available data sources.

Regarding this matter, we can find much of the data in statistic number web pages, special health and safety sites, specialized journals, companies, courts, insurance companies, accident books, safety publications, interviews, accident records, and state of art like the publications of Health and Safety Executive which are available onlinewww.hse.gov.uk/statistics/ .The table below shows an example of this data taken from Health and Safety Executive (2003).

Table 4-3 Example of the accidents data resources, after (Health and Safety Executive, 2003)

Operatives were on level one striking out shuttering from a hole next to a column. They knew that the formwork would drop a single level and as procedures, they cordoned off the area below. The area directly below was of the same design, but the shuttering to the hole had already been knocked out and a board had been placed over the gap. As the formwork was knocked out it fell down onto the board on the ground level, went straight through it and landed in the basement. Two bricks workers and the S.O. were 1 m away from the falling debris in the basement (bricks worker sustained a slight crutch as the boarding dropped flat to the floor, but this has been recorded as a dangerous occurrence).
Worker was stripping finish from a kitchen cabinet using a lacquer thinner, a flash fire, broke out and spread to the kitchen, another worker was severely burned.
An operative was carrying 4 brick guards in each hand. As walking along, he stepped onto an electrical cable, slipped, and twisted his ankle.
A worker was descending the stairs carrying a toolbox. He slipped on an oil patch, which had been covered with paper resulting in a bruised elbow & hip.
Whilst walking through site a piece of timber from upper level fell and struck the worker.

4.5.1 *Determine if there is a space-time-conflict*

After determining the time- overlapping activities, each overlaying pair of activities will be checked whether they have spatial interaction or not. The space-time-conflict means that there is a spatial interaction between the two activities, even if they are run in separated spaces, since the conflict could be present in the hazardous area of one activity which is out of its work area.

Therefore, we must refer back to the design department to detect where the two activities take place. If the two activities run in different places without space interface, then space-time-conflict cannot occur.

If there is an interference or spatial interaction in the area where such activities take place, then the design department will be asked to provide information on the total work, path, and hazardous areas as well as the interfaces between them. Figure 4-5 illustrates the interfaces between these areas, Figure 4-6 shows an example of the space-overlapping pair of activities, while Figure 4-7 shows the required information.

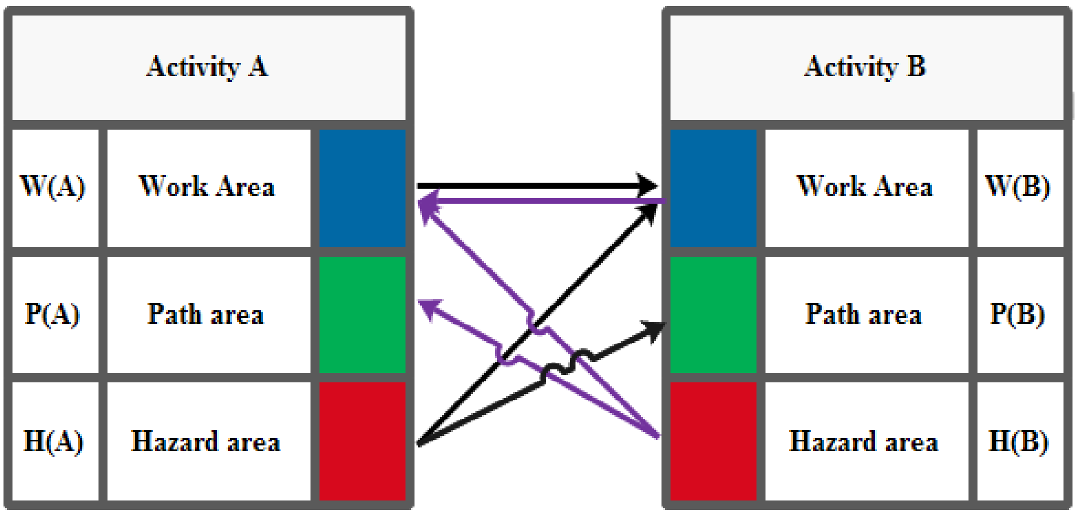


Figure 4-5 Area conflicts in this research

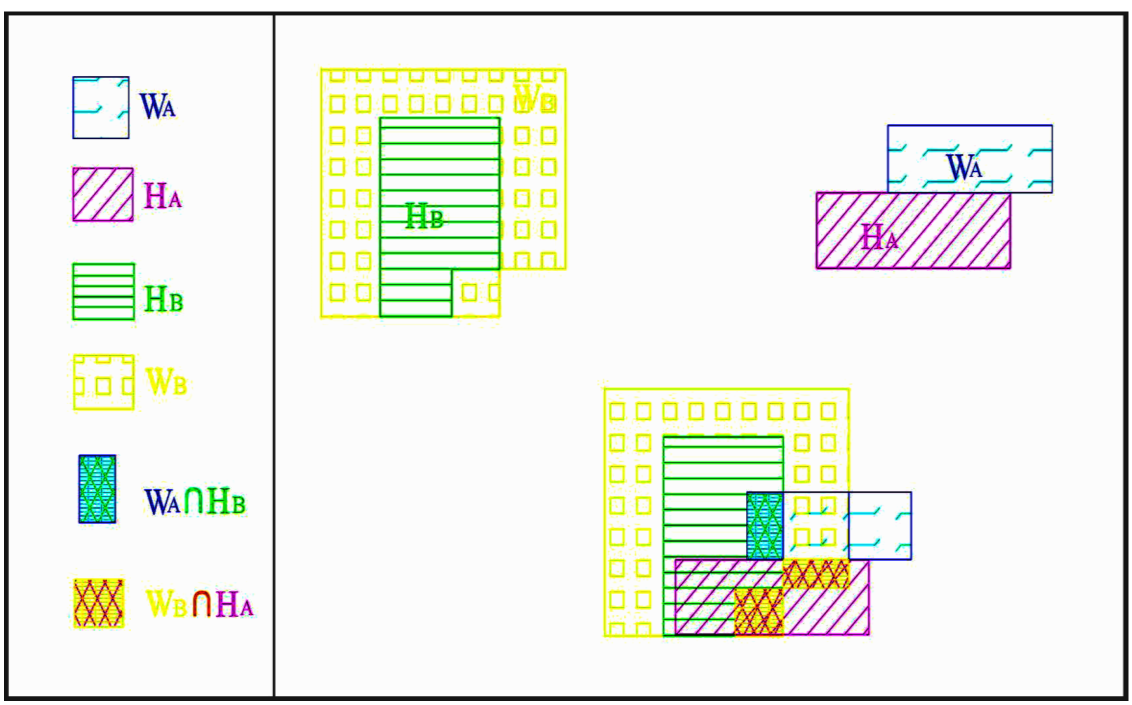


Figure 4-6 Example of overlapping pair of activities

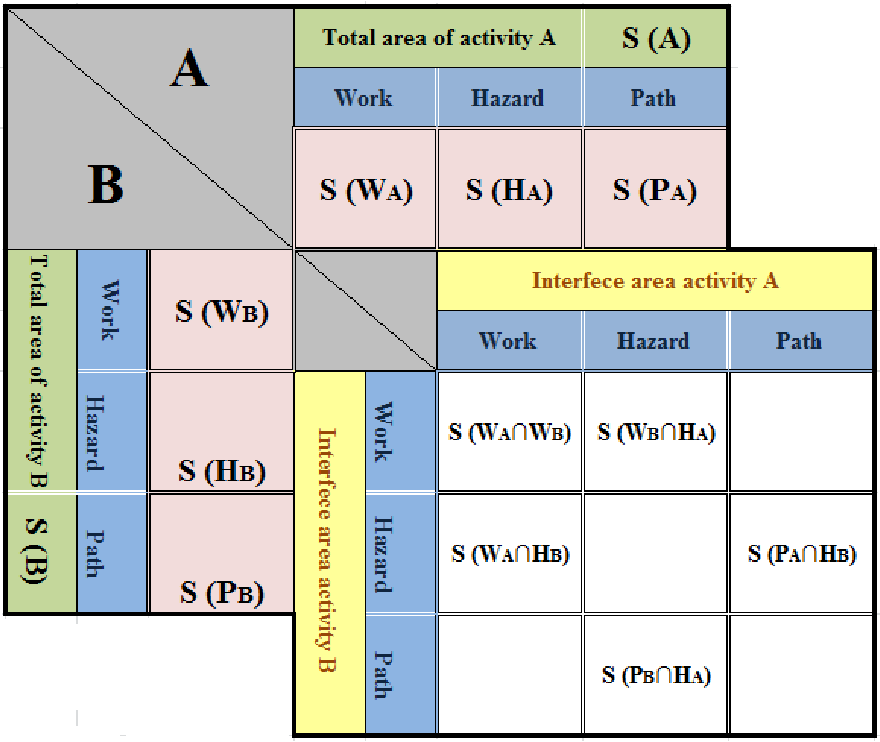


Figure 4-7 Requested area information in this research

We will consider the work area as the movement area of both human resources and equipment resources of an activity, which does not include the path area, since it will be calculated separately.

4.6 Qualitative risk analysis

After determining the space-time-conflict activities, which create hazardous situations for workers and identifying the hazard type, we must predict the extent of such a risk (qualitatively and quantitatively).

A risk assessment matrix modified from (Toole, 2009), see 2.4.3.2 and **Figure 2-6**, will be used for qualitative risk assessment, this matrix will also be used to compare the calculated results in this research.

The model in this research consists of five levels of probability and five levels of severity. The severity is predicted by the experience and the use of statistic numbers of past accidents, Table 4-4 show this ranking model.

Table 4-4 Qualitative risk analysis matrix, modified from (Toole, 2009)

		Probability				
		very unlikely	unlikely	likely	probable	frequent
Severity	very minor					
	minor					
	major					
	grave					
	very grave					

This model fails to distinguish whether the hazard to the workers is caused due to the first activity or the second. While it considers that the severity of the accident is linear, it remains imprecise.

In the WSiCPM framework of this research, the user can indicate the severity from a drop-down list with values “very minor; minor; major; grave; very grave”, see Figure 4-8, belonging to value from 1 to 5 in the database.

Similarly, the probability is chosen from the drop-down list with the values “very unlikely; unlikely; likely; probable; frequent”, while the database takes values from 1 to 5.

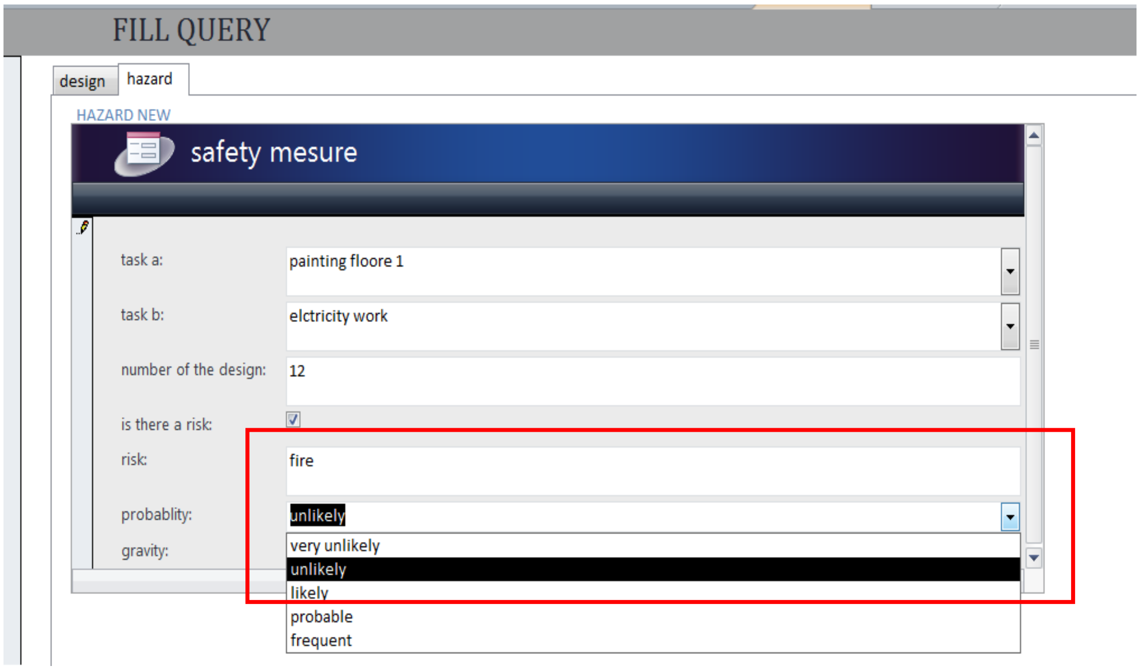


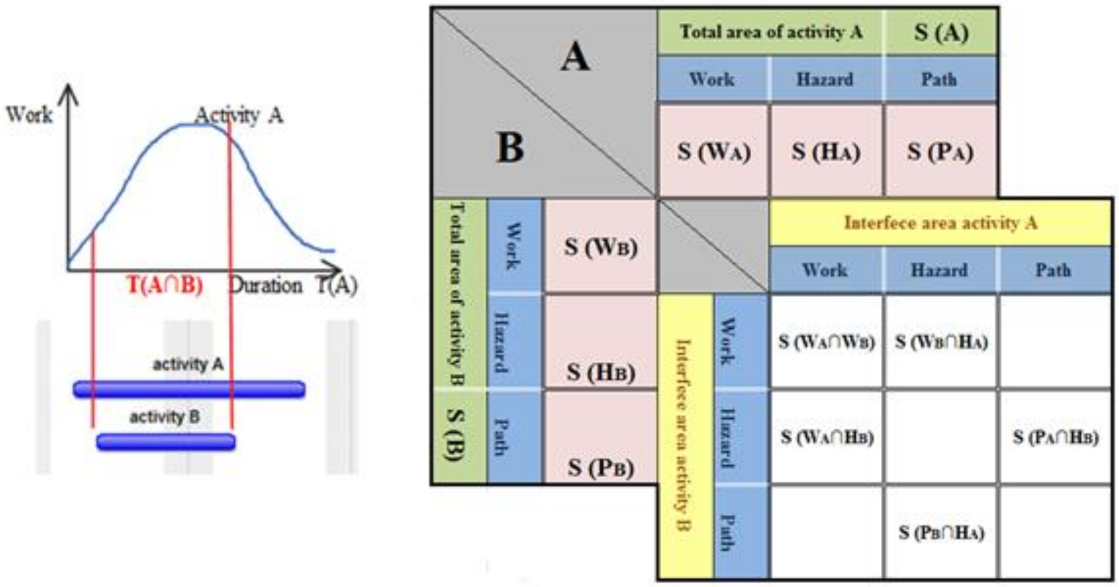
Figure 4-8 Choosing the probability level by the user in the WSiCPM framework

As a result, the framework of a colour rectangle will appear which will be used to express the qualitative measure of the risk:

- Red: not acceptable, we have to stop and change the design or reschedule the activities.
- Orange: we study alternatives modifying the design, rescheduling, or putting more measures.
- Green: accepted, it is enough to take some measures.

4.7 Quantitative risk analysis

The inputs of this step are the information from CPM (resources of the two activities, their (start, end) dates, durations, overlap duration, the number of workers in each activity, the distribution of the work in the time, and information from the design; as we can see in Figure 4-9 .



S (A), S (B) the total area of activity A, B,

$S(W_A)$, $S(W_B)$ the work area (human and equipment) of activity A, B,

$S(P_A)$, $S(P_B)$ the path area of activity A, B,

$S(H_A)$, $S(H_B)$ the hazard area of activity A, B,

$S(W_A \cap W_B)$ the interface work area between A, B,

$S(W_A \cap H_B)$ the interface of work area of A with the hazard area of B,

$S(W_B \cap H_A)$ the interface of work area of B with the hazard area of A,

$S(P_A \cap H_B)$ the interface between hazard area of B and path of A,

$S(P_B \cap H_A)$ the interface between hazard area of A and path of B,

T (A), T (B) duration of activity A, B,

$T(A \cap B)$ time- overlapping between A and B

Figure 4-9 Space-time-conflict symbols of the quantitative method suggested in this research

4.7.1 ***The hazard (B⇒A)***

In this method we will distinguish between hazard (B ⇒ A), and hazard (A ⇒ B), hazard (B ⇒ A) means the hazard to the workers in activity A ~~is~~ caused by activity B, while hazard (A ⇒ B) means the hazard to the workers in activity B caused by activity

A. The risk (B ⇒ A) which is a combination of the probability and the severity can be calculated as follows, see Figure 4-10.

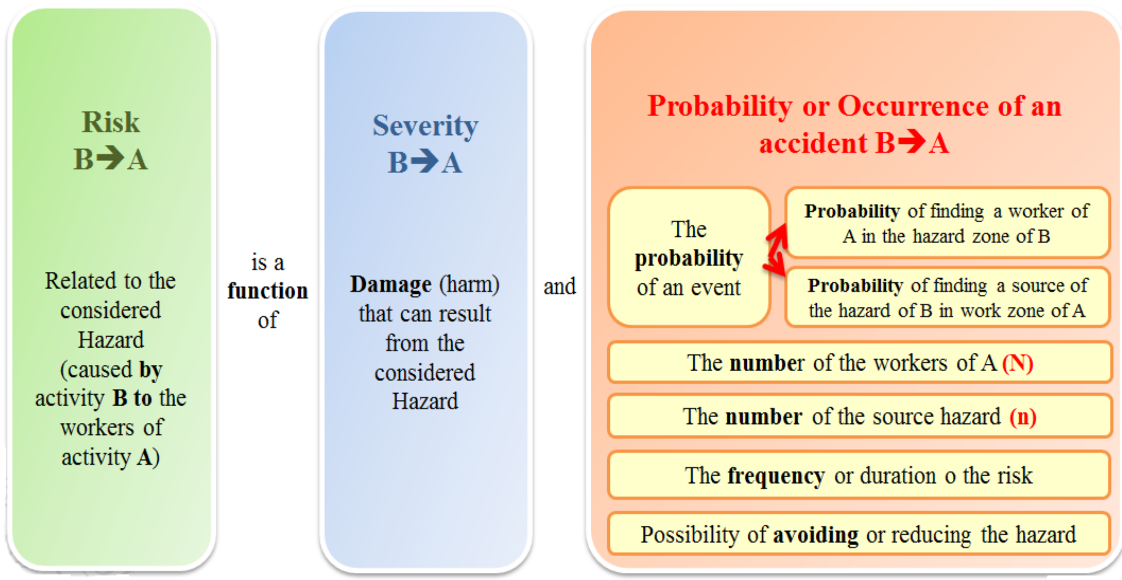


Figure 4-10 Risk (B ⇒ A)

4.7.1.1 The probability calculation

4.7.1.1.1 Activity A

The probability to find one worker of activity A in the hazard zone of activity B as spatial concept is

$$S\,(A) = (\,S\,(WA \cap HB) + \,S\,(PA \cap HB))\ \ /\,S(A)$$

However, since there is a time-overlap, the time probability Ft of this interface must be taken into account.

$$Ft\,(A)\ = \ T(A \cap B)\ /\,T(A)$$

So the probability to find a worker of activity A in the hazard zone of activity B becomes

$$F(A) = \frac{(S(WA \cap HB) + \mathrm{S}\,(PA \cap HB)) * \mathrm{T(A \cap B)}}{S(A) * T(A)}$$

EQ 4-1 Probability to find a worker of activity A in the hazard zone of activity B

Nevertheless, when the work progress of each activity is not linear in time, a factor β will be added. In fact, the work progress of the activity in time could take several shapes, as it is possible that most of the work occurs at the beginning, end, or in between.

In addition, it is possible that the work is distributed unequally on the activity area; we will add a factor α to describe that.

Then the EQ 4:1 takes the form

$$F(A) = \left(\frac{S(WA \cap HB) + S\,(PA \cap HB)}{S(A)}\right)^{\frac{1}{1+\alpha}} * \left(\frac{T(A \cap B)}{T(A)}\right)^{\frac{1}{1+\beta}}$$

EQ 4-2 Probability to find at least one (or more) worker of activity A in the hazard zone of activity B with α and β factors

Factor β

The factor *β* takes into account that the work of the activity is not distributed equally on its duration. This factor depends on the shape of activity progression in the time and position of the overlap-time, from the activity period.

Generally, it is acknowledged by the construction management that the progress of an activity is similar to the project progress itself. This is because at the beginning the work progress is slow, it then increases until it reaches its peak, later it decreases until the end of the activity, see Figure 4-11.

We will use a branch of mathematics (finding the great values) to analyse the value of this factor, the two variables in this matter are:

- The shape of the curve, which presents the progress of the activity in time,
- The location of the T (A∩B) from the duration of activity A.

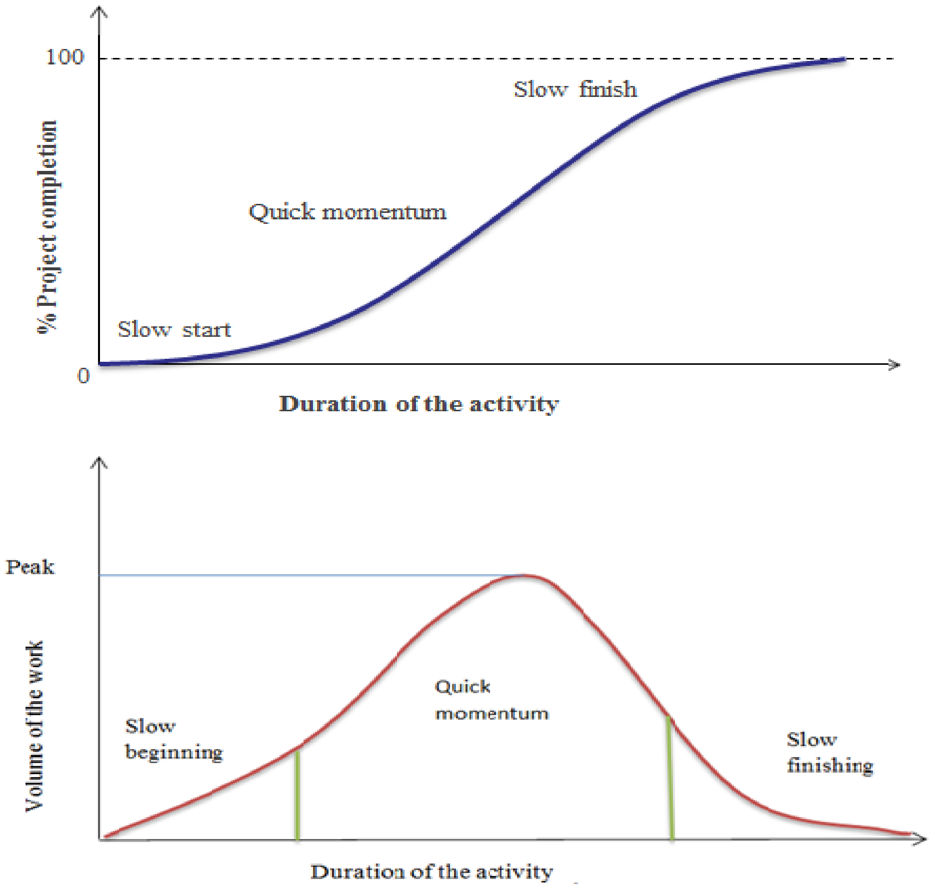


Figure 4-11 Traditional life cycle of an activity

Starting with this, we can present the curve of the completion as cumulative percentage of the work in the duration of an activity.

Figure 4-12 shows two different shapes of the curve, which represent the work progress of the activity with time.

We will create a hypothetical envelope curve to present the uppermost curve and the lowest one, and assume that most of the possible activities progress graphs are located between these two graphs.

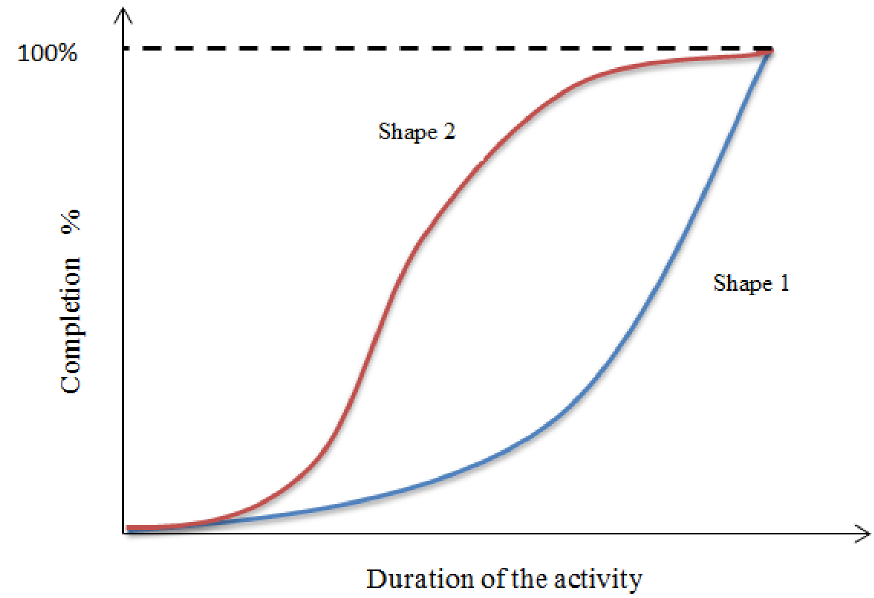


Figure 4-12 Two different shapes of the activity progress

For the second variable factor, the location of the T (A∩B) from the duration of activity A, see Figure 4-13.

It is clear that the great value of the work of the activity A, in other words the worst interface for the activity A, when T (A∩B), is in the middle of the activity A near the peak.

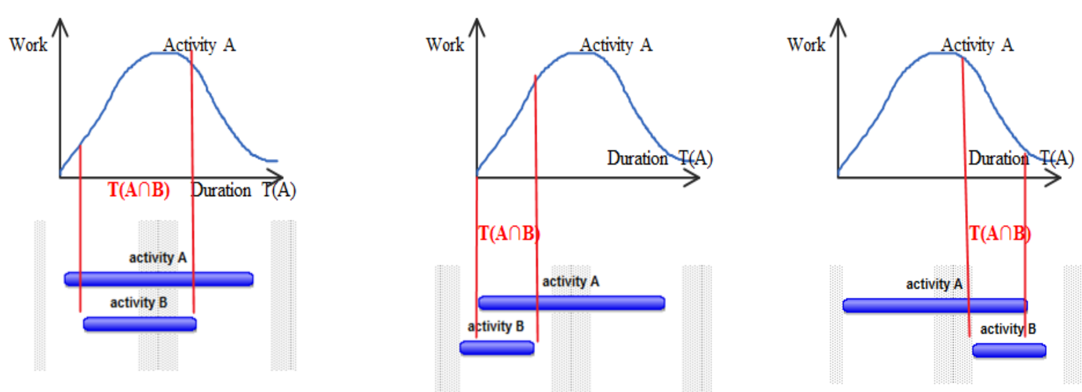


Figure 4-13 Location of the T (A∩B) from the duration of activity A

Figure 4-14 represents the lowest supposed curve with the worst time-overlapping T (A∩B) comparing with the linear curve.

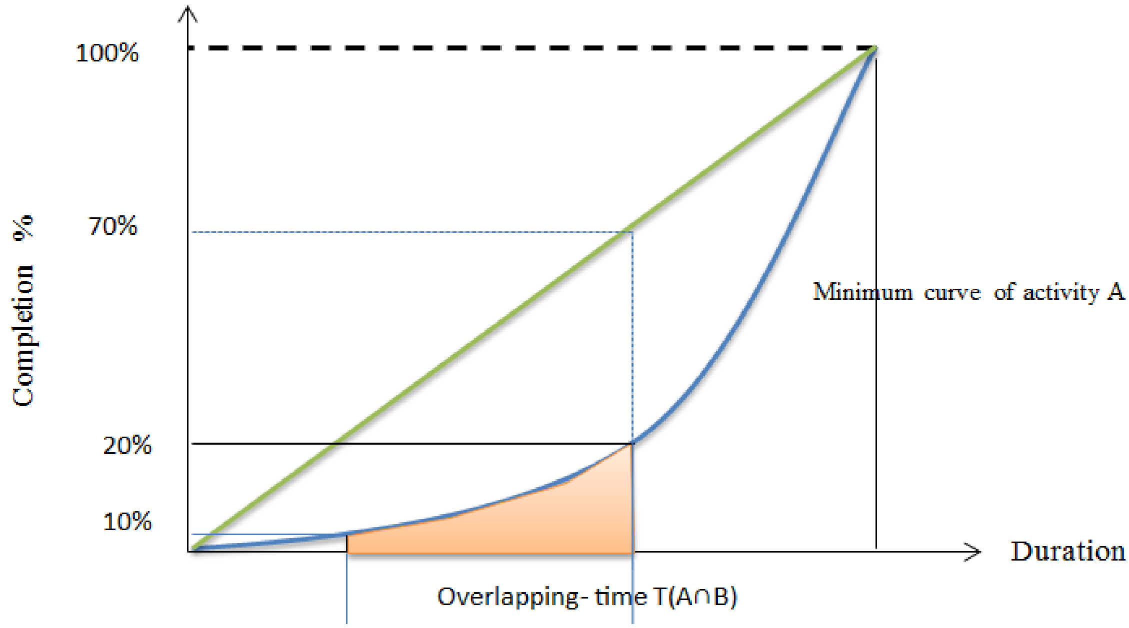


Figure 4-14 Minimum curve of activity A

Figure 4-15 represents the uppermost-supposed curve with the worst time-overlapping T (A∩B) comparing with the linear curve.

It is clear that the linear curve matches the value of β = 0.

In this research we will ignore the values under the linear curve, which match the negative values of β, since they reduce the volume of work in the selected part of the duration. Hence, they reduce the time-probability of finding a worker of activity A in the hazard zone of B. This means that the factor β can only take positive values.

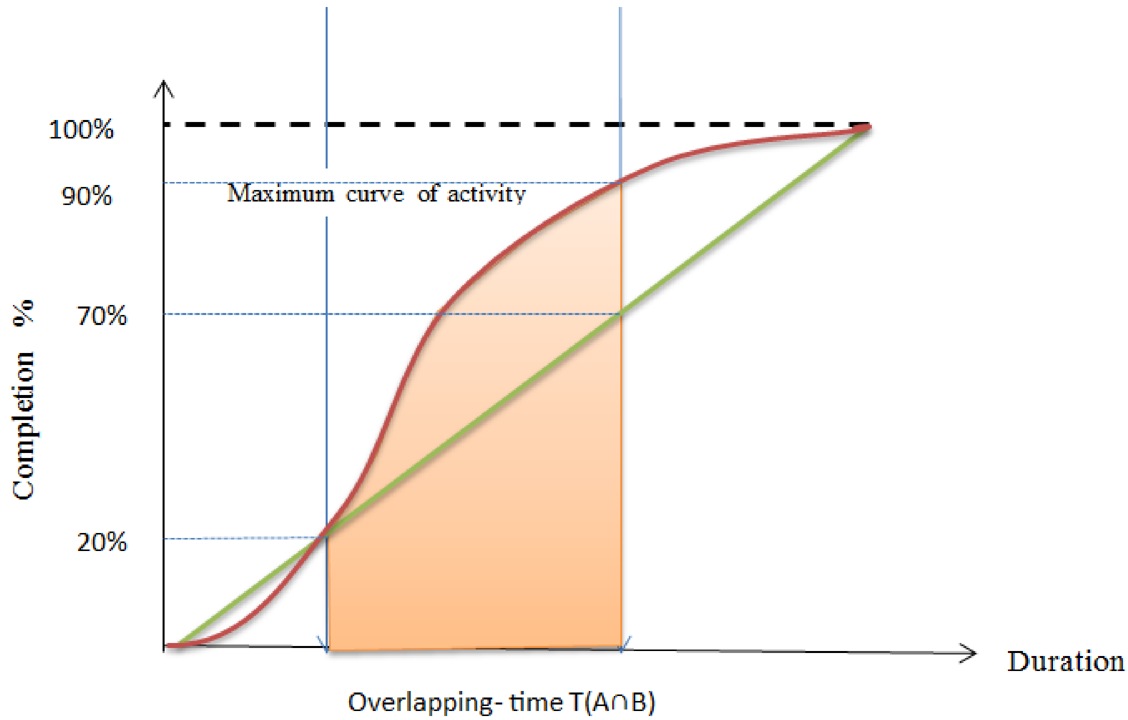


Figure 4-15 Maximum curve of activity A

By mathematical analysis of the curve presented in Figure 4-15 we find the range of the factor β values; this range is $\beta \in]0, 3]$.

<u>Factor α</u>

The factor α is used to take into account an unequal distribution of the work of the activity on its area. It is difficult to estimate the value of this factor, since the construction spaces change with work progress.

This value can be calculated by applying critical space analysis method, graph method or space syntax method.

We can essentially accomplish that by drawing the possible lines of the movement, then finding the areas with a maximum of junctions and crowding, while it could also be estimated by experience.

We will also ignore the values which give less probability, this value could be $\alpha \in]0, 2]$.

4.7.1.1.2 For the source of the hazard activity B

In regards to the probability of finding the cause of hazardous activity B in the work area of activity A, we can distinguish three values:

- Value (Y): continuous then the probability of finding a source of danger of activity B in the zone of A is 1. In this case, the probability of the accident is equal to the probability of the presence of worker A in the hazard area of B see EQ 4-5.
- Value (Z): a number between [0-1].
- Value (X): is related to the equipment or the worker movement, then we can calculate it as we can see below:

$$F\ (B \Rightarrow A) = \ (S(WA \cap HB) + S\ (PA \cap HB))\ \ / \ S(B)$$

$$Ft\ (B \Rightarrow A)\ =\ T(A \cap B)\ \ \ / \ T(B)$$

$$F(B \Rightarrow A) = \left(\frac{S(WA \cap HB) + S\ (PA \cap HB)}{S(B)}\right)^{\frac{1}{1+\alpha'}} * \left(\frac{T(A \cap B)}{T(B)}\right)^{\frac{1}{1+\beta'}}$$

EQ 4-3 Probability of finding a source of danger of activity B in the zone of activity A (value X)

α′, β′ factors as defined before,

$F(B \Rightarrow A)$ can give an idea about the probability of finding a source of danger of activity B in the zone of A.

4.7.1.1.2.1 The value of the probability according to the type of hazard

As we have mentioned before, this framework will request that the user determines the type of the hazard. Depending on the type, the value of probability and severity can then be calculated.

By studying and analysing the types of accidents on construction sites (see 2.2.3) we can logically conclude whether the hazard is a result of the conflict situation or not, as well as agreeing on the appropriate type of the equation.

Table 4-5 Value of the probability of the hazard according to its type

	The hazard	could be caused by conflict situation (the scope of the framework)	Value
1	Fall from height – roof	no	
2	Fall from stepladder	no	
3	Fall from height roof lights	yes	(Y)
4	Falling through fragile roofs	yes	(Y)
5	Fall from height scaffold	no	
6	Fall from height - moveable platform	no	
7	Falling at the same level	yes	(X)
8	Falling into the digging	yes	(Y)
9	Contact with portable objects by cranes	yes	(X)
10	Struck by moving vehicle	yes	(X)
11	Being struck by excavators, lift tricks or dumpers	yes	(X)
12	Lifting forks	yes	(X)
13	Being crushed by collapsing structures	yes	(Z)
14	In the vehicle with loss of control	yes	(Z)
15	On moving vehicle with loss of control	yes	(X)
16	Contact with electricity	yes	(X)
17	Cut by an equipment	yes	(X)
18	Cut with knife, cutting board	yes	(X)
19	Contact with falling objects	yes	(X)
20	Contact with hanging objects	yes	(X)
21	Diving in liquid	yes	(Y)
22	Chemicals materials	yes	(X)
23	Flammable materials	yes	(X)
24	Contact with moving parts of machine	yes	(X)
25	Contact with flying objects	yes	(Z)
26	Hit by sliding object	yes	(Y)
27	Hit by sliding persons	yes	(X)
28	Trapped between	yes	(X)
29	Fire	yes	(Y)
30	Buried by bulk mass	yes	(Y)

Then the probability of the accident is

$$P\,(B\Rightarrow A) = F\,(A) * F\,(B\Rightarrow A)$$

$$= \left(\frac{S(WA \cap HB) + S\,(PA \cap HB)}{S(A)}\right)^{\frac{1}{1+\alpha}} * \left(\frac{T(A \cap B)}{T(A)}\right)^{\frac{1}{1+\beta}}$$

$$* \left(\frac{S(WA \cap HB) + S\,(PA \cap HB)}{S(B)}\right)^{\frac{1}{1+\alpha'}} * \left(\frac{T(A \cap B)}{T(B)}\right)^{\frac{1}{1+\beta'}}$$

EQ 4-4 Probability of the accident type X

or

$$P(B \Rightarrow A) = \left(\frac{S(WA \cap HB) + S\,(PA \cap HB)}{S(A)}\right)^{\frac{1}{1+\alpha}} * \left(\frac{T(A \cap B)}{T(A)}\right)^{\frac{1}{1+\beta}}$$

EQ 4-5 Probability of the accident type Y

or

$$P(B \Rightarrow A) = \left(\frac{S(WA \cap HB) + S\,(PA \cap HB)}{S(A)}\right)^{\frac{1}{1+\alpha}} * \left(\frac{\mathrm{T(A \cap B)}}{T(A)}\right)^{\frac{1}{1+\beta}} * f(B \Rightarrow A)$$

$f(B \Rightarrow A)$ Є] 0, 1]

EQ 4-6 Probability of the accident type Z

P (B⇒A) is the probability of a predicted accident to a worker of activity (A) caused by activity (B).

4.7.1.1.3 Quantitative measure of the severity of the accident

As we have mentioned before, the model of (Tolle, 2009), which was later used by most researchers in the workers' safety field, states that the nature of the severity is linear.

The severity of the accident can be measured by its cost; this research will therefore assume that the curve of the severity with its grade must be increasing, in comparison with the cost of the actual accident.

Hence, we will develop an equation to calculate the cost of the accident to predict the severity of possible occurrences.

However, as we discuss prediction, we only consider the two most significant factors of the accident cost, which are lost working days and the compensation.

One benefit of this method is that it makes it easier to estimate the increasing cost; this is due to the predicted accidents, since it relies on the damage and simulates the real cost of an actual accident. We can also obtain the feedback easily by comparing the result with a previous accident, while the other benefit is that it considers the nonlinear nature of the increased severity.

However, we will not calculate the cost as a sum of money but as a number of units, which can be altered to a predicted accident cost by multiplying it with the price of ten points.

A similar process is used by insurance companies; however they have tables to calculate the price of the point according to the number of the points. In these tables, the price of the point is not fixed, it increases with the number of the points. Therefore, the price follows the rule known as the "the more points, the more expensive the point". Figure 4-16 shows one page of these tables taken from Milan court.

The concept of the point is similar to the level of the severity, which is estimated by the health and safety management division. Though they calculate it prior to the accident, while insurance companies calculate the points after the accident so it is more precise and could have a large range, this range of the points worldwide is 100 points.

This follows the hypothesis of this research that states that the curve of severity cannot be linear with its level, but must instead be increasing.

In addition, the way in which insurance companies calculate sick days shows that ten days are equal to one point.

Referring back to the insurance company data, the court tables can be used to calculate the compensation by implementing the following strategies:

- Convert the currency on the tables into comparative numbers regarding the points by dividing them by the price of the point,
- Consider that every ten points refer to one level of the severity of an accident,

– Consider that the maximum of the severity is the death and estimate the severity with a number between 1 and 10, 10 is the death, see Table 4-6,
– Ignore the factor of the age of the casualty, considering that workers are generally young, and that this piece of information is unpredictable.

By drawing the results on two axes as we can see in Figure 4-17, the axis X shows the number of the points given by the insurance company to assess the damage of the casualty divided by ten, it indicates the level of the severity g which is an integer number between 1 and 10. While the axis Y shows the corresponding severity G, this is calculated by dividing the compensation which matches the number of the points shown in the tables by ten times of the price of one point. By the use of approximation methods we can find the suitable equation below:

$$G(B \Rightarrow A) = \frac{d}{100} + \frac{g^{\left(1+\left(\frac{1}{g}\right)^{1/n}\right)}}{10}$$

EQ 4-7 Severity of a predicted accident

with

g : the level of the severity estimate by the user (safety engineer),

n : variable from country to another as we see below,

d: lost days.

aumento percentuale ISTAT (FOI) rispetto ad anno precedente :+2,4%							(su 2 anni = +5,6535%)				Indennità temporanea assoluta (ITA) da € 96 a € 144 giornaliere				
				Risarcimento: fasce di età 1-10											
				Fasce di età											
				1	2	3	4	5	6	7	8	9	10		
				Demoltiplicatore											
Invalidità	Punto biologico 2008 riv. al 2013	aumento	Punto danno "non patrimoniale" al 2013	1,000	0,995	0,990	0,985	0,980	0,975	0,970	0,965	0,960	0,955	aumento personalizzato	Invalidità
1	1.161,83	25%	1.452,28	1.452,00	1.445,00	1.438,00	1.430,00	1.423,00	1.416,00	1.409,00	1.401,00	1.394,00	1.387,00	+ max 50%	1
2	1.234,44	25%	1.543,05	3.086,00	3.071,00	3.055,00	3.040,00	3.024,00	3.009,00	2.994,00	2.978,00	2.963,00	2.947,00	+ max 50%	2
3	1.307,05	25%	1.633,82	4.901,00	4.877,00	4.852,00	4.828,00	4.803,00	4.779,00	4.754,00	4.730,00	4.705,00	4.681,00	+ max 50%	3
4	1.379,67	25%	1.724,58	6.898,00	6.864,00	6.829,00	6.795,00	6.760,00	6.726,00	6.691,00	6.657,00	6.622,00	6.588,00	+ max 50%	4
5	1.452,28	25%	1.815,35	9.077,00	9.031,00	8.986,00	8.941,00	8.895,00	8.850,00	8.804,00	8.759,00	8.714,00	8.668,00	+ max 50%	5
6	1.597,51	25%	1.996,89	11.981,00	11.921,00	11.862,00	11.802,00	11.742,00	11.682,00	11.622,00	11.562,00	11.502,00	11.442,00	+ max 50%	6
7	1.742,74	25%	2.178,42	15.249,00	15.173,00	15.096,00	15.020,00	14.944,00	14.868,00	14.791,00	14.715,00	14.639,00	14.563,00	+ max 50%	7
8	1.887,97	25%	2.359,96	18.880,00	18.785,00	18.691,00	18.596,00	18.502,00	18.408,00	18.313,00	18.219,00	18.124,00	18.030,00	+ max 50%	8
9	2.033,19	25%	2.541,49	22.873,00	22.759,00	22.645,00	22.530,00	22.416,00	22.302,00	22.187,00	22.073,00	21.959,00	21.844,00	+ max 50%	9
10	2.178,42	26%	2.744,81	27.448,00	27.311,00	27.174,00	27.036,00	26.899,00	26.762,00	26.625,00	26.487,00	26.350,00	26.213,00	+ max 49%	10
11	2.278,63	27%	2.893,86	31.832,00	31.673,00	31.514,00	31.355,00	31.196,00	31.037,00	30.877,00	30.718,00	30.559,00	30.400,00	+ max 48%	11
12	2.378,11	28%	3.043,98	36.528,00	36.345,00	36.163,00	35.980,00	35.797,00	35.615,00	35.432,00	35.249,00	35.067,00	34.884,00	+ max 47%	12
13	2.478,32	29%	3.197,03	41.561,00	41.354,00	41.146,00	40.938,00	40.730,00	40.522,00	40.315,00	40.107,00	39.899,00	39.691,00	+ max 46%	13
14	2.577,80	30%	3.351,14	46.916,00	46.681,00	46.447,00	46.212,00	45.978,00	45.743,00	45.508,00	45.274,00	45.039,00	44.805,00	+ max 45%	14
15	2.678,01	31%	3.508,19	52.623,00	52.360,00	52.097,00	51.834,00	51.570,00	51.307,00	51.044,00	50.781,00	50.518,00	50.255,00	+ max 44%	15
16	2.777,49	32%	3.666,29	58.661,00	58.367,00	58.074,00	57.781,00	57.487,00	57.194,00	56.901,00	56.607,00	56.314,00	56.021,00	+ max 43%	16
17	2.877,70	33%	3.827,34	65.065,00	64.739,00	64.414,00	64.089,00	63.763,00	63.438,00	63.113,00	62.787,00	62.462,00	62.137,00	+ max 42%	17
18	2.977,18	34%	3.989,42	71.810,00	71.450,00	71.091,00	70.732,00	70.373,00	70.014,00	69.655,00	69.296,00	68.937,00	68.578,00	+ max 41%	18
19	3.077,39	35%	4.154,47	78.935,00	78.540,00	78.146,00	77.751,00	77.356,00	76.962,00	76.567,00	76.172,00	75.778,00	75.383,00	+ max 40%	19
20	3.176,87	36%	4.320,54	86.411,00	85.979,00	85.547,00	85.115,00	84.683,00	84.250,00	83.818,00	83.386,00	82.954,00	82.522,00	+ max 39%	20
21	3.277,07	37%	4.489,59	94.281,00	93.810,00	93.339,00	92.867,00	92.396,00	91.924,00	91.453,00	90.982,00	90.510,00	90.039,00	+ max 38%	21
22	3.376,56	38%	4.659,65	102.512,00	102.000,00	101.487,00	100.975,00	100.462,00	99.949,00	99.437,00	98.924,00	98.412,00	97.899,00	+ max 37%	22
23	3.476,76	39%	4.832,70	111.152,00	110.596,00	110.041,00	109.485,00	108.929,00	108.373,00	107.818,00	107.262,00	106.706,00	106.150,00	+ max 36%	23
24	3.576,24	40%	5.006,74	120.162,00	119.561,00	118.960,00	118.359,00	117.759,00	117.158,00	116.557,00	115.956,00	115.355,00	114.755,00	+ max 35%	24
25	3.676,45	41%	5.183,80	129.595,00	128.947,00	128.299,00	127.651,00	127.003,00	126.355,00	125.707,00	125.059,00	124.411,00	123.763,00	+ max 34%	25
26	3.775,93	42%	5.361,82	139.407,00	138.710,00	138.013,00	137.316,00	136.619,00	135.922,00	135.225,00	134.528,00	133.831,00	133.134,00	+ max 33%	26
27	3.876,14	43%	5.542,88	149.658,00	148.909,00	148.161,00	147.413,00	146.665,00	145.916,00	145.168,00	144.420,00	143.671,00	142.923,00	+ max 32%	27
28	3.975,62	44%	5.724,89	160.297,00	159.496,00	158.694,00	157.893,00	157.091,00	156.290,00	155.488,00	154.687,00	153.885,00	153.084,00	+ max 31%	28

Figure 4-16 One table of the assessment of damages, Court of Milan Tables 2013

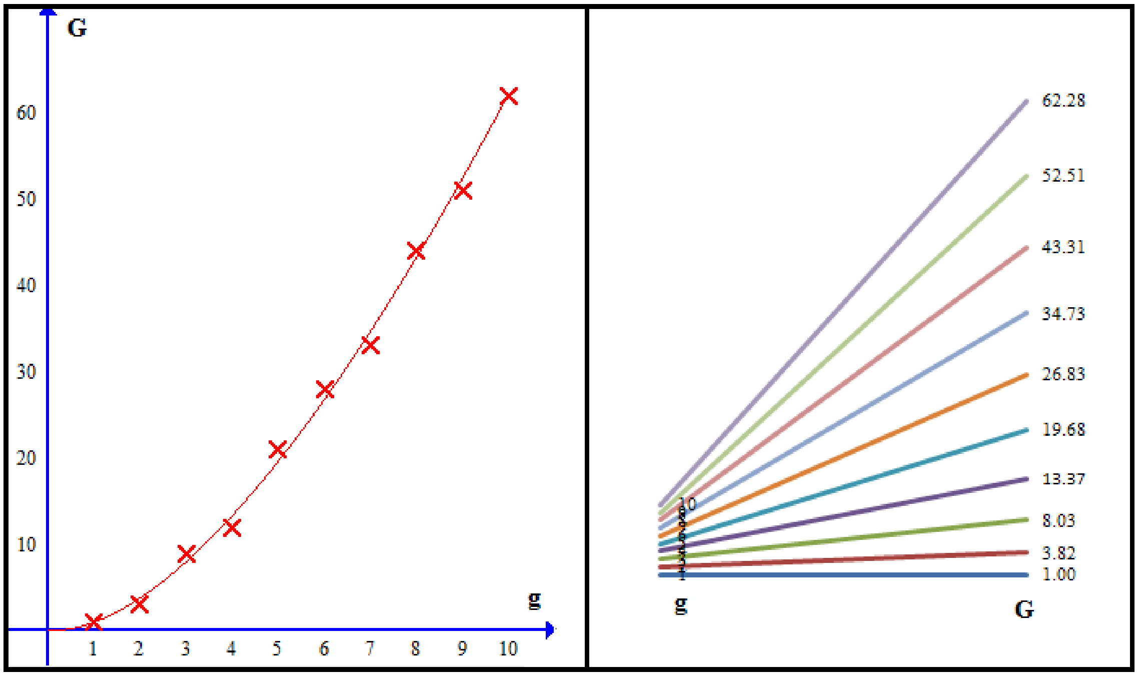


Figure 4-17 Increase the point price with the increasing of the points number in the insurance company.

Taking into account that these tables are not fixed and can differ from one country to another and with new domestic laws, we suggest the variable number (n) which could be adapted to the law.

However, since severity is of an increasing nature, the calculations simulate the cost of the real accidents.

The number g indicates the severity of the predicted accident may be classified, similarly to the previous way of this field, into rather broad classes depending on the available accidents data. Figure 4-18 shows an example of this data (major injuries classifications, RIDDOR).

Major injuries

"Major injuries" are defined as (reg.2(1)/ Sch.1):

Fracture, other than to fingers, thumbs or toes	Amputation
Dislocation of the shoulder, hip, knee or spine	Loss of sight, temporary or permanent
Chemical or hot metal burn to, or penetrating injury of, the eye	Injury from electric shock or burn leading to unconsciousness or requiring resuscitation or more than 24 hours in hospital
Injury leading to hypothermia, heat-induced illness or to unconsciousness	Injury requiring resuscitation
Injury requiring admittance to hospital for more than 24 hours	Loss of consciousness through asphyxia or exposure to a harmful substance or biological agent
Acute illness requiring medical treatment or loss of consciousness, resulting from the absorption of any substance by inhalation, ingestion or through the skin	Acute illness requiring medical treatment where there is reason to believe that it resulted from exposure to a biological agent or its toxins or in

Figure 4-18 Example from injury kind classifications, RIDDOR

This research determines g along with its definition in accordance with the assessment of casualties in insurance companies, Table 4-6 shows suggestions of the g classes with the equivalent RIDDOR (Reporting of Injuries, Diseases and Dangerous Occurrences Regulations) category.

Table 4-6 Suggested g classes with equivalent RIDDOR category

g	The prediction hazard	Equivalent RIDDOR Category
10	Death	Fatality
9	High level of permanent disability	Amputation; Loss of Sight
8	Permanent disability	Dislocation of the shoulder, hip, knee or spine;
7	Incurable major injury	Chemical or hot metal burn to the eye or any penetrating injury to the eye; Loss of consciousness caused by asphyxia or exposure to harmful chemical or biological agent;
6	Burns	Incurable fire burn ; chemical or hot metal burn;
5	Major injury	Any fracture except fingers, thumbs or toes; Acute illness requiring medical treatment; loss of consciousness as a result of absorption of a chemical or biological agent by inhalation, ingestion or through the skin; Also acute illness as a result of exposure to a biological agent, its toxins or infected material
4	electrical shock	Injury resulting from an electric shock or electrical burn leading to unconsciousness or requiring resuscitation or admittance to hospital for more than 24 hours;
3	Minor injury	More than 3 days
2	Very minor injury	1-3 days
1	Without injury	

To estimate the degree of severity caused by a hazard, we find numerous amounts of data on the statistic numbers web including the special health and safety sites, specialized journals, companies, courts, insurance companies, accident books, interviews, accident records, and state of art like the publications of Health and Safety Executive which are available online www.hse.gov.uk/statistics/. Figure 4-19 shows an example of these data.

Potential Accident Severity

Study No	Outcome / injury (actual)[15] (1)	Potential outcome /injury (likely)[16] (2)	1-3-days[17]	> 3-day	Major	Fatality	Potential outcome / injury (possible)[2] (3)	1-3-days	> 3-day	Major	Fatality	Comments (4)
001	Struck by rebar tie-wire – injured eye	Loss of sight or penetrating injury to eye			✓		Loss of sight or penetrating injury to eye			✓		Severity depends on 'chance'
002	Cut by circular saw – injured hand	More serious hand lacerations requiring time off		✓			Even more serious hand injury – loss of fingers or use of hand			✓		Severity depends on 'chance'
003	Fire – no injury?	Injuries from fire – eg requiring hospitalisation			✓		Fatalities from fire				✓	Severity depends on chance and effectiveness of emergency procedures
004	Struck by falling prop – injured back	More serious back injury or shoulder dislocation – eg requiring hospitalisation			✓		Serious head injury leading to fatality or permanent disability				✓	Severity depends on body part hit
005	Struck when dropped steel angle – injured finger	More serious crush injury to hand - eg requiring hospitalisation			✓		Loss of finger / hand			✓		Severity depends on 'chance'
006	Ring snagged on protrusion – injured finger	Fracture to finger requiring time off		✓			Loss of finger			✓		Severity depends on 'chance'
007	Cut with knife whilst cutting board – injured leg	More serious leg laceration requiring time off		✓			Other laceration – eg leading to loss of finger or hospitalisation			✓		Severity depends on 'chance'
008	Hit self with scaffold tube – injured foot	Fracture to toe requiring time off		✓			Serious fracture to foot / ankle leading to hospitalisation			✓		Severity depends on 'chance'
009	Struck by steel 'banding' to brick pack – cut arm	More serious laceration to arm or other body part requiring time off		✓			Loss of sight or penetrating injury to eye			✓		Severity depends on body part hit and use of appropriate PPE

Figure 4-19 Example of potential accident severity, from (Health and Safety Executive, 2003)

4.7.1.2 Calculation of the risk

The risk H is defined as a function of the probability P and the severity G:

$$H\,(B{\Rightarrow}A) = f\,(P\,(B{\Rightarrow}A),\, G\,(B{\Rightarrow}A))$$

$$H(B \Rightarrow A) \;=\; N * \left(\frac{S(WA \cap HB)}{S(A)}\right)^{\frac{1}{1+\alpha}} * \left(\frac{T(A \cap B)}{T(A)}\right)^{\frac{1}{1+\beta}} * n * \left(\frac{S(WA \cap HB)}{S(B)}\right)^{\frac{1}{1+\alpha'}} * \left(\frac{T(A \cap B)}{T(B)}\right)^{\frac{1}{1+\beta'}} * \left(\frac{d}{100} + \frac{g^{\left(1+\left(\frac{1}{g}\right)^{\frac{1}{4}}\right)}}{10}\right)$$

N: number of the workers

n: number of the sources of the hazard

EQ 4-8 Risk (B⇒A) type X

$$H(B \Rightarrow A) \;=\; N * \left(\frac{S(WA \cap HB)}{S(A)}\right)^{\frac{1}{1+\alpha}} * \left(\frac{T(A \cap B)}{T(A)}\right)^{\frac{1}{1+\beta}} * \left(\frac{d}{100} + \frac{g^{\left(1+\left(\frac{1}{g}\right)^{\frac{1}{4}}\right)}}{10}\right)$$

EQ 4-9 Risk (B⇒A) type Y

$$H(B \Rightarrow A) = N * \left(\frac{S(WA \cap HB)}{S(A)}\right)^{\frac{1}{1+\alpha}} * \left(\frac{T(A \cap B)}{T(A)}\right)^{\frac{1}{1+\beta}} * \left(\frac{d}{100} + \frac{g^{\left(1+\left(\frac{1}{g}\right)^{\frac{1}{4}}\right)}}{10}\right) * f(B \Rightarrow A)$$

EQ 4-10 Risk (B⇒A) type Z

In the same way, we can calculate the risk (A⇒B).

The total risk of the conflict is then expressed by the sum:

Risk (A, B) = Risk (B⇒A) + Risk (A⇒B).

This risk number can provide an indication on the risk of the A and B space-time-conflict.

One of the most significant uses of this method is that the calculated risk number can be easily altered into an estimated monetary value, stating the predicted cost of the accident.

4.7.2 *The total risk in the project*

$$H\ Project = \sum_{n=1}^{n=T} (P(i -> i+1) + P(i+1 -> i))$$

EQ 4-11 H Project

H Project can offer an indication about the risk in the project due to conflicting activities.

It can also be modified into an expected monetary value expressing the predicted accident costs occurring during the project period.

4.8 The form in the WSiCPM framework

In the WSiCPM framework, we use both qualitative and quantitative analysis. Figure 4-20 provides a screenshot of an example application, illustrating how these two measures appear in the framework.

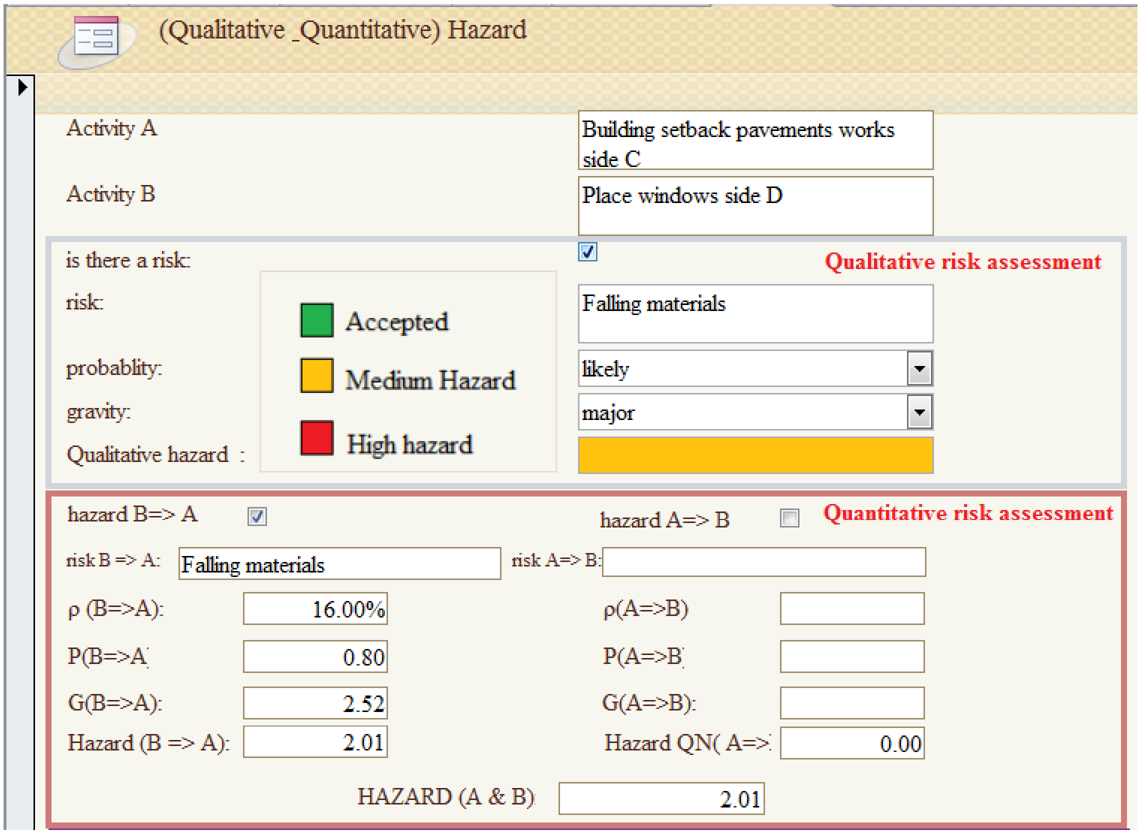


Figure 4-20 Form of qualitative and quantitative analysis of conflicting activities on the construction site

4.9 Risk response and change request

The WSiCPM framework functions like an expert system; the outputs of the quantitative risk prediction in addition to spatial information and time information from CPM are the input in this operation. For each hazardous space-time-conflict pair, the software in the framework suggests a solution depending on the analysis of the input data.

The framework aids the decision maker in resolving the conflict, i.e. to eliminate or mitigate the risk or to accept it positively (taking some measures). Therefore, this process is acceptable as risk response since it fulfils the definition of the PMBOK of risk response.

4.9.1 *The suggestions of the framework*

The decision where the change is helpful, in the design or in the schedule, relies on several parameters:

- The percentage of the interface area to the activity area,
- The percentage of the interface between the hazardous area with the path to the interface between the hazard area with the work area,
- The percentage of the time-overlapping to the activity time,
- Whether the activity is critical or not.

These parameters and others play an important role in the suggestion proposed by the WSiCPM framework.

As a result, the framework suggests several solutions, as will be illustrated below.

4.9.1.1 The first case

If the interference of the hazard area of one activity with the path area of another one is greater than that with its work area, the framework recommends a change to be made to the path of the last one.

S ($P_A \cap H_B$) is greater than S ($W_A \cap H_B$) ➔changing path (A).

S ($P_B \cap H_A$) is greater than S ($W_B \cap H_A$) ➔changing path (B).

Figure 4-21 shows an illustration of the alternative paths.

This recommendation must be discussed in a safety meeting. If it is found to be appropriate, a change request is then sent to the safety designer to modify the related BDS table or to add another, to resolve this hazardous situation.

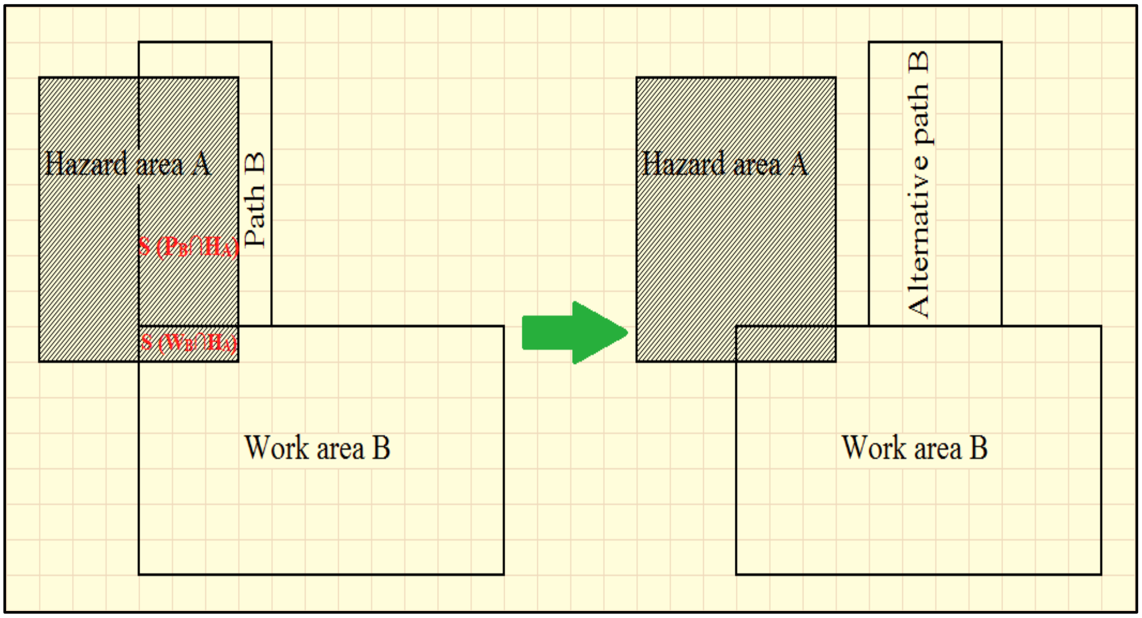


Figure 4-21 Change the critical path of an activity

4.9.1.2 The second case

Considering the interference of the hazard area of an activity with the work area of another activity is minor in comparison with the work area itself, and the overlap time is less than the duration of the last activity, taking into account the ability of the last activity to be divided, then the framework will suggest subdividing it.

I.e. the area of the second activity will be divided into two parts, so the work can be done in the safe area whilst the hazard activity takes place.

$S(W_A)/S(W_A \cap H_B) > 2$ and $T(A \cap B) < T(A) \rightarrow$ Division of the work area of activity A.

$S(W_B)/S(W_B \cap H_A) > 2$ and $T(A \cap B) < T(A) \rightarrow$ Division of the work area of activity B.

Figure 4-22 clarifies the work area division

If the proposed solution is found to be convenient, a request to make changes is sent to the safety designer, who would provide an alternative BDS drawing or modify the existing one.

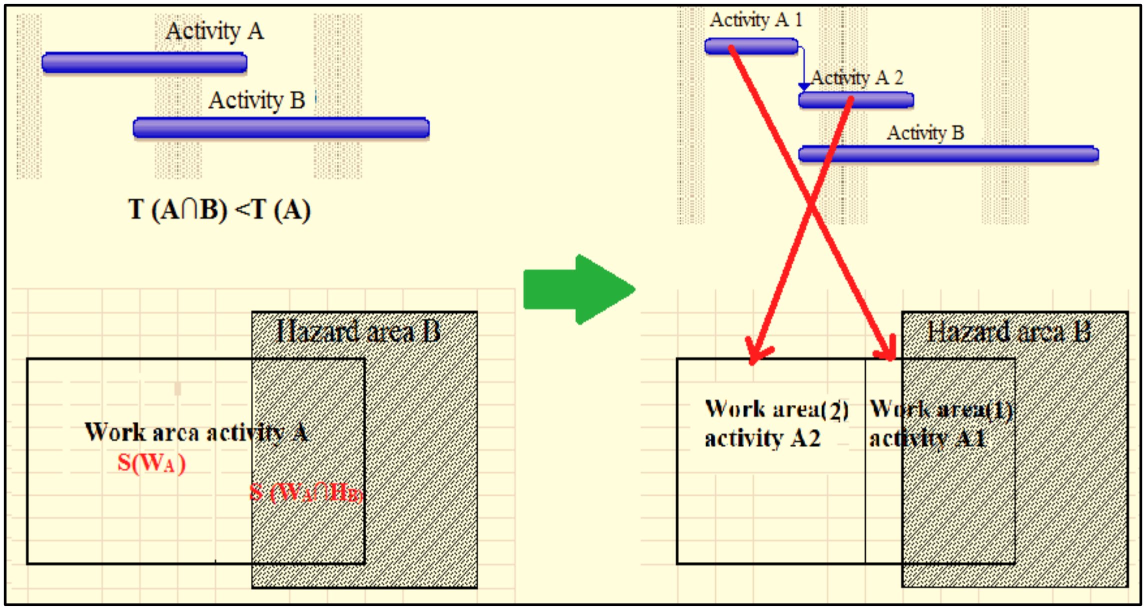


Figure 4-22 Area division

4.9.1.3 The third case

If the overlap-time is small in comparison with the duration of one of the activities, which can be achieved in two phases and is not critical, the framework proposes dividing of the workload. Thus, the work in the long activity is halted and later continues after the end of the hazard (time dividing), as seen in Figure 4-23.

T (A∩B) << T (A)➔ Split (A).

T (A∩B) << T (B)➔ Split (B).

This solution has to be evaluated, and if found to be adequate, a change request will be sent to the planner to adjust the schedule and examine the impact of it on the project schedule.

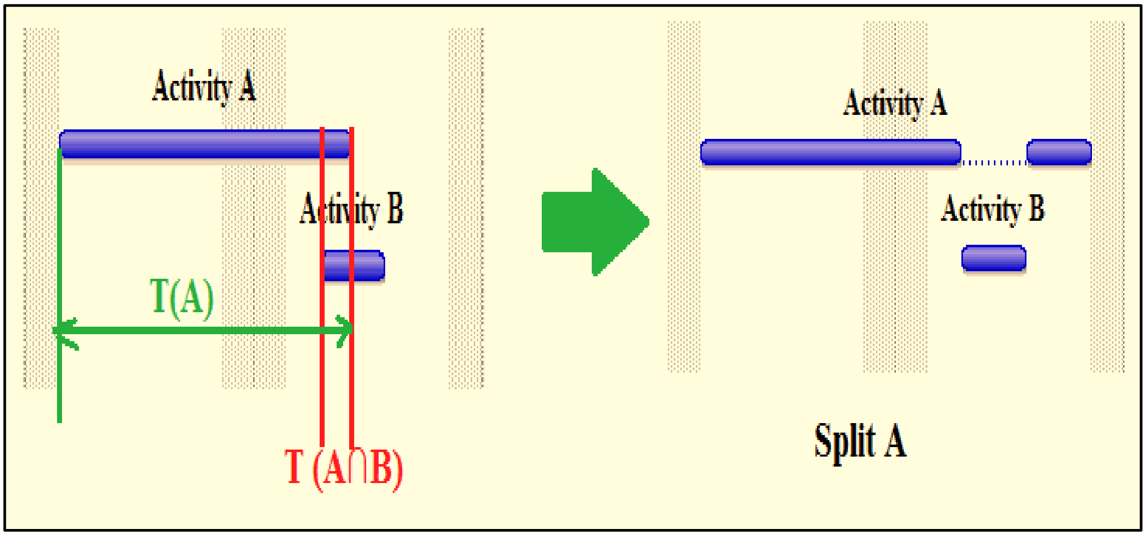


Figure 4-23 Activity split

4.9.1.4 The fourth case

When the risk is high and the interference of the space is substantial (the two works take place almost in the same place), and the overlap of time is equal to the duration of one of the two activities; re-scheduling the non-critical activities would be the main solution proposed by the framework.

$S(W_A \cap W_B) \approx S(W_A) \approx S(W_B)$ and $T(A \cap B) = T(A)$ or $T(A \cap B) = T(B)$ ➔

Reschedule (A)
if A is not critical

Reschedule (B)
if B is not critical

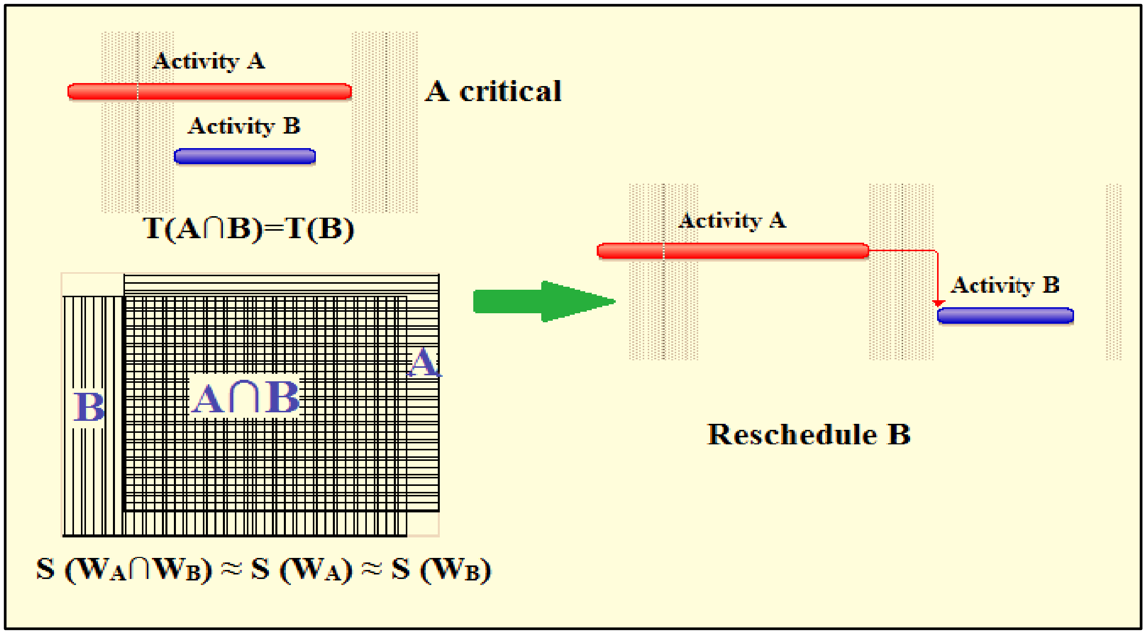


Figure 4-24 Rescheduling

4.9.1.5 The fifth case

When the area of the conflict is small and the risk is low, we can take some measures in the site and clarify them in BDS.

When the risk is low, it is enough to take measures on the site and notes in the BDS.

4.9.1.6 The sixth case

If both activities are critical without free or total float, we must consider an alternative, since changing the schedule in this case means the delay of the project. However, if there is no other solution, we must accept the additional length of the project and include it in the calculation of the project cost as well as the end date.

4.9.2 *Design change request*

Using graphic method of (BDS) (Building Design for Safety), see 2.4.5, allows the process of determining the drawings that must be altered to be easily accomplished. This is due to the WBS used in this method, which is key in the database, therefore getting the numbers of the drawings related to the activities is not challenging.

The BDS change request includes three cases:

- Change the path,
- Divide the work area,
- Take other measures (e.g. notes, add other risks, other safeguards, other PPE, etc.).

4.9.3 *Schedule change request*

The schedule change request includes two cases:

- Split an activity;
- Reschedule an activity.

The impact of this change has to be examined and if both activities are critical, the schedule change means additional costs and increased duration, which have to be taken into account.

4.10 Conclusion

The framework WSiCPM was introduced in this chapter, beginning with the presentation of the methodology and later discussing the steps of the CPM method.

The probability and severity of predicted accidents were then addressed, both qualitatively and quantitatively.

For the qualitative assessment, a modification of the previous model in this field (Toole, 2009) was used.

An alternative theory was then introduced to determine the probability and severity of the predicted accident quantitatively. The probability calculation was based on probability theory in mathematics, considering the overlapping duration, overlapping spaces of the interfering activities and number of the workers, as well as sources of danger.

To calculate the severity, it was assumed that the equation is not linear as it was in earlier researches, yet must be increased. The equation developed in this research depends on the damage measure, and therefore simulates the real cost of the accident and the compensation paid. This was derived from the data of insurance companies that are transferred from currency to quantitative factors.

It continues to explain how this framework calculates the risks created by overlapping activities in the whole project, and how this number of quantitative risks could be modified into expected money value, asserting the predicted accident costs.

The chapter concludes with illustrations on how the WSiCPM framework could work as an expert system, while proposing a solution for each hazardous space-time-conflict pair of activities to aid the planner in resolving the conflict and eliminate the hazard or reduce it.

Therefore, the proposals introduced by this framework were assessed and found to be appropriate.

CHAPTER 5

INTEGRATION OF THE DESIGN FOR SAFETY INTO THE SCHEDULE FOR WORKERS' SAFETY

5.1 Introduction

As mentioned previously in the introduction of this research, the approach of 'schedule for safety' is rarely considered.

In this chapter, we will attempt to achieve safety in schedule through incorporating health and safety into the construction critical path method (CPM) scheduling software, as well as considering health and safety early in the design and construction phase. This integration of safety within the schedule allows for advanced safety planning.

5.2 Linking the CPM with BDS

5.2.1 *The main underlying attributes of this linking*

We are finding a link between numerous concepts, which are traditionally analysed separately:

- Constructability, which expresses construction knowledge and experience,
- Safety in design,
- Planning and particularly scheduling.

We can rely on the theory of the PMBOK management school, which determines the relationship between management fields. This relationship has been altered, as seen in Figure 5-1, which outlines the scope of this research.

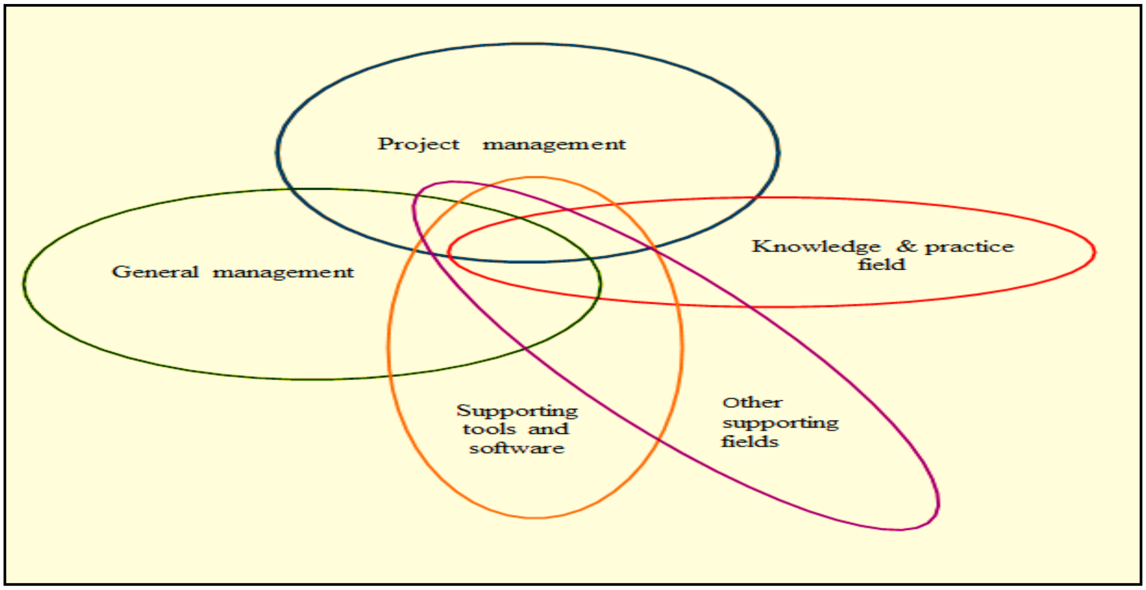


Figure 5-1 Relationships between project management and other fields modified from (PMBOK Guide)

Considering a recent research carried out by Capone et al. to develop a BDS tool which conveys the integration between the constructability and safety in design, as seen in Figure 5-2.

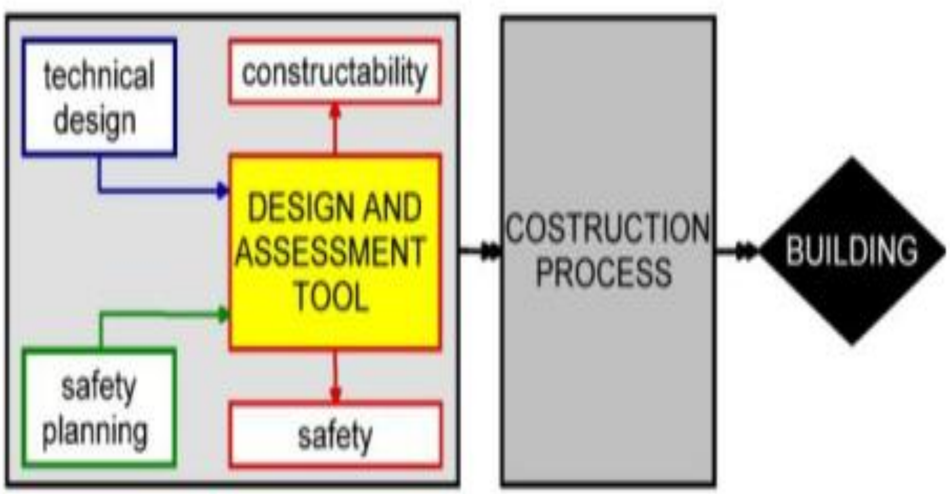


Figure 5-2 Integration of constructability and safety in the design (P. Capone, V. Getuli and T. Giusti, 2014)

In this research, we attempt to link BDS to the schedule to achieve the integration of schedule, safety and constructability, and to apply the BDS tool during the construction and control phases as well as in the design phase.

5.2.2 *Enabling BDS in all project phases by linking it with CPM*

The methodology in this research studies the interaction between the phases described by PMBOK, see3.2, while taking into account the relationship between the design and construction phases presented by (P. Capone, V. Getuli, and T. Giusti, 2014), see Figure 5-2.

Figure 5-3 describes the methodology which enables BDS application in all project phases (design, planning, construction, controlling & monitoring, closing) by linking it with CPM.

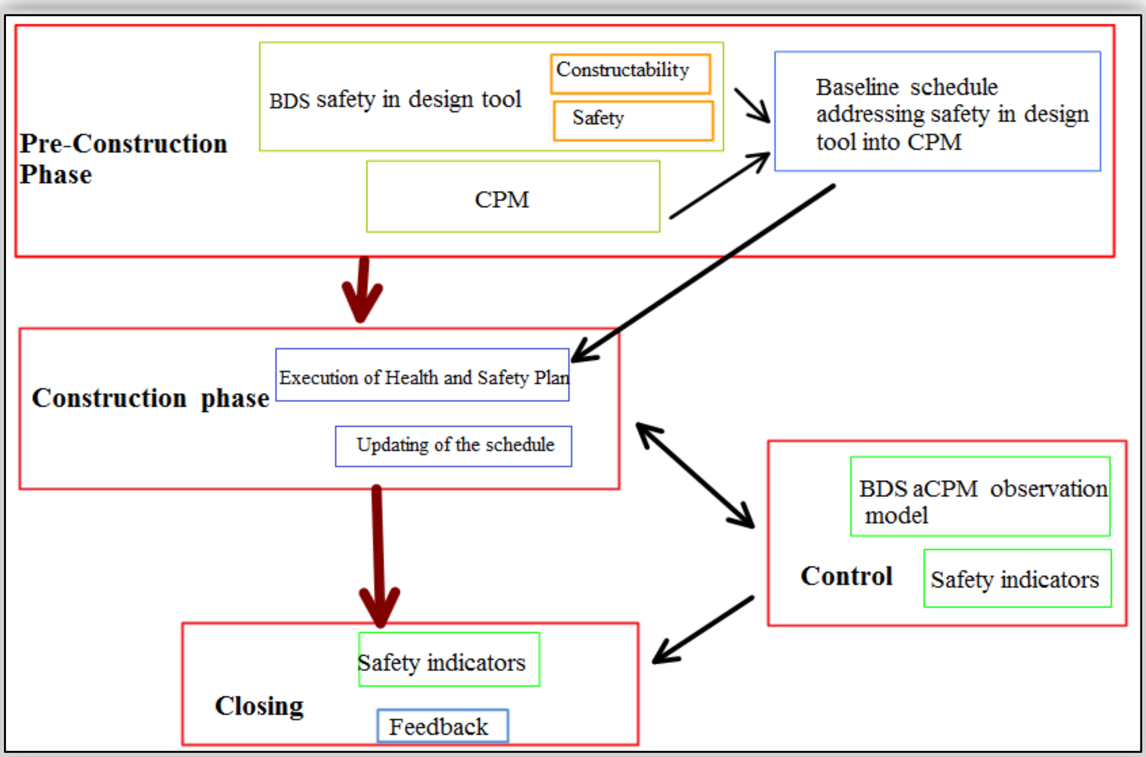


Figure 5-3 Methodology of linking BDS with CPM

5.2.3 *The advantage of this link*

The expected benefits of this link are:

- Enabling space consideration in the CPM,
- Add the time dimension to the design in safety tool (BDS), i.e. provide the BDS with the ability to consider time, and give it the feasibility to continue along with the construction phase,
- Add the time data to the BDS tables when necessary, see Figure 5-4,
- Allow the BDS the ability to be followed up, observed, and controlled,
- Integrate the BDS in the short-term scheduling,
- Incorporate BDS into the construction, control, and close phases.

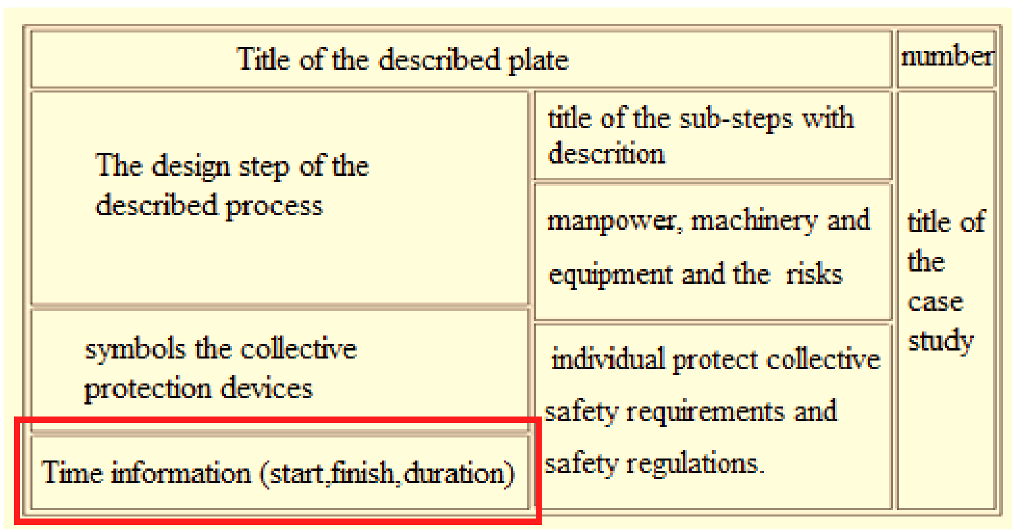


Figure 5-4 Adding the time information to BDS

5.2.4 *The mechanism to perform this linking in this research*

To integrate the safety in design tool BDS into the schedule, we must adopt the same division of work package WBS (work breakdown structure) in both the design and schedule, which will be the key of linking in the database.

As seen previously, the crucial gap in the activity-based schedule is the lack of integration with the design. To achieve this integration, we must link the safety in design with the schedule, and through adding an extra tool with the design information to the CPM method, see Figure 5-5.

The link in the database is (one - many) since one activity may have one or more tables. On the other hand, this link adds the time dimension to the BDS and offers many advantages to this tool as a short-term planning and safety control on the site, as will be realised in the upcoming paragraphs.

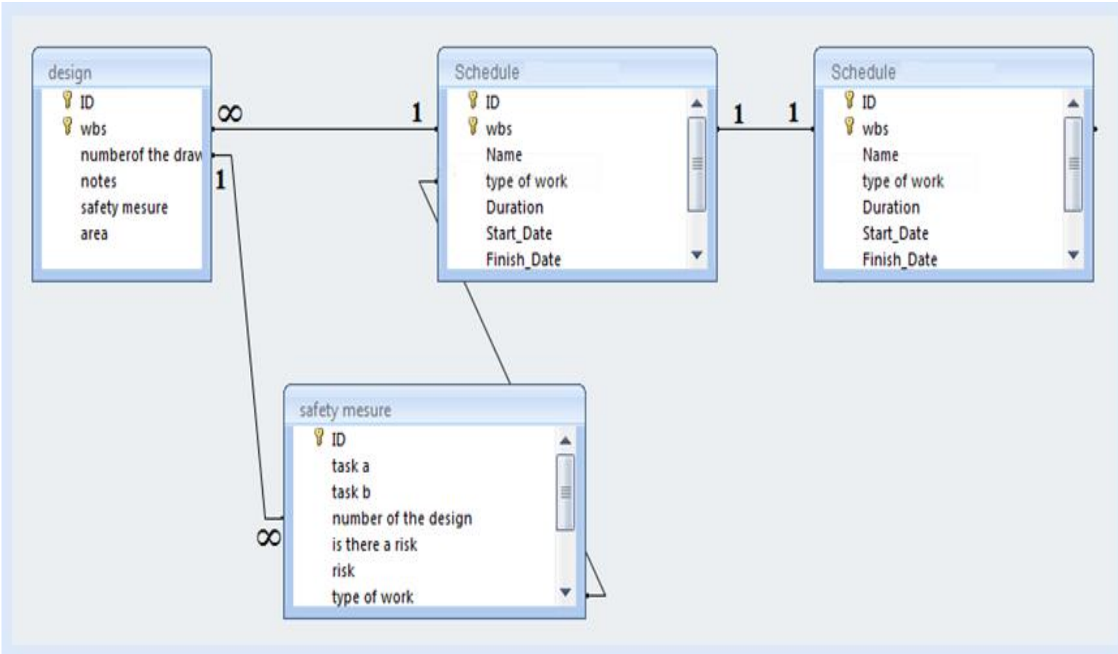


Figure 5-5 The link in the database

This additional view contents provides information on:

- The numbers of design,
- Personal protective equipment (PPE), e. g breathing apparatus, apron, gloves hard hats, harnesses, hearing protection, and safety shoes, etc.,
- Safeguards, e. g. handrails, safety signals, safety nets, fire extinguishers, and air bags, etc.,
- Technology used,
- Design Notes,
- Risks,
- Safety measures.

We will program this view in MS Project by using VBA. It will be an additional tool for workers' safety, and will appear in an additional tool bar; see Figure 5-6.

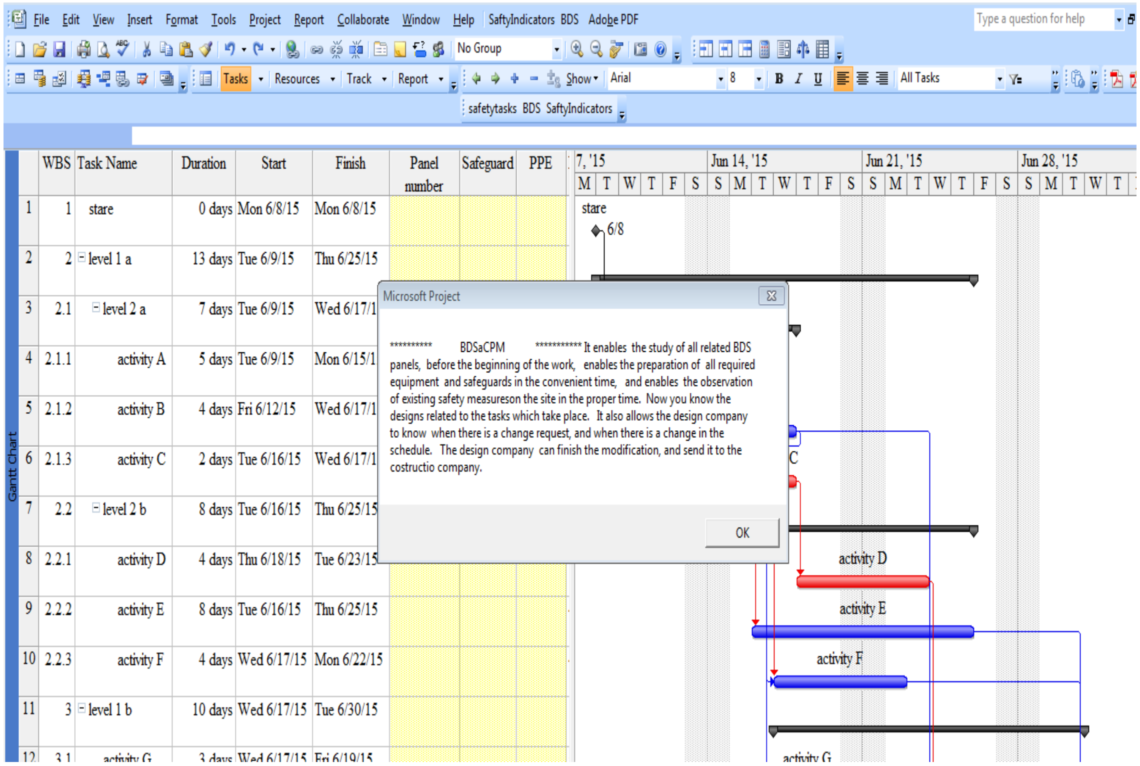


Figure 5-6 BDS table in the CPM method (MS Project Software)

5.3 Addressing workers' safety in the baseline schedule

Once the initial plan has been approved by all project participants and administration, it must be saved as a baseline schedule. The concept of baseline refers to the agreed schedule representing the original plan to complete the project, which must be completed and approved before work commences. The baseline is the benchmark against which the project progress will be compared at every update, at times referred to as the as-planned schedule.

To address safety in the baseline schedule, we must consider the rules mentioned below. Although we can find state-of-the-art examples of these operations or tasks, they are presented as safety guide information, safety notes, or accidents reports, not as a program or plan.

5.3.1 *Safety operations*

There are operations which must be added to the schedule to ensure workers' safety during the construction phase is a crucial part of the work and its presentation through vital activities with start day, duration, resources, and budget. This guarantees that they will be readable to all, and therefore not neglected.

Some examples of these operations are:

- Schedule an operation to construct permanent electrical systems early in the construction phase,
- Schedule an operation to construct permanent lighting systems early in the construction phase,
- Schedule an operation to construct underground firewater at the beginning of the project to have early fire fighting,
- Schedule an operation to construct a permanent stairway at the beginning of the project to reduce the hazards of using temporary stairs and ladders,
- Schedule an operation to construct permanent handrails with the structural steel to ensure workers safety,
- Schedule an operation to construct permanent guardrails around skylights,
- Schedule an operation for each safeguard performance.

5.3.2 *Safety tasks*

There are several tasks to ensure improved safety performance. Some examples of these activities are:

- Schedule a task to paint and install prior materials, piping, and equipment to reduce worker accidents,
- Schedule a task to mark the locations of existing underground facilities,
- Schedule a task for remind the workers of the use of the suitable personal protective equipment (PPE) in the grave hazard cases,
- Schedule a task for removing concrete remains,
- Schedule a task to mark the power lines with warning flags, paint, etc.,

- Schedule a task to remove all debris, scattered tools, and other obstacles from work area to reduce tripping hazard,
- Schedule a task to keep containers of chemicals in a separate and secure store,
- Schedule a task to remove or hammer down any projecting nails.

5.3.3 *Tasks related to an activity itself*

There are tasks related to an activity or work package to reduce the hazard associated with this specific activity.

The activities generally involve specific hazards, which could be:

- Known and repeated with these activities in the same project or other projects. Some examples of these tasks are:
  - Schedule a task to erect a safety decking (lightweight platform) where the working platform is at a height less than 850 mm below wall-plate level to protect the workers from falling into the building,
  - Schedule a task to erect air bags or other soft landing system where there is work at height with the probability of falling,
  - Schedule a task to wear protective glasses when welding activities.
- Alternatively, these hazards are related to a unique activity in the project.

The design department, planner, and safety manger can determine these tasks, which are special actions related to a unique activity to determine a date to remind those responsible for doing so.

For example, if there was a demolition of a wall then the process must be done in or out due to the presence of electric cables, this task with its date must be included in the schedule.

A further example is if there was a special welding causing an accumulation of toxic gases and fumes in an enclosed place, a task to provide the welder with respiratory protection and a supply of fresh air would be crucial.

5.3.4 *Dependences and time consideration*

Achieving workers' safety at times requires rescheduling specific activities. Below we can find some examples:

- Schedule sufficient time for material installing,
- Schedule the project to lower the duration when the excavations are open to minimize the risk of falling into them,
- When there are activities at night, it is preferable to send a request to the design department to select the suitable type of light, and include it in the schedule,
- Some operations must be rescheduled to take place during cold periods, others in hot times, or reschedule others work during cooler periods (such as early mornings) and cooler places (such as sheltered or shaded areas) and so in, as far as possible,
- Schedule for temporary interruption of work tasks to allow additional clearance for crane, work area, etc.,
- In cold temperatures, schedule the cleaning of slippery surfaces and scaffoldings.

5.3.5 *Recurring task*

Recurring task is a repeated operation occurring every selected cycle (day, week, multi weeks, month, etc.).

- Schedule the task of site housekeeping regularly and allow enough time to ensure a clean and safe work area,
- Since most health and safety organisations recommend holding safety meetings regularly, it is necessary to schedule safety meetings every two weeks (this cycle depends on the duration of the project and its type).

5.3.6 *Safety milestones*

As seen previously, milestones are marked points in scheduling which have zero duration, no resources, no cost, and a different shape.

Many researchers suggest the use of milestone in the flow diagram, HSE recommend the use of the milestones to highlight major risks, or when the safety approval should be obtained (HSE, 2004). They can also be used to refer to safety measures, the presence of more than one risky operation, risky overlapping operations, or a sequence of risky operations. These milestones either allow the control of the hazards when necessary, set up the warning banners and signals, or remind workers of possible risks immediately before the hazardous activity commences.

For example:

- When excavation work takes place, it would be beneficial to add a milestone to reduce the number of workers and equipment near the excavation.
- When there is an activity requires a crane, a milestone could refer to setup the suitable signals
- Add a milestone to obtain the safety approval before work on the scaffold has begun.
- Also adding a milestone to obtain an approval to determine the condition of the soil before setting up a crane.

5.3.7 *Flexible and solid safety constraints*

Restrictions (conditions) must be considered and included in the schedule for the purpose of workers' safety. Therefore, the scheduled tasks will not only commence in accordance to the sequence of the operation, while safety conditions will be considered as well.

These constraints may be:

- Solid constraints
  - Must (start /finish) on
- Flexible constraints
  - As (soon/late) as possible
  - (Finish/start) no (earlier/later) than, etc.

5.3.8 *Obtaining equipment*

The contractors use the schedule to determine when various types of equipment will be needed at the site. These can be obtained in several ways – purchasing or hiring. In any case, it is imperative to include an inspection of the equipment condition in the schedule, prior to their use, to improve workers' safety.

5.3.9 *Obtaining permits*

Permits are written documents, which granting authorisation to build, remodel, or repair. It is essential to inspect the site and make sure it is safe for workers before any permits.

5.3.10 *Obtaining materials*

A list of materials is created during the estimation process. The time of when specific materials are required can be determined depending on the schedule.
Scheduling material delivery to the site is a crucial job to complete the project by deadline, and has a major impact on the workers' safety. Hence, this research recommends performing this process while taking into account workers' safety.
E.g. Schedule the delivery of materials to prevent storing a large amount of materials on construction sites, which leads to overcrowding and increased number of accidents on-site. Also, organising specific hazardous materials to only be stored on-site at the time of which they are required.

5.3.11 *Communications*

The communications for the purpose of workers' safety must be included in the general communication plan. This must determine the safety information required by individuals and the time of which it is necessary. The plan also specifies team safety meetings and reports of safety. Since MS Project is used in this research, we suggest the use of MS Outlook as an appropriate communication tool, since it is easy to be linked to the MS Project and automatically send messages to responsible individuals.

5.3.12 *Delay of time due of the accidents and injuries*

Finding the time delayed in the project due to accidents and injuries of workers at the work site can be achieved by calculating the lost days for each activity, taking into account the available float of it, which means days lost in the critical path and semi-critical path.

5.3.13 *Increase of project cost due to accidents and injuries*

Several researchers in the health and safety field have assessed the cost resulting from accidents and injuries, they can generally be briefed as:

- Health treatment costs,
- Time lost from work by casualties,
- Loss of efficiency by breaking up the work staff;
- Cost to train new employees,
- Failing to meet contract requirements,
- Overhead costs accompanied by work disruption,
- Insurance,
- Damages,
- Fines,
- Loss of production,
- Workers' crashes,
- Fines resulting from time delay in the project,
- Repair costs,
- Non-investment project in the its plan date,
- Administrative costs of investigations and reports,
- Increased insurance premiums,
- Negative publicity,

- Economic losses and lower standards of living of casualty workers and their families,
- Other direct and indirect costs.

5.3.14 *Cost of safety*

The cost of safety includes expenses due to safety planning, actions and measures, safe-guards, safety team salary, training courses, as well as safety meetings.
Contrary to other type of costs, safety cannot be compared with the cost of accidents by drawing both curves and choosing the lowest point, since it relates to the lives of workers.

5.3.15 *Choice of technology*

Construction and material technology has the potential to facilitate construction, reduce its time, upgrade its quality, reduce cost, get better productivity of workers and machine, and improve safety on the construction site.
In this research, we approve its role in improving the workers' safety, resolving the problem of overlapping operations, and resolving the problem of overcrowding on the site.
For example, considering alternative methods for pouring concrete can reduce the hazard on construction sites. Other examples of material and technology methods, which make the work on the construction site safer, are prefabricated and light materials.

5.3.16 *Documentation*

All safety laws such as OSHA laws ensure that accidents, illnesses, injuries, fatalities, as well as any near miss are registered and reported. A near miss is an incident that did not result in either injury or damage, yet had the potential to, (ENR, 2009).
These reports can be recorded online, as they are used by several organisations for annual accidents reports, the statistical number of accidents, and for further studies. These are all available online, such as OSHA, HSE, ENR, and Eurostat.

Record-keeping is highly essential for making decisions in the project itself, and for future projects in the company itself as well as other companies. In addition, it is used as information relevant to management, the project team, other stakeholders, and as data-base for the statistic reports.

A record of safety meetings must be documented, which will be used in the case of an accident to determine the responsibility.

These reports will be used in this research to track the safety in the project, and to assess safety indicators.

5.4 Derivative safety schedule

We recommend making an additional and separate safety program. This safety schedule will contain all safety operations (especially tasks related to the project itself) with its start date, finish date, duration, resources, all safety milestones, and the number of related safety designs.

In addition, it provides a description of all safety notes, warnings, and safeguards when they need to be followed or set up.

This concept has been influenced by derivative schedules (resources, materials, cash flow).

The derivative safety schedule can be extracted from the original schedule through the help of VBA in the environment of the MS Project.

5.5 Safety in schedule suggestion data base

We propose to add a data base to the CPM method. This data base should contain helpful suggestions for addressing safety in the schedule, based on experience, analyses of preceding projects, accidents reports, and records.

5.6 Look-ahead and short-term scheduling for safety

Traditionally, the safety in design is only executed once in the pre-construction phase. However, since the risk is not a one-time occurrence, it must be implemented in the construction phase along with the progress of the work. In this research, we will allow the BDS the ability to be applied during the construction and controlling phases by linking it with CPM.

As seen in 5.2.2 , this link provides the BDS with the time dimension, on the other hand it also allows the CPM to consider the spatial attributes, see Figure 5-3.

The general levels of planning are illustrated in Figure 5-7.

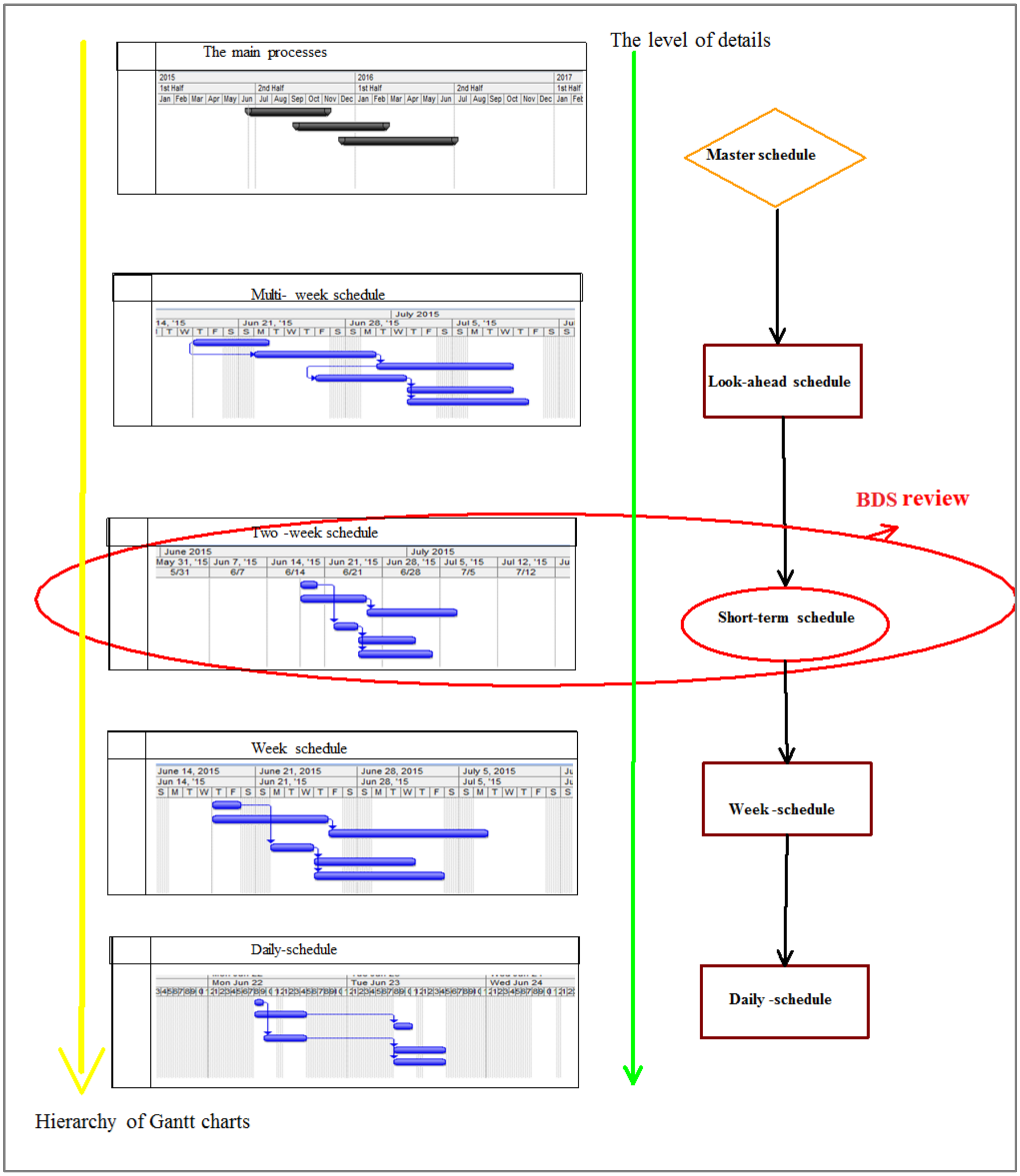


Figure 5-7 Planning levels

The master schedule concept refers to the first plan of the main (high level or summery level) activities and displays a strategic overview. It also contains crucial activities, although details are not included in this, it is prepared in the pre-construction phase depending on the design. This schedule must be clarified, while taking in account health and safety drawings.

This research recommends the implementation of two-weeks planning dedicated to BDS. This will allow the implementation of BDS to be carefully supervised and followed, while also enabling the study of all related tables, preparation of all required equipment and safeguards at the convenient time, as well as the monitoring of existing safety measures on the site at the proper time.

We propose sending the two-week schedule, containing the activities that run within the next 14 days, to the observer who must check whether the safety measures in BDS are sufficient, and register failures of the safeguards, as well as identifying the needs of other safeguards, see Figure 5-9.

If a hazardous situation is not included in the BDS, it must be identified and its causes explained, while an appropriate solution is proposed. This hazardous situation may arise due to work conditions, for example when it rains, or other unforeseeable factors. It may also be a result of the work being altered. When work is carried out, it is a common occurrence that some changes are introduced to the design and schedule. For example, if the BDS table relies on a finishing part, we need the (as-built) drawing to complete it.

The hazardous situation must be controlled and conditions eliminated, or other activities protected. This means that BDS drawings must be modified or other graphic tables added. In serious situations, if changes in the schedule lead to a hazardous conflict or if conditions do not allow an activity progress, they must be rescheduled.

The BDS must be examined by the site engineer and supervisors to make it easier to determine what must be done and when, for the purpose of safety.

Important notes must be registered, especially if conditions have changed. The site engineer must then send the relevant notes to the site manager, whose role includes sending a change request to the designer to modify BDS tables.

Figure 5-8 illustrates the recommended process of short-term planning linked with BDS, while Figure 5-9 presents the suggested observation model.

This information exchange allows tables to be ordered depending on the level of progress as well as a review before activities commence.

We also recommend documenting every accident in the preceding activities, as well as the near misses, failures, and lost days.

A change in the work on construction sites means frequent updating of the schedule is vital, which highlights the importance of BDS links to the CPM method and makes it more valuable and effective.

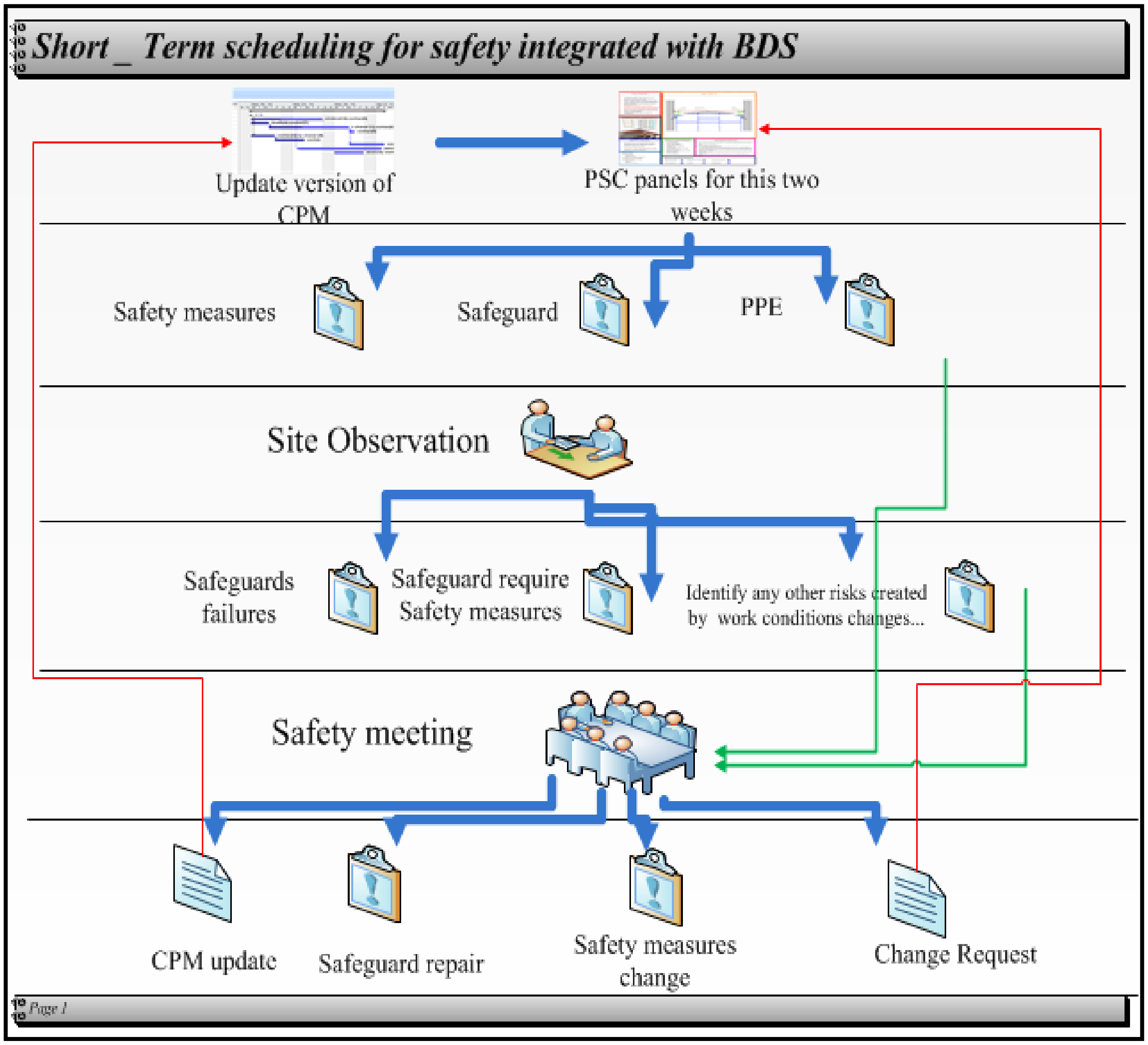


Figure 5-8 Suggested process of short-term planning linked with BDS

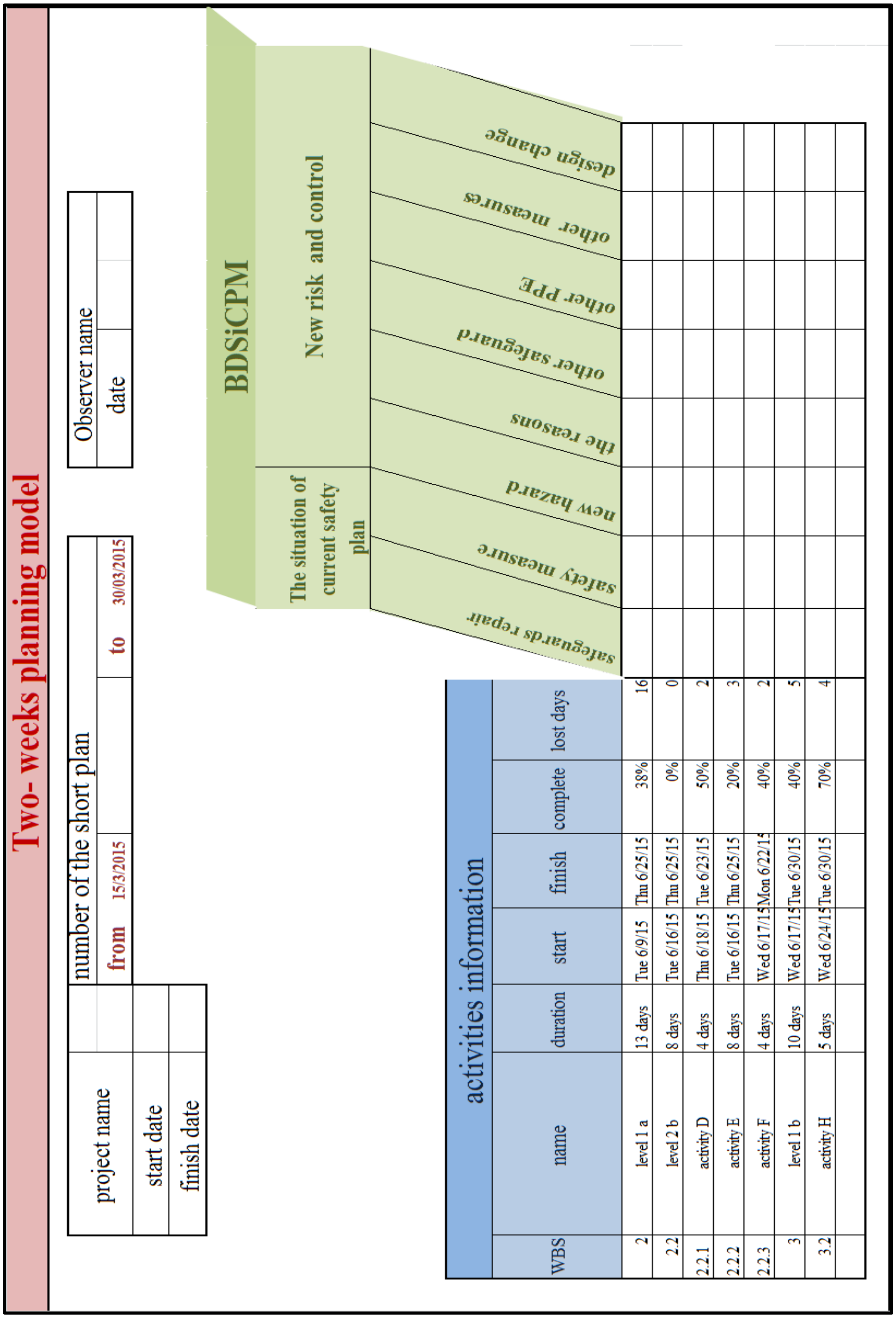


Figure 5-9 Suggested observation model

To link the BDS with CPM and automate the observation model, several codes programed by the VBA in MS Project environment can be applied to produce a report of activities that take place in the next two-weeks, according to the updated schedule and the progress of the project. This program also allows the observation notes to be implemented into the CPM to reach decisions and order the change requests.

The model of short-term planning must be printed, while supervisors complete it. This information must be later incorporated into the CPM, thus the change requests of the redesign, reschedule and other measures are enabled.

Figure 5-10 shows the model in the CPM.

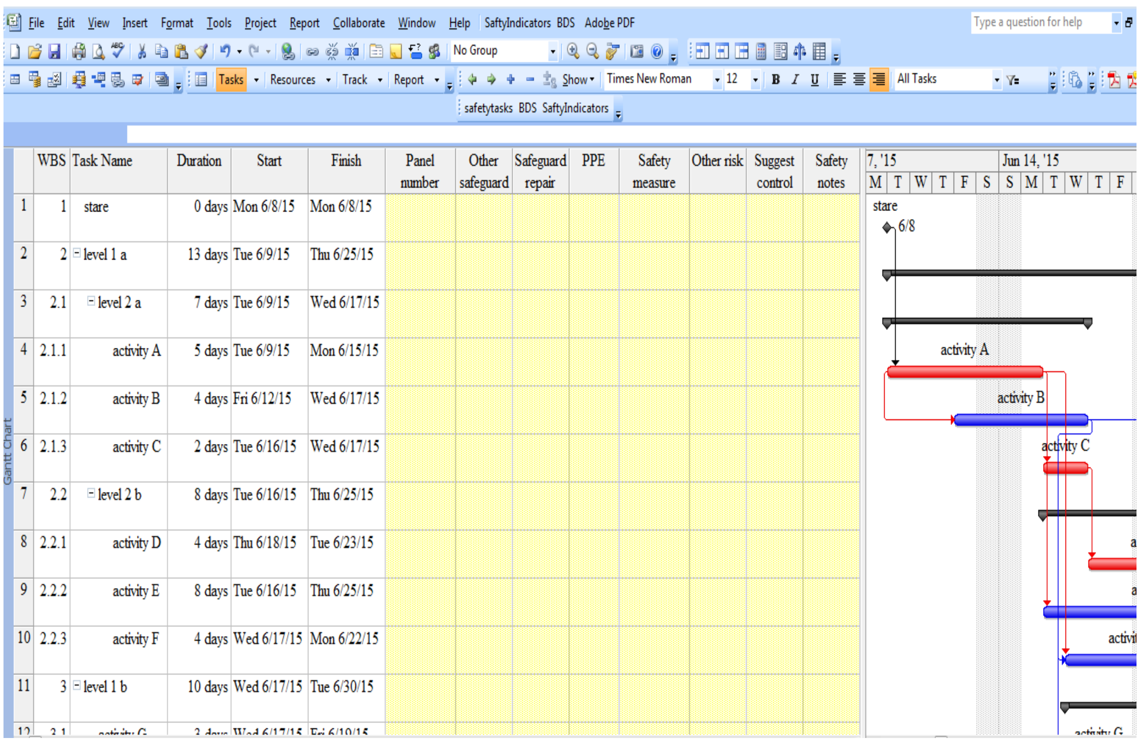


Figure 5-10 Observation model in CPM

5.7 Tracking and safety control during the project

5.7.1 *Tracking concept*

Tracking refers to the control system of the schedule change, which includes the actual start date, finish date, and completed percentage of each activity.

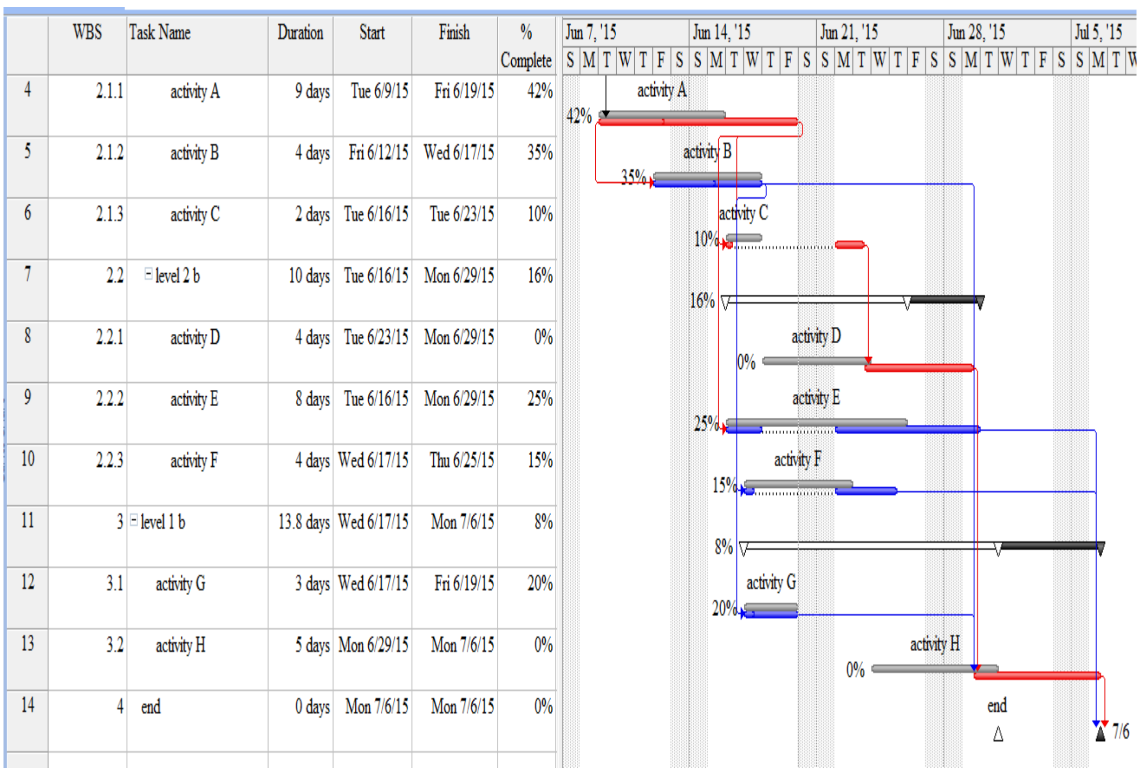
As seen before, the baseline schedule is the benchmark against which the project progress at every update will be compared. During the tracking process, a comparison between the baseline schedule and the update versions will be presented to review the progress of the schedule, as seen in Figure 5-11.

The update will be carried out at every specific cycle, in our case (two-weeks) to track the project. The update represents the level of progress, reviews the difference between planned and actual cost, duration, and work, while it also calculates the percentage of work completed.

The percentage of work completed (PWC), known in construction management field as PWC, is the ratio of the work completed to the work volume.

$$(PWC) = \frac{the\ work\ completed}{the\ work\ volume}$$

Figure 5-11 shows the baseline schedule with the update schedule and the complete percentage, the baseline schedule is in grey colour.



	WBS	Task Name	Duration	Start	Finish	% Complete
4	2.1.1	activity A	9 days	Tue 6/9/15	Fri 6/19/15	42%
5	2.1.2	activity B	4 days	Fri 6/12/15	Wed 6/17/15	35%
6	2.1.3	activity C	2 days	Tue 6/16/15	Tue 6/23/15	10%
7	2.2	level 2 b	10 days	Tue 6/16/15	Mon 6/29/15	16%
8	2.2.1	activity D	4 days	Tue 6/23/15	Mon 6/29/15	0%
9	2.2.2	activity E	8 days	Tue 6/16/15	Mon 6/29/15	25%
10	2.2.3	activity F	4 days	Wed 6/17/15	Thu 6/25/15	15%
11	3	level 1 b	13.8 days	Wed 6/17/15	Mon 7/6/15	8%
12	3.1	activity G	3 days	Wed 6/17/15	Fri 6/19/15	20%
13	3.2	activity H	5 days	Mon 6/29/15	Mon 7/6/15	0%
14	4	end	0 days	Mon 7/6/15	Mon 7/6/15	0%

Figure 5-11 Baseline schedule with an update schedule

5.7.2 *Existing performance measurement indicators in construction management*

Performance measurement indicators are the most commonly used method to measure the performance in construction projects, see Figure 5-12.

The definition of the main performance measurement indicators can be referred to in many resources, books, organizations, and sites like (PMBOK® Guide), (Earned Value Management EVM), National Aeronautics and Space Administration NASA), which are available online.

These indicators are:

- Budgeted cost of work performed (BCWP) or earned value (EV): is the sum of budgets for completed work packages and completed portions of open work packages (EVM, NASA).
- Budgeted cost of work scheduled (BCWS) or planned value (PV): is the planned cost of the work in a period of time according to the schedule, in other words it is the sum of budgets for all activities and portions of the activities to be performed within a given time period.
- Actual cost of work performed (ACWP) or actual cost (AC): the actual cost incurred in accomplishing the work performed within a given time period (EVM**,** NASA).
- Budget at completion (BAC): the sum of the budgets of all the project activities.
- Schedule variance (SV): the difference between the work actually performed (BCWP) and the work scheduled (BCWS), it indicates how much the project is faster or slower than it is scheduled.
  - SV= EV – PV
- Schedule variance (%)
  - SV% = (EV - PV) / PV = (BCWP - BCWS) / BCWS
- Cost variance (CV): the difference between the planned cost of work performed (BCWP) and the actual cost of work performed (ACWP). CV indicates how much over- or under-budget the project is.
  - CV = EV – AC

- Cost variance (%)
  - CV% = (EV - AC) / EV = (BCWP - ACWP) / BCWP
- Cost performance index (CPI): the ratio of cost of work performed (BCWP) to actual cost (ACWP).
  - CPI (Cost performed index): CPI = EV / AC
    - CPI = 1 (project on budget)
    - CPI > 1 (real cost is less than it was planned or budgeted)
    - CPI < 1 (project cost is over budget)
- Schedule performance index (SPI): the ratio of work performed (BCWP) to the work planned (BCWS), for a given time period. SPI indicates the project progress rate.
  - SPI (schedule performed index): SPI= PV / EV
    - SPI = 1 (project on time);
    - SPI <1 (project is slower than it is planned);
    - SPI > 1 (performing is faster than it is planned).
- Estimate at completion (EAC): it is the predicted total cost of the completed project, depending on the performance and real costs in the project; it is calculated during the project depending on the previous indicators.

  While BAC is calculated at the start of the project before the work is begun, then at the start of the project EAC = BAC.

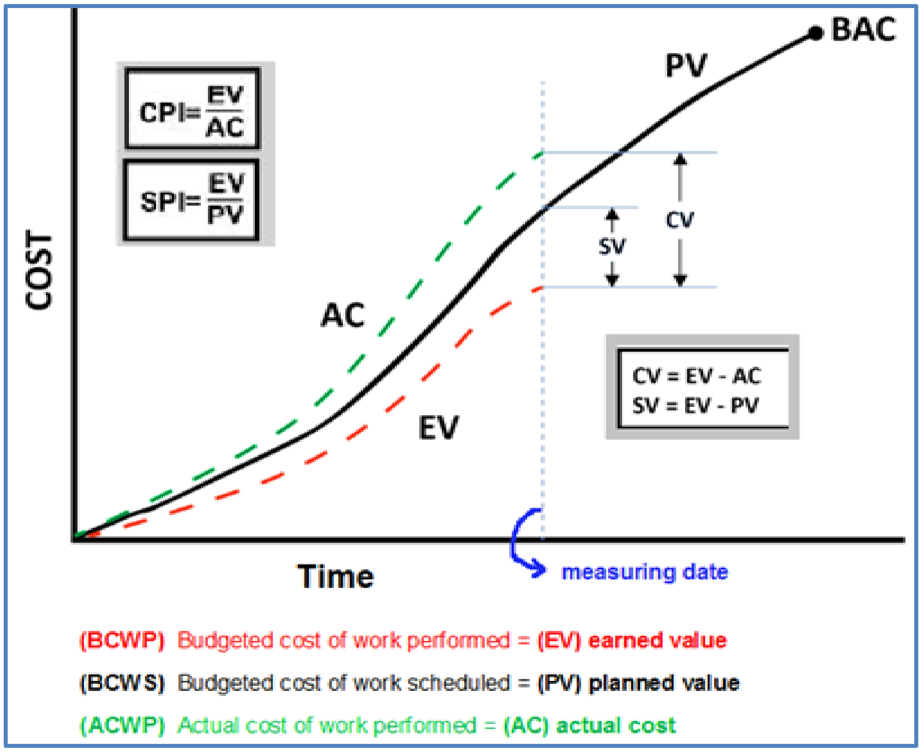


Figure 5-12 Performance measurement indicators

5.7.3 *Safety indicators suggested in this research*

This research suggests some indicators to control the level of accidents during the construction phase, to review the safety and to study the impact of the accident on the project cost. These indicators could also be used to assess the failure of safety measures and safety in design.

5.7.3.1 The ratio of the accidents

The ratio of the accidents could be calculated to the whole project to the measure date as well as to each completed activity or to the completed portion of open work package to the measure date.

$$\textit{The ratio of the accidents} = \frac{\textit{lost days because of the accident}}{\textit{work days}}$$

EQ 5-1 Ratio of accidents

The curve representing the progress of the ratio of accidents with the time provides a clear indication of the level of accidents. This is compared with the curve of the percentage of work completed (PWC) with the time, by drawing both curves in the same area. This comparison indicates the ratio of the accidents, comparing with the complete percentage of a project as the project progresses. A hypothetical example of these two curves is presented in Figure 5-13.

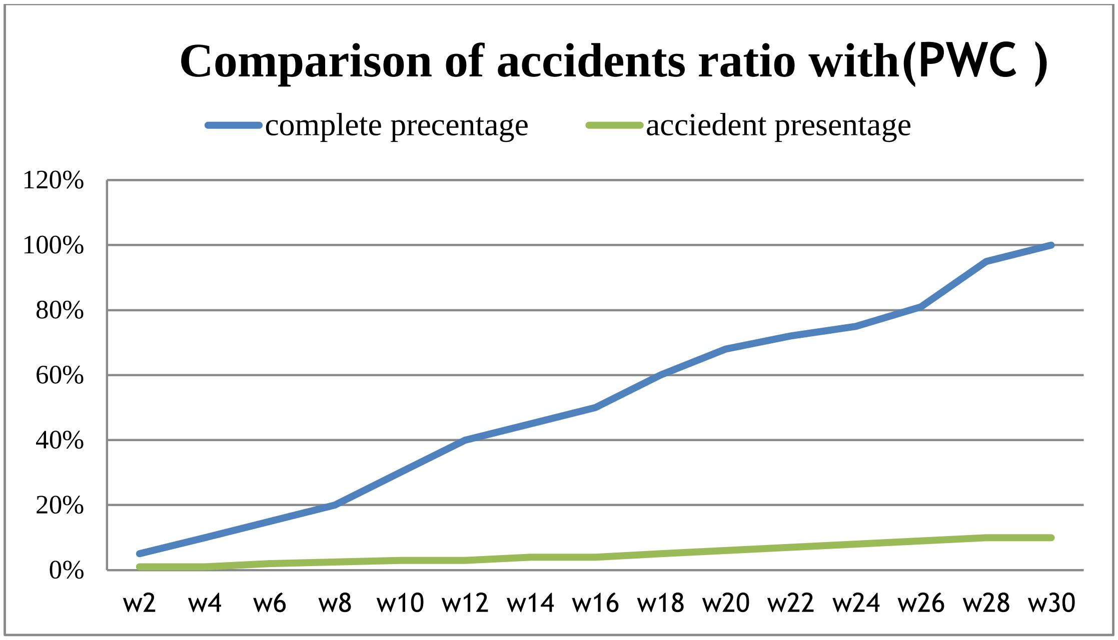


Figure 5-13 Comparison of the ratio of accidents with (PWC)

5.7.3.2 The accident role in the cost variance

The accident role in the cost variance, is the ratio of the accident cost to the cost variance, this also could be calculated to the whole project to the measure date as well as to each completed activity or to the completed portion of open work package to the measure date.

$$\text{The accident role in the cost variance(DCV)} = \frac{Accident\ cost}{Cost\ varinece} = \frac{Accident\ cost}{Earned\ value - actual\ cost}$$

$$\text{DCV} = \frac{DC}{CV} = \frac{DC}{EV - AC}$$

EQ 5-2 Accident role in the cost variance (DCV)

This indicator delivers an idea on the role of accidents on the change in project cost; i.e. the contribution of the accident cost in the cost variance. It determines the percentage of the cost of an accident to the total cost variance.

Here we can distinguish two different values:

- If AC > EV then this indicator gives an idea about the role of the accidents in the increasing of the project cost, and logically the value of ABS (DCV) is less than 1.
- If AC < EV that means was money saved in the project for positive reasons or due to the assessment of the budget being imprecise, yet accident costs consume the money saved. In this case, this indicator can also take values greater than 1.

5.7.3.3 The ratio of the accident cost to the earned value

The ratio of the accident cost to the earned value gives an idea on the amount of the accident cost.

This also could be calculated to the whole project to the measure date as well as to each completed activity or to the completed portion of open work package to the measure date.

$$\text{Ratio of accident cost to the earned value(DEV)} = \frac{cost\ accident}{earned\ value}$$

$$DEV = \frac{DC}{EV}$$

EQ 5-3 Ratio of accident cost to the earned value (DEV)

To verify the value of these indicators and link them to performance measurement indicators; we will follow these steps.

Referring back to the definition of cost variance

$$CV\% = (EV - AC) / EV = (BCWP - ACWP) / BCWP$$

we can find that

$$CV\% = \frac{EV - AC}{EV}$$

Then

$$EV - AC = EV * CV\% \qquad \text{(a)}$$

but from our equation

$$\text{DCV} = \frac{DC}{CV} = \frac{DC}{EV-AC}$$

$$EV - AC = \frac{DC}{DCV} \qquad \text{(b)}$$

Then by comparison of equations (a) and (b) we can find that

$$\frac{DC}{DCV} = EV * CV\%$$

$$DC = CV\% * DVC * EV$$

$$\frac{DC}{EV} = CV\% * DVC$$

The result is

$$\text{Ratio of accident cost to the earned value } = \frac{cost\ accident}{earned\ value} = \text{cost variance} * role\ of\ accident\ in\ varienc$$

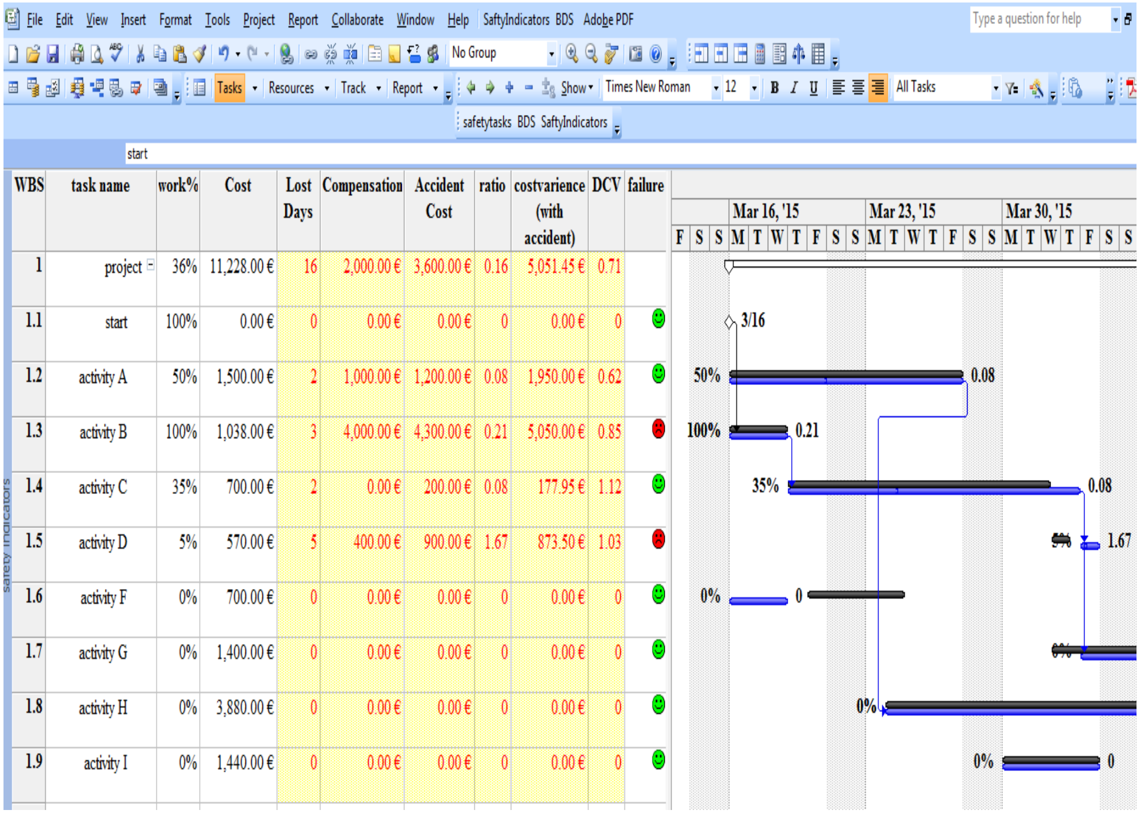
$$DEV = \frac{DC}{EV} = CV\% * DVC$$

EQ 5-4 Ratio of accident cost to the earned value calculated by cost variance

5.7.4 *Apply safety indicators with CPM*

We have programmed these indicators by the use of VBA in the MS Project environment to apply them in the CPM method, automate them, and link them to the main performance indicators. This software has been added as an additional tool to the MS Project. Additional workers' safety toolbar has also been added, this toolbar contains workers' safety analysis icons related to the programmed software.

Figure 5-14 shows the programming of safety indicators in the CPM method.



WBS	task name	work%	Cost	Lost Days	Compensation	Accident Cost	ratio	costvarience (with accident)	DCV	failure
1	project	36%	11,228.00 €	16	2,000.00 €	3,600.00 €	0.16	5,051.45 €	0.71	
1.1	start	100%	0.00 €	0	0.00 €	0.00 €	0	0.00 €	0	
1.2	activity A	50%	1,500.00 €	2	1,000.00 €	1,200.00 €	0.08	1,950.00 €	0.62	
1.3	activity B	100%	1,038.00 €	3	4,000.00 €	4,300.00 €	0.21	5,050.00 €	0.85	
1.4	activity C	35%	700.00 €	2	0.00 €	200.00 €	0.08	177.95 €	1.12	
1.5	activity D	5%	570.00 €	5	400.00 €	900.00 €	1.67	873.50 €	1.03	
1.6	activity F	0%	700.00 €	0	0.00 €	0.00 €	0	0.00 €	0	
1.7	activity G	0%	1,400.00 €	0	0.00 €	0.00 €	0	0.00 €	0	
1.8	activity H	0%	3,880.00 €	0	0.00 €	0.00 €	0	0.00 €	0	
1.9	activity I	0%	1,440.00 €	0	0.00 €	0.00 €	0	0.00 €	0	

Figure 5-14 Programming safety indicators in the CPM method

5.7.4.1 The benefits of the final value indicators at the close phase of the project

Benefits of values of these indicators at the end of the project are listed below:

- Track the accidents during the construction phase,
- Get an idea on the accident impact to the project cost,
- Assess the safety measures in the project,
- Assess the safety in design drawings,
- Deliver a report of the accident level in the project,
- Provide a measure as a score which enables the compression, differentiation and analysis of the impact of various factors.

In addition to the benefits mentioned above, these indicators enable the study of the impact of the constructible design on the safety.

5.7.4.2 The role of safety indicators to study the impact of constructible design model on the safety

Although the impact of constructability attributes on the workers' safety has not been analysed thoroughly in the state-of-art, it seems clear that it plays an important role to improve the safety in the design and construction site.

Furthermore, the effect of each constructability attribute on the safety is apparent, as we have seen in 2.1.4.

Important examples of the constructability attributes, which improve the safety in design and on construction sites, are:

- Less work below ground,
- Maximize prefabrication,
- Maximize standardization,
- Simple installation,
- Consider impact of weather,
- Employ visualization tools.

But it is not clear how each attribute affects the safety in the design, as well as the degree of impact.

The safety indicators enable a quantitative study of the impact of a constructible design model on the safety by assessing the relationship between the score of the safety and the score of constructability in several projects.

This is possible due to many studies, which deliver a broad classification of formulas, equations, and schemes to quantify the buildability. The most famous ones are that of Buildable Design Appraisal System (BDAS). Although it may be modified from time to time, it generally depends on the number of the repeated elements, structural system, wall system, standardization, and other properties, to provide a score for the buildability in the design.

5.8 **Conclusion**

In this chapter, the concept of the schedule for safety has been identified, and the main factors which link the BDS with the CPM have been introduced. It is then explained how this tool can be applied in all the project phases and how the link is automated.

The two most significant gaps can be closed by this link:

- The lack of the integration of the design for safety with the schedule,
- The lack of the temporal attribute consideration in the safety in design tools.

In addition, this link offers the BDS the ability to be scheduled, tracked, and controlled.

Vital rules for baseline scheduling for safety were introduced and clarified through examples.

Subsequently, this chapter presents an integral short-time planning method to control safety progress and monitor the BDS performance on-site. This tool also specifies the need of other safety measures or modifications of the BDS tables.

Safety indicators were introduced to assess the level of accidents on the construction site, and the impact of the accidents on the project cost. They can also be used to review the failure of safety measures and safety in design.

These indicators have been automated and programmed as an additional software tool, which is valuable when studying the impact of buildable design on safety.

CHAPTER 6

TESTING THE FRAMEWORK AND SOFTWARE

6.1 Introduction

In this chapter, the established framework with safety indicators is applied to examples with data from a previous project to illustrate how the framework and software work as a valuable risk management tool in the field of workers' safety.

Another aim of this application is to demonstrate the benefits of comparing current methods with previous measures and tools.

The main objectives of this chapter are:

- Test the framework,
- Present the advantages of comparisons with previous methods,
- Prove that the framework with safety indicators delivers a complete risk management tool.

As seen previously, this research has two key interrelated objectives corresponding to the same ground, which combine the safety in design with the CPM method. The first objective refers to the space-time-conflict resolution, while the second aims to improve workers' safety as a crucial concern in all project phases.

Two important examples will be discussed, one for each objective along with smaller examples covering the cases described above.

6.2 Example description

The example consists of a set of activities taken from the principal schedule of the residential complex construction in a provincial tourist area.

These activities run according to the schedule, when the construction of a three-story building is at its final stages.

Figure 6-1 displays the location drawings, ground floor, and the sides of the building.

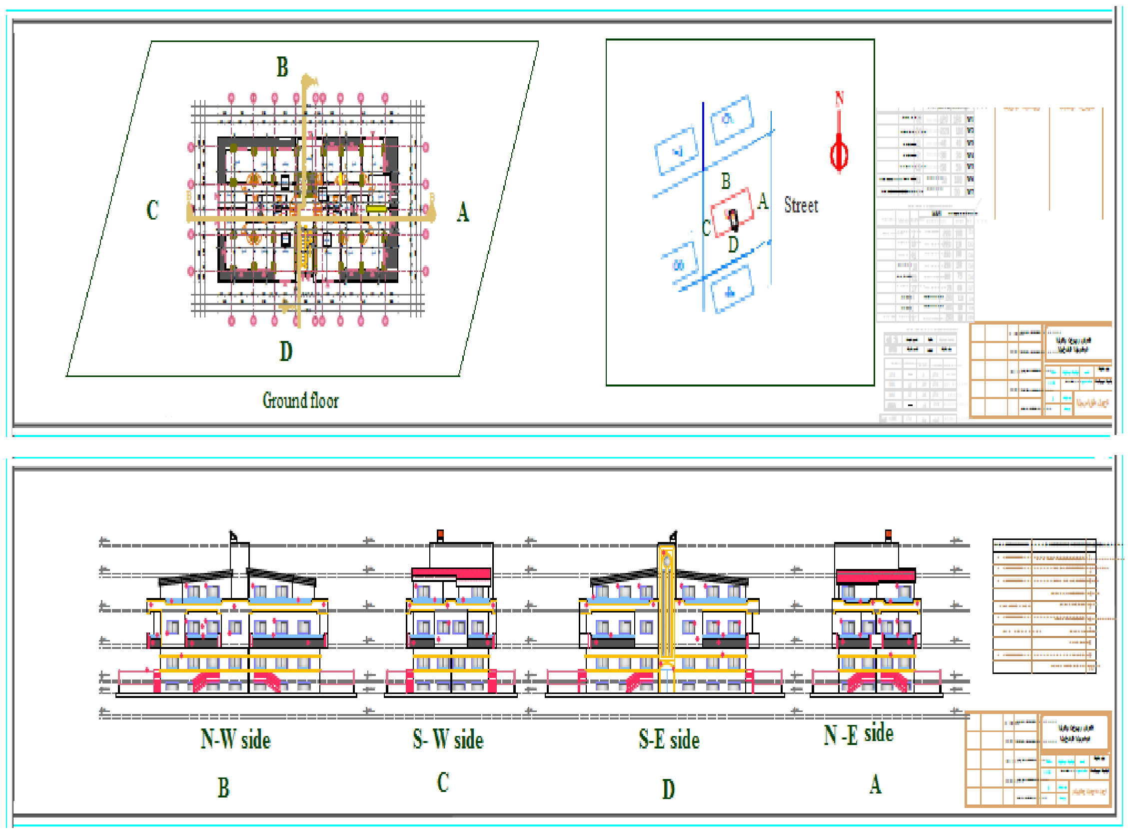


Figure 6-1 General drawings of the building

We attempt to explain the application of the developed methodology through simple and clear examples to cover several types of solutions, without repeating similar procedures.

There are various activities in other buildings and on the main site, yet there are numerous steps included in the schedule with over a thousand activities.

However, to test the framework, it is sufficient to consider a part of the work which covers the cases discussed in the chapters 4 and 5. This part is the group of activities in the building in its final phase, shown in Figure 6-1.

Figure 6-2 shows the Gantt chart schedule of the selected set of activities completed by the CPM technique, while the red bars represent the critical activities.

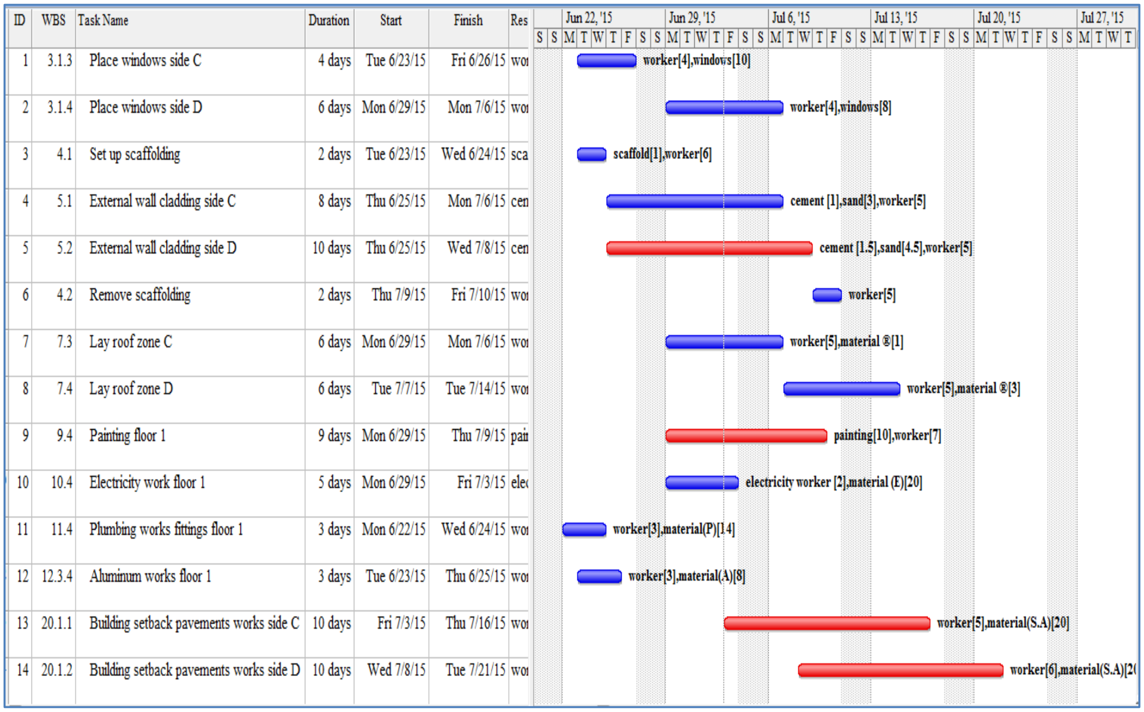


Figure 6-2 CPM of the selected set of activities

6.3 The first example application of the WSiCPM framework

6.3.1 *The introduction of the schedule into the WSiCPM framework*

The CPM will be incorporated into the database of the WSiCPM framework. This is possible due to the framework being built through the use MS Access. CPM is accomplished by through MS Project, which are easily linked and can be programmed by the VBA, as previously explained in chapter 4.

Once the CPM has been incorporated to the framework, its analysis will be enabled, therefore allowing the insertion of other input data in the fill query. This will deliver the results of the risk analysis, solutions and gain access to this report by clicking the related reports icon in the interface of the WSiCPM framework. Figure 6-3 shows the interface of the WSiCPM framework. The different steps will be explained in upcoming paragraphs.

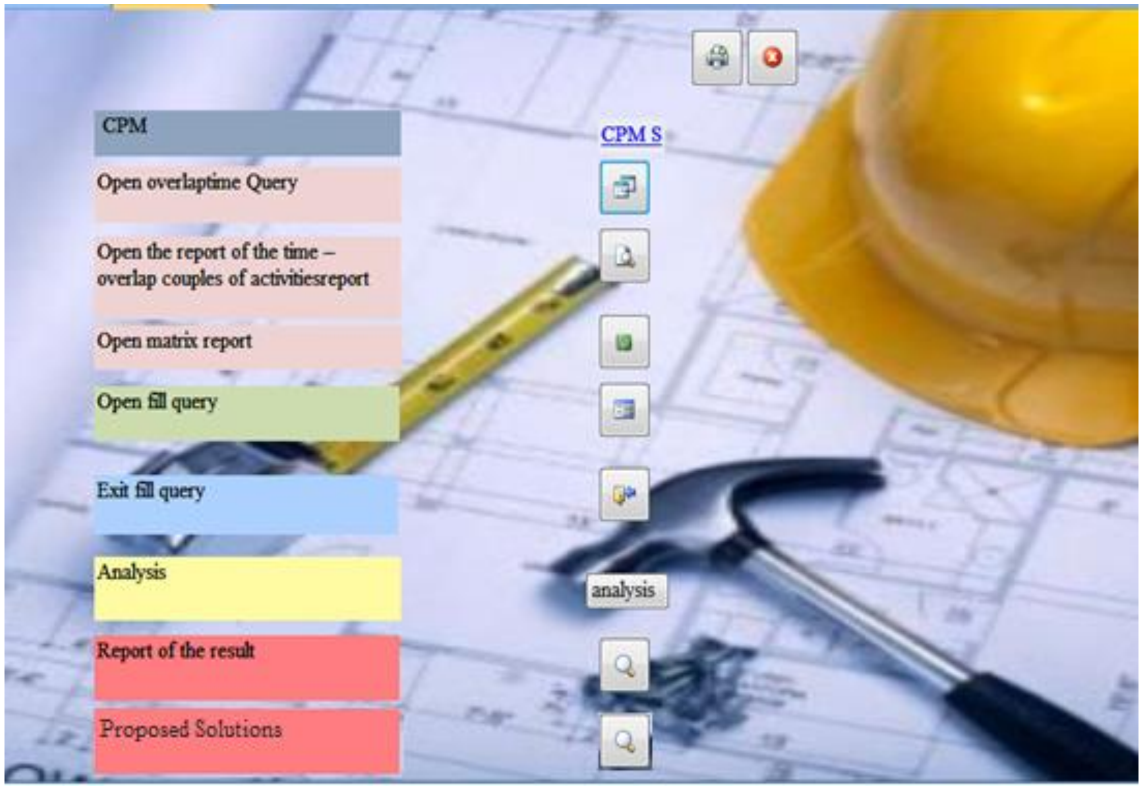


Figure 6-3 WSiCPM framework interface

6.3.2 *Finding the activities with space-time-conflict creating a hazard situation*

6.3.2.1 The time-overlap pairs of the activities

For the purpose of this research, it is insufficient to find other activities taking place in the same week, as customarily applied in the 4D approach, as mentioned in chapter 4.

A pair of overlapping activities must be found to enable a study of the interrelationship between its two activities, as well as the impact of the first activity on the second and vice versa.

Once the CPM has been exported into the database, the framework applies the overlap matrix to the CPM to determine the overlapping pairs of activities.

When referring to the report of the time-overlap pair of activities, we conclude that there are 40 overlapping pairs of activities, see Figure 6-4.

Name	Total Of Expr1010	Aluminum works floor 1	Building setback pavements work	Electricity work floor 1	External wall cladding side C	External wall cladding side D	Lay roof zone C	Lay roof zone D	Painting floor 1	Place windows side C	Set up scaffolding	Place windows side D	Plumbing works fittings floor 1	Remove scaffolding
Aluminum works floor 1	2										1		1	
Building setback pavements works side C	8			1	1	1	1	1	1			1		1
Building setback pavements works side D	5		1			1		1	1					1
External wall cladding side C	4	1		1			1			1				
External wall cladding side D	6	1		1	1		1			1		1		
Lay roof zone C	1			1										
Lay roof zone D	3					1			1					1
Painting floor 1	5			1	1	1	1					1		
Place windows side C	3	1									1		1	
Place windows side D	2			1			1							
Remove scaffolding	1								1					
	40													

Figure 6-4 Report of the overlapping pairs in the WSiCPM framework

6.3.2.2 The space-time-conflict spatial interaction (areas input)

For each pair of activities occurring in the same area or having a spatial interaction, the framework will request information on the spatial interaction between them, as seen in chapter 4.

The space-time-conflict means there is a spatial interaction between two activities, even if they run in wide spaces, since the conflict could derive from the hazardous area of one activity, out-with its work area.

The input data, which is supplied by the safety designer, must be completed in the fill form. These will be used in the background software of the WSiCPM framework to calculate the risk, using the equations introduced in chapter 4, see section 4.7.

For the pair of activities:

- building setback pavements works side C and
- place windows side D

the input data used is shown in Figure 6-5.

					Activity A		S (A)
					Building setback pavements works side C		400
					Work $S(W_A)$	Path $S(P_A)$	Hazard $S(H_A)$
					250	150	60
					Interface areas		
Activity B	Place windows side D	Work $S(W_B)$	120	Interface areas	$S(W_A \cap W_B)$ **4**		$S(W_B \cap H_A)$ **0**
		Path $S(P_B)$	40				$S(H_A \cap P_B)$ **0**
S (B)	160	Hazard $S(H_B)$	120		$S(W_A \cap H_B)$ **4**	$S(P_A \cap H_B)$ **60**	

Figure 6-5 Example of the input area data

This data is completed in the fill query of the framework, as seen in Figure 6-6.

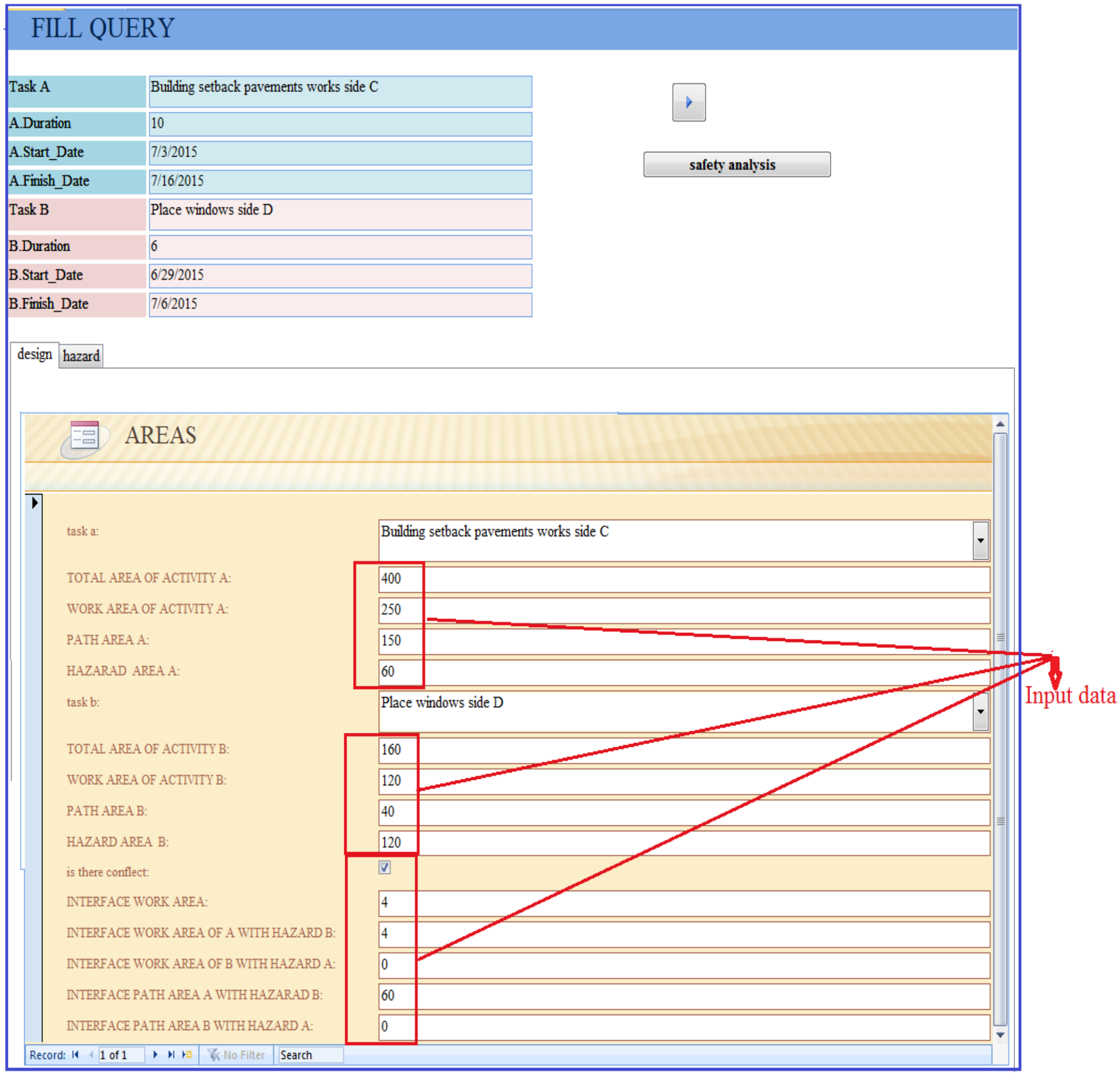


Figure 6-6 Example of the fill query

6.3.2.3 Hazard input data

When a space-time-conflict situation is detected, the hazard information will then be requested. This data is later applied in the background software of the frame-work to predict the risk qualitatively and quantitatively.

To achieve a qualitative estimation, the user (safety engineer) must determine the probability and severity of the predicted hazard caused by a conflict situation (as seen in chapter 4) while the framework software will calculate the result.

For a quantitative estimation, as introduced in section 4.7, the user must distinguish between the risk (B=>A) – risk to activity A caused by activity B –

and the risk (A=>B) – risk to activity B caused by activity A –.

It is also necessary for the user to estimate the level of risk by a number (g) between 1and 10.

Figure 6-7 shows the second page of the fill query for the pair of activities mentioned above.

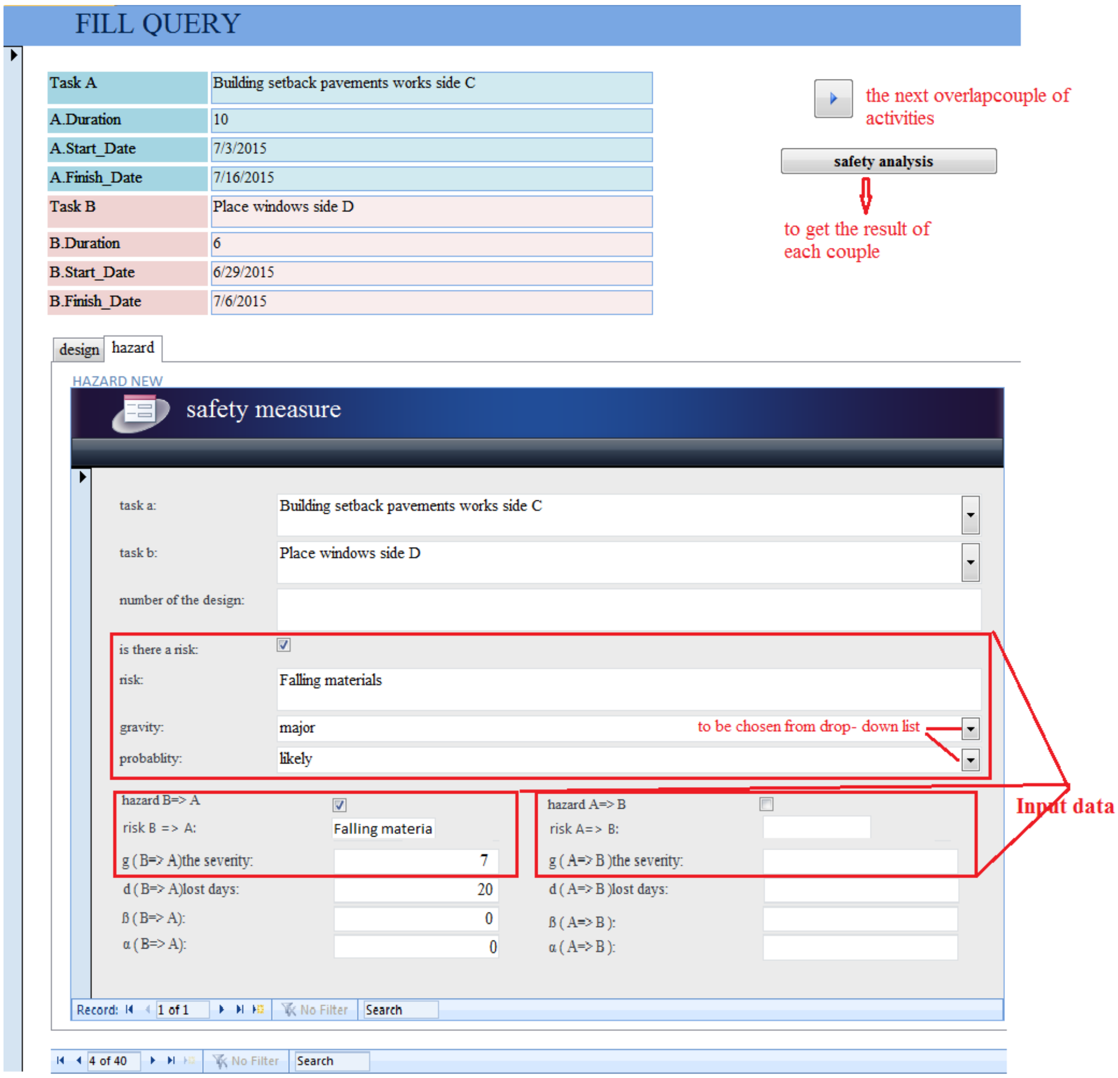


Figure 6-7 Example of the hazard input data

6.3.3 *The qualitative and quantitative results*

6.3.3.1 The individual result for each pair

The software in the framework background provides the result for each pair of activities by clicking the safety analysis icon in the upper right corner of the fill query interface, see Figure 6-7.

For the pair of activities mentioned above, the results are presented in Figure 6-8.

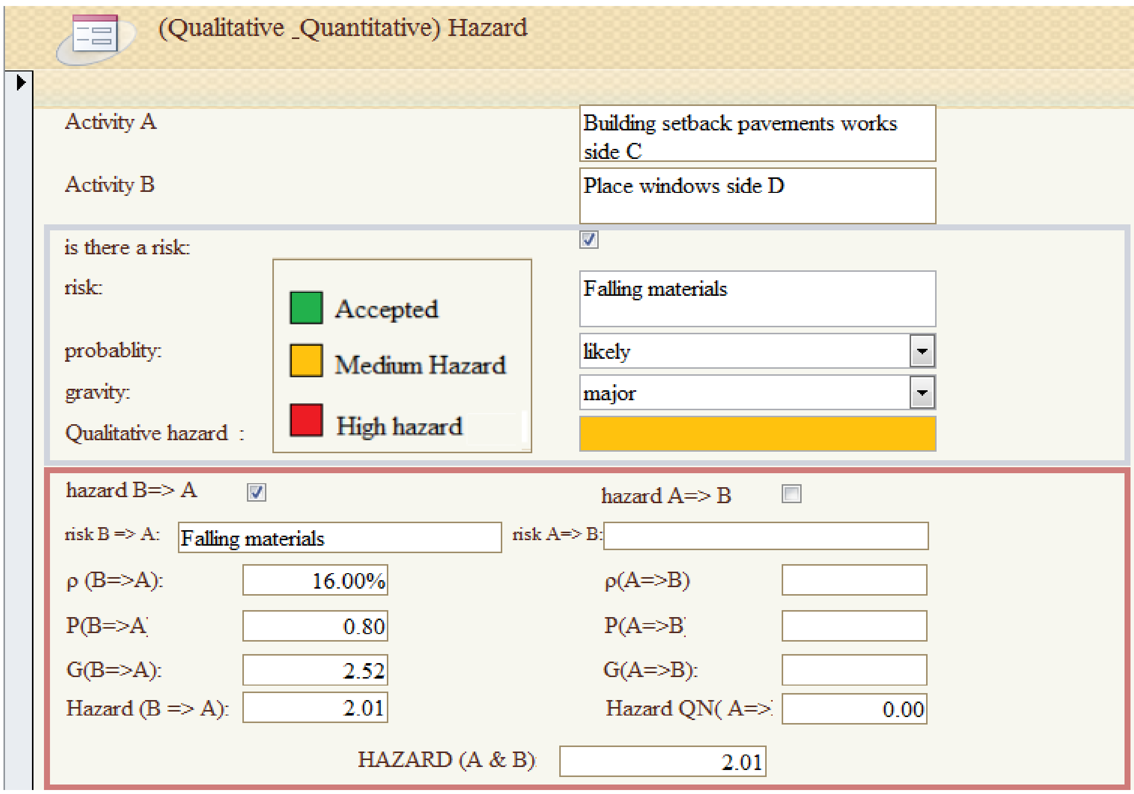


Figure 6-8 Example of the individual qualitative and quantitative hazard analysis for each pair

We conclude that the risk detected through qualitative measure is medium, while the quantitative measure yields that the risk is caused by activity B “Place windows side D” and affecting activity A “Building setback pavements works side C”; its value is 2,01.

6.3.4 *The result of the whole project*

6.3.4.1 Spatial interaction, space-time-conflict report

Referring to the report of activities containing space-time-conflicts with or without hazard, we note that there are 21 space-time-conflict situations, 15 of them hazardous; Figure 6-9 shows the report of space-time-conflicts.

We note that from 40 overlap-time activities there are 21 with spatial interface and 15 of which are hazardous.

The number of the overlap-time activities not leading to hazardous situations would be an issue in the framework, and therefore require improvement in further studies.

interface result

Wednesday, July 01, 2015
5:34:22 PM

Activity A	Activiity B	Conflict	Hazard
Aluminum works floor 1	Plumbing works fittings floor 1	☑	☐
Building setback pavements works side C	Place windows side D	☑	☑
Building setback pavements works side C	Remove scaffolding	☑	☑
Building setback pavements works side C	External wall cladding side C	☑	☑
Building setback pavements works side C	External wall cladding side D	☑	☑
Building setback pavements works side C	Lay roof zone C	☑	☑
Building setback pavements works side C	Lay roof zone D	☑	☑
Building setback pavements works side D	Remove scaffolding	☑	☑
Building setback pavements works side D	External wall cladding side D	☑	☑
Building setback pavements works side D	Lay roof zone D	☑	☑
Place windows side C	Plumbing works fittings floor 1	☑	☐
Place windows side C	Aluminum works floor 1	☑	☐
Place windows side C	Set up scaffolding	☑	☐
Place windows side D	Electricity work floor 1	☑	☐
External wall cladding side C	Place windows side C	☑	☑
External wall cladding side C	Lay roof zone C	☑	☑
External wall cladding side D	Place windows side D	☑	☑
Lay roof zone D	Remove scaffolding	☑	☑
Lay roof zone D	External wall cladding side D	☑	☑
Painting floor 1	Electricity work floor 1	☑	☑
Painting floor 1	Place windows side D	☑	☐
	21	21	15

Page 1 of 1

Figure 6-9 Report of the spatial interaction, space-time-conflicts

6.3.4.2 The result of the qualitative and quantitative risk prediction for the whole project

For every pair of the 15 hazardous conflict situations, the framework assesses the risk qualitatively and quantitatively, this allows the user to produce a report separately for every pair, see Figure 6-8.

In addition, report of the qualitative and quantitative risk analysis for the whole project can be attained, see Figure 6-10 and Figure 6-11.

This report presents the 15 hazardous space-time-conflict pairs with qualitative and quantitative risk estimates.

A contradiction will not be found when making a comparison of qualitative and quantitative results, but certain differences between the estimation. The qualitative method assesses the risk based on previous experience and history of accidents, while the quantitative method calculates the probability and severity, thus the quantitative method is more informative and precise.

The accepted risk of the qualitative method matches a quantitative value less than 1.5, the medium risk matches quantitative values between 1.5 and 4, while the high risk matches values greater than 5.

Another vital part of this report is the sum of the risk below, mentioned at the end of the report, which refers to the risk in the whole project created by conflict situations.

As revealed in chapter 4, since the severity of the accident relies on damage measure, meaning it is calculated analogously with the cost of the accident by the insurance companies so it can be transferred to currency states an estimation of the monetary value by multiplying the number of this entire hazard with the 10 then by the point price.

Referring bake to the assumptions of the severity calculation we assume that 100 points in the tables match the 10 level of the severity so for transferring the total risk number to monetary value, it must be multiple by 10.

While the point price is the price of one point of the damage given by the insurance company, this is used to calculate the compensation for the damage caused to the casualty assessed by one point.

As mentioned that the price of n point is not n times of the price of the point, the tables described in chapter 4 are used to calculate the price of n point, these tables match the equation of the severity.

So in our example the calculated total risk in this example is 59.54, therefore considering the price of the point is 500 €, then the predicted monetary value is 59.54*10*500 = 297.700 € which refers to the estimated cost of the predicted accidents.

However, this provides a pessimistic forecast as it is illogical that all the predicted accidents will occur simultaneously.

Qualitative Quantitative hazard

Wednesday, July 01, 2015
4:19:53 PM

Activity A	Activity B	is there a risk	risk	probablity	gravity	hazard QL	hazard B=>A	risk B => A	ρ	P	G	Hazard B=>A	hazard A=>B	risk A=> B	ρ2	P2	G2	Hazard A=>B	HAZARD (A B)
Building setback pavements works side C	Place windows side D	☑	Falling materials	likely	major		☑	Falling materials	16 %	0.80	2.52	2.01	☐					0.00	2.01
Building setback pavements works side C	Remove scaffolding	☑	Struck by moving vehicle ; Contact with falling objects	probable	grave		☑	Contact with falling objects	33 %	1.95	1.77	3.45	☑	Struck by moving vehicle	17%	0.33	1.77	0.59	4.03
Building setback pavements works side C	External wall cladding side C	☑	Falling material ; Struck by moving vehicle	likely	grave		☑	Falling material	21 %	1.06	1.27	1.35	☑	Struck by moving vehicle	50%	2.50	0.79	1.98	3.32
Building setback pavements works side C	External wall cladding side D	☑	Falling material ; Struck by moving vehicle	unlikely	minor		☑	Falling material	10 %	0.41	1.17	0.48	☑	Struck by moving vehicle	16%	0.78	1.27	0.98	1.46
Building setback pavements works side C	Lay roof zone C	☑	Falling material	unlikely	major		☑	Falling material	30 %	1.20	1.67	2.00	☐					0.00	2.00
Building setback pavements works side C	Lay roof zone D	☑	Falling material	unlikely	minor		☑	Falling material	15 %	0.60	2.09	1.25	☐					0.00	1.25
Building setback pavements works side D	Remove scaffolding	☑	Struck by moving vehicle ; Contact with falling objects	unlikely	minor		☑	Contact with falling objects	27 %	1.08	0.74	0.80	☑	Struck by moving vehicle	13%	0.27	0.74	0.20	0.99
Building setback pavements works side D	External wall cladding side D	☑	Falling material ; Struck by moving vehicle	probable	grave		☑	Falling material	29 %	1.73	1.17	2.02	☑	Struck by moving vehicle	59%	2.96	1.17	3.45	5.48
Building setback pavements works side D	Lay roof zone D	☑	Falling material	likely	grave		☑	Falling material	32 %	1.93	1.87	3.61	☐					0.00	3.61

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Figure 6-10 Report of the qualitative and quantitative risk for the whole project (page 1of 2)

Activity A	Activity B	is there a risk	risk	probablity	gravity	hazard QL	hazard B=> A	risk B => A	ρ	P	G	Hazard B=>A	hazard A=> B	risk A=> B	ρ2	P2	G2	Hazard A=>B	HAZARD (A B)
External wall cladding side C	Place windows side C	☑	Falling material	probable	grave		☑	Falling material	75 %	3.75	1.57	5.88	☐					0.00	5.88
External wall cladding side C	Lay roof zone C	☑	Falling material	likely	grave		☑	Falling material	84 %	4.19	1.67	6.98	☐					0.00	6.98
External wall cladding side D	Place windows side D	☑	Falling material	probable	grave		☑	Falling material	81 %	4.07	1.67	6.79	☐					0.00	6.79
Lay roof zone D	Remove scaffolding	☑	Falling material	likely	grave		☐					0.00	☑	Falling material	57%	2.83	1.57	4.44	4.44
Lay roof zone D	External wall cladding side D	☑	Falling material	probable	grave		☐					0.00	☑	Falling material	81%	4.07	1.67	6.79	6.79
Painting floor 1	Electricity work floor 1	☑	Fire	unlikely	very grave		☑	Fire	20 %	1.97	2.29	4.50	☐					0.00	4.50
15	15																		**59.54**

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Figure 6-11 Report of the qualitative and quantitative risk for the whole project (page 2of 2)

6.3.4.3 Comparison of the Qualitative and Quantitative risk assessment

To compare these two assessments we must consider the same factors in both. By fixing the other factors and considering N=1, we have calculate the result for the qualitative matrix, as we can see in Table 6-1

Table 6-1 Comparison of the qualitative and quantitative risk assessment

P \ G		v.minor	minor		major		grave		v.grave		
		1	2	3	4	5	6	7	8	9	10
v.unlikely	0.1	0.01	0.04	0.08	0.13	0.20	0.27	0.35	0.43	0.53	0.62
unlikely	0.2	0.02	0.08	0.16	0.27	0.39	0.54	0.69	0.87	1.05	1.25
	0.3	0.03	0.11	0.24	0.40	0.59	0.80	1.04	1.30	1.58	1.87
likely	0.4	0.04	0.15	0.32	0.53	0.79	1.07	1.39	1.73	2.10	2.49
	0.5	0.05	0.19	0.40	0.67	0.98	1.34	1.74	2.17	2.63	3.11
probable	0.6	0.06	0.23	0.48	0.80	1.18	1.61	2.08	2.60	3.15	3.74
	0.7	0.07	0.27	0.56	0.94	1.38	1.88	2.43	3.03	3.68	4.36
freqent	0.8	0.08	0.31	0.64	1.07	1.57	2.15	2.78	3.47	4.20	4.98
	0.9	0.09	0.34	0.72	1.20	1.77	2.41	3.13	3.90	4.73	5.60
	1	0.10	0.38	0.80	1.34	1.97	2.68	3.47	4.33	5.25	6.23

6.3.5 *Deciding where the change is helpful*

The results of the quantitative risk analysis, data from the CPM, and the schedule are the inputs of this operation.

As seen in 4.9, the operation of the WSiCPM framework performs as an expert system to help the decision maker to eliminate or reduce the risk created by the conflict.

The response of the risk could be:

- Rescheduling,
- Sub-division of work,
- Separating the activity,

– Changing the path,

– Taking measures in the design (positive acceptance).

For the same example presented above in Figure 6-5, Figure 6-6, Figure 6-7, Figure 6-8, the recommended solution proposed by the framework is to change the path of the activity "building setback pavements works side C", as we can see in Figure 6-12.

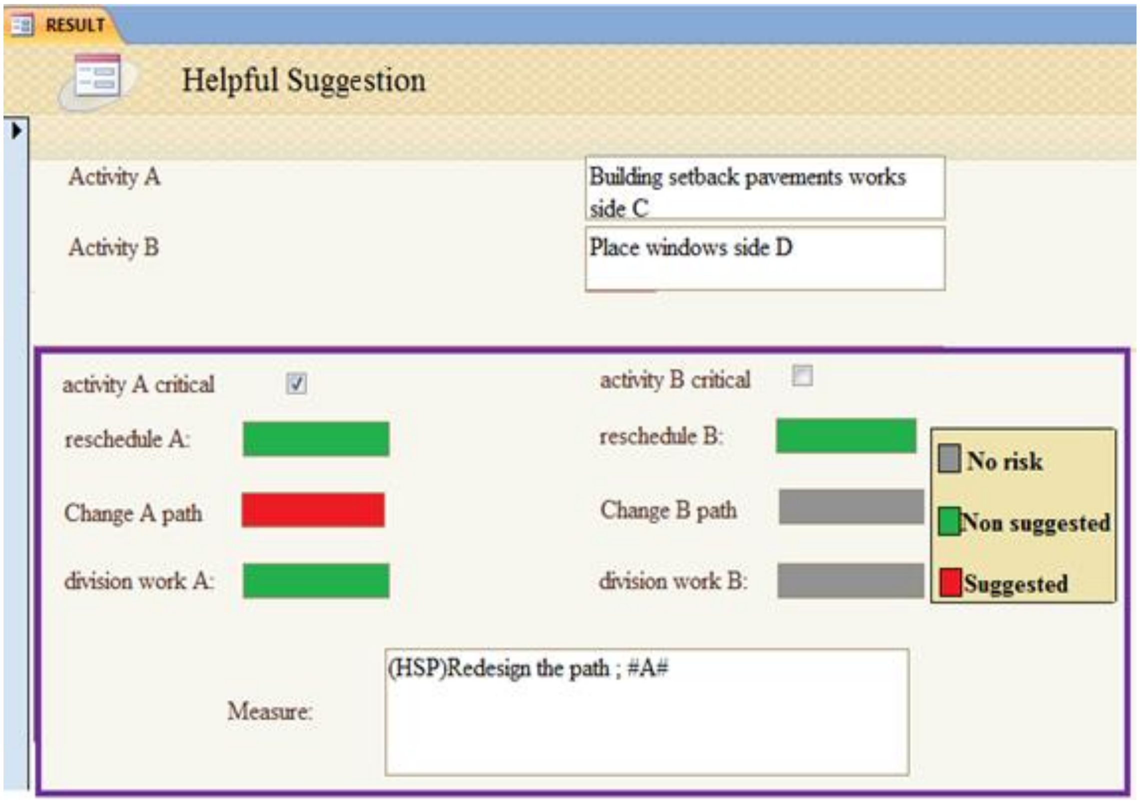

Figure 6-12 First example of suggestions of the framework (change of the path)

6.3.5.1 For the whole project

The WSiCPM framework provides a recommendation for each hazardous pair of activities separately, seen in Figure 6-12, as well as a report with all the proposed solutions. This report contains the entire hazard conflict situations along with the estimated risk and their proposed solutions.

We can gain access to this report by clicking the solution report icon at the primary interface of the program.

Figure 6-13 and Figure 6-14 show a report of the recommended solutions.

Helpful suggestion

Thursday, July 02, 2015
12:45:26 PM

Activity A	Activity B	hazard B=> A	risk B => A	H(A)	P (A)	D (A)	C (A)	R (A)	hazard A=> B	risk A=> B	H(B)	P (B)	D (B)	C (B)	R (B)	HAZARD (A B)	measure
Place windows side D	Building setback pavements works side C	☑	Falling materials	2.01			☑		☐		0.00			☐		2.01	(HSP)Redesign the path ; #A#
Remove scaffolding	Building setback pavements works side C	☑	Contact with falling objects	3.45			☑		☑	Struck by moving vehicle	0.59			☐		4.03	(HSP, CPM)Work division ; #A#
External wall cladding side C	Building setback pavements works side C	☑	Falling material	1.35			☑		☑	Struck by moving vehicle	1.98			☐		3.32	(HSP, CPM)Work division ; #A#
External wall cladding side D	Building setback pavements works side C	☑	Falling material	0.48			☑		☑	Struck by moving vehicle	0.98			☑		1.46	(HSP) PPE ,SIGNALS #A# Or (HSP) Redesign the path ;#A#; Or(HSP) Redesign the path#B#
Lay roof zone C	Building setback pavements works side C	☑	Falling material	2.00			☑		☐		0.00			☐		2.00	Work division (HSP, CPM) ; #A#
Lay roof zone D	Building setback pavements works side C	☑	Falling material	1.25			☑		☐		0.00			☐		1.25	(HSP) PPE ,SIGNALS #A# Or (HSP)Redesign the path; #A#
Remove scaffolding	Building setback pavements works side D	☑	Contact with falling objects	0.80			☐		☑	Struck by moving vehicle	0.20			☐		0.99	(HSP) PPE ,SIGNALS ; #A#&#B#

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Figure 6-13 Proposed solutions for the whole project (page 1 of 2)

Activity A	Activity B	hazard B=> A	risk B => A	H(A)	P (A)	D (A)	C (A)	R (A)	hazard A=> B	risk A=> B	H(B)	P (B)	D (B)	C (B)	R (B)	HAZARD (A B)	measure
External wall cladding side D	Building setback pavements works side D	☑	Falling material	2.02			☑		☑	Struck by moving vehicle	3.45			☑		5.48	(HSP, CPM)Work division ; #A#
Lay roof zone D	Building setback pavements works side D	☑	Falling material	3.61			☑		☐		0.00			☐		3.61	(HSP, CPM)Work division ; #A#
Place windows side C	External wall cladding side C	☑	Falling material	5.88			☐		☐		0.00			☐		5.88	(CPM)Reschedule ; #A#or #B#
Lay roof zone C	External wall cladding side C	☑	Falling material	6.98			☐		☐		0.00			☐		6.98	(CPM)Reschedule ; #A#or #B#
Place windows side D	External wall cladding side D	☑	Falling material	6.79			☑		☐		0.00			☐		6.79	(CPM)Reschedule ; #B#
Remove scaffolding	Lay roof zone D	☐		0.00			☐		☑	Falling material	4.44			☐		4.44	(CPM) Reschedule ; #A#or#B#
External wall cladding side D	Lay roof zone D	☐		0.00			☐		☑	Falling material	6.79			☑		6.79	(CPM) Reschedule ;#A#
Electricity work floor 1	Painting floor 1	☑	Fire	4.50			☑		☐		0.00			☐		4.50	(CPM) Reschedule ;#B#
15																59.54	

H (A): hazard B=>A
C(A) :Is (A) Critical ?
P (A) : change path A
D (A) :devision work
R(A) : reschedule A
H (B): hazard A=>B
C(B): Is (B) Critical?
P (B): change path B
D (B): devision work B
R(B): reschedule B

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Figure 6-14 Proposed solutions for the whole project (page 2 of 2)

6.3.6 *Change request discussing the suggestions of the framework*

Depending on the predicted risk, a suitable solution can be examined. Several examples will be discussed and presented.

6.3.6.1 Change the path

When the interference of the hazardous area of one activity with the path area of another is greater than that with its work area, the framework suggests altering the path of the last one, as we have seen in 4.9.1.1.

A similar example is illustrated in Figure 6-5, Figure 6-6, Figure 6-7, Figure 6-8, and Figure 6-12, the interference of the work area of activity A with the hazard area of B is $S(W_A \cap H_B) = 4$. When the interference between the hazard area B and the path of A is $S(P_A \cap H_B) = 60$, then the recommended solution of the framework is to “redesign the path of building setback pavements works side C”.

By studying this solution, it is evident to be logical.

Figure 6-15 shows how this solution could be presented by the BDS.

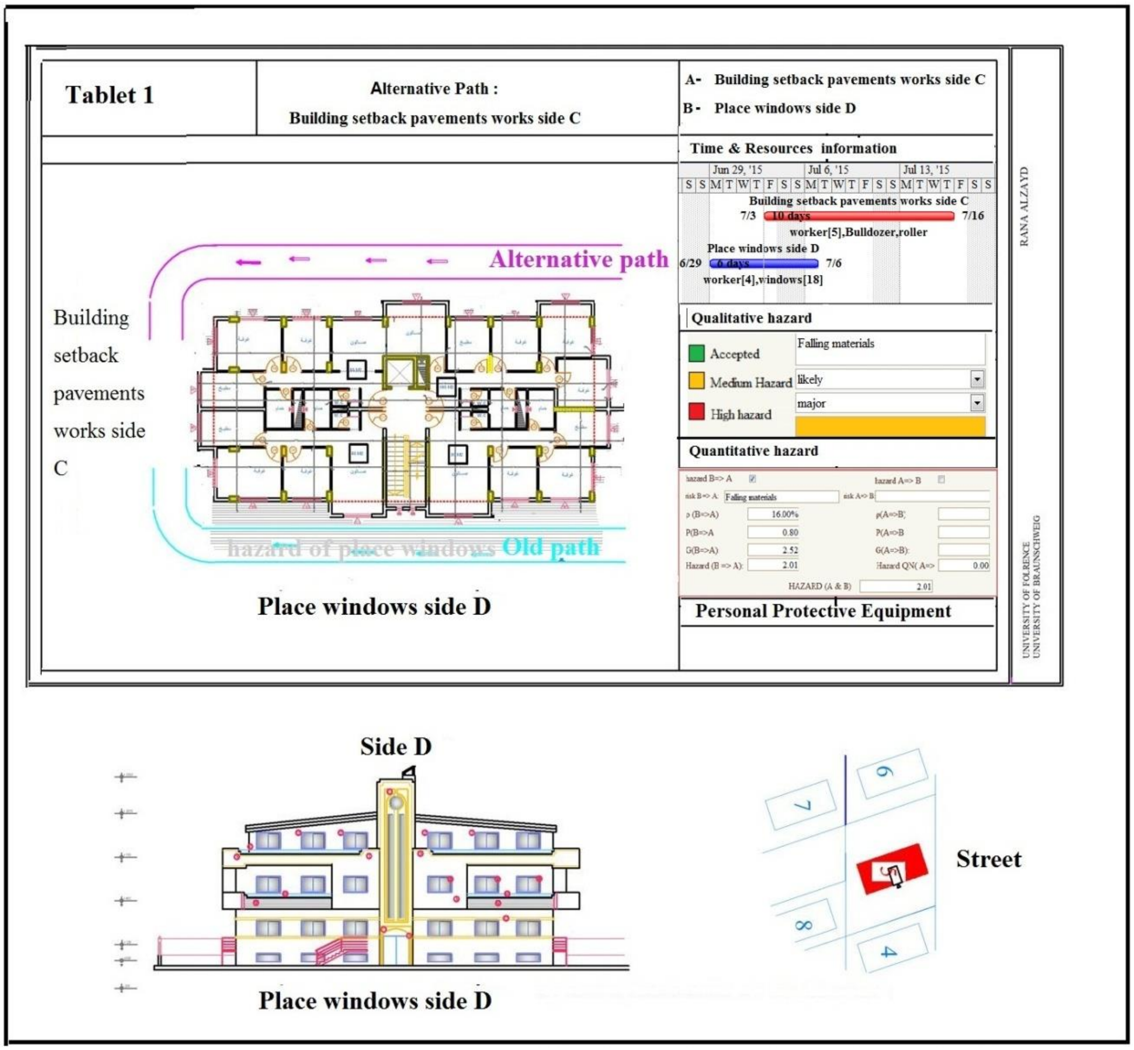

Figure 6-15 Example of the change the path solution

6.3.6.2 Subdivision of the work area

When the interference of the hazardous activity with the work area of another activity is small compared with the work area of the last one, taking into account the ability of the last being divided, the framework suggests to subdivide the last activity, see 4.9.1.2.

An example of this solution for the pair of activities:

- Building setback pavements works side D,
- External wall cladding side D,

see the schedule shown in Figure 6-2.

The results of the qualitative and quantitative risk assessment of the predicted hazard can be seen in Figure 6-16.

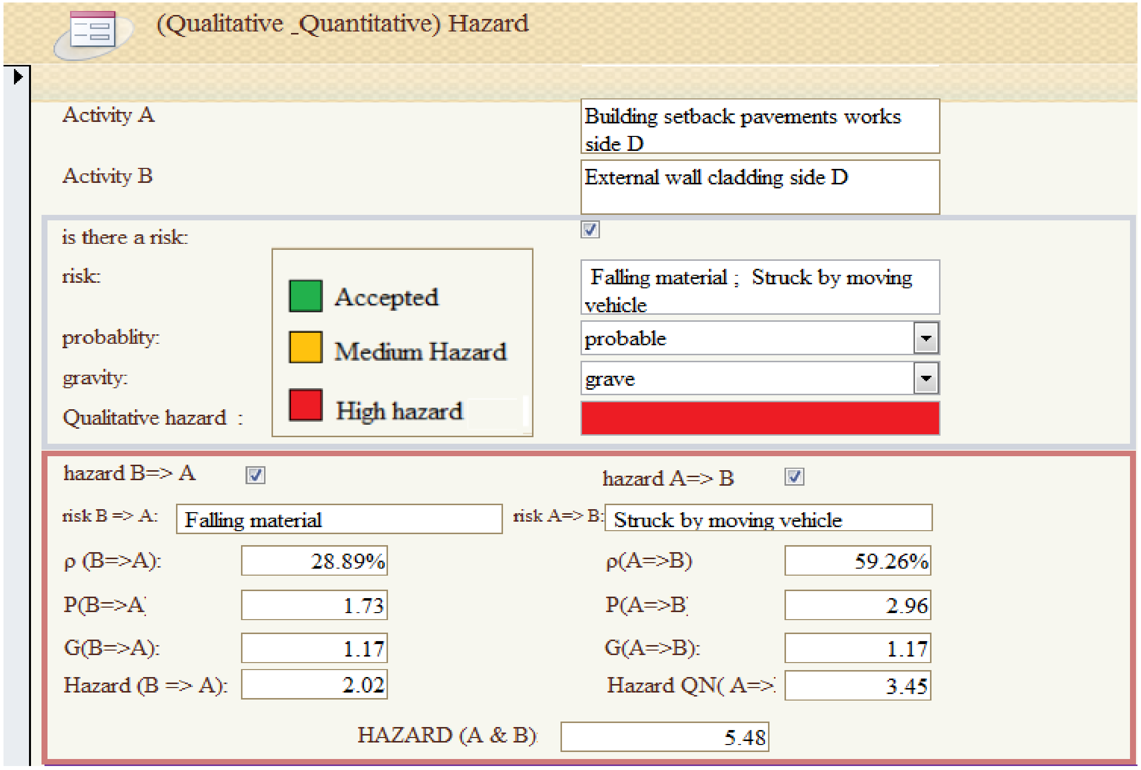

Figure 6-16 Risk of the second example (subdivision of the work)

Since T (A∩B) = 1 day and T (A) = 10; the time-overlap occurs on the first day of the activity "setback pavements works side D".

The interference of the work area activity A with the hazard B, $S(W_A \cap H_B) = 90$ is less than the work area of activity A itself:

$S(WA) = 450$; $S(W_A)/S(W_A \cap H_B) = 5$.

The solution later proposed by the framework is “the subdivision of the activity “setback pavements works side D”, as shown in Figure 6-17 seems appropriate.

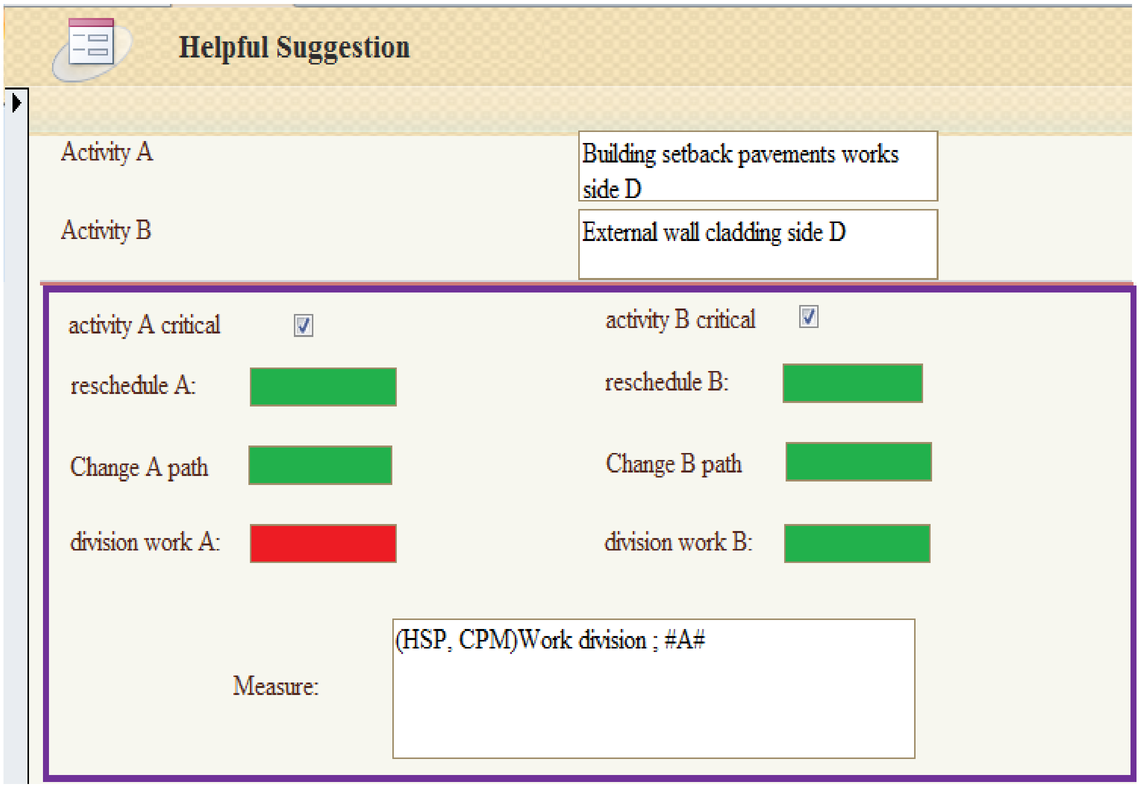

Figure 6-17 Suggestion of the second example (dividing the work)

Figure 6-18 displays how the BDS could present the sub-division of work, while Figure 6-19 explains this solution.

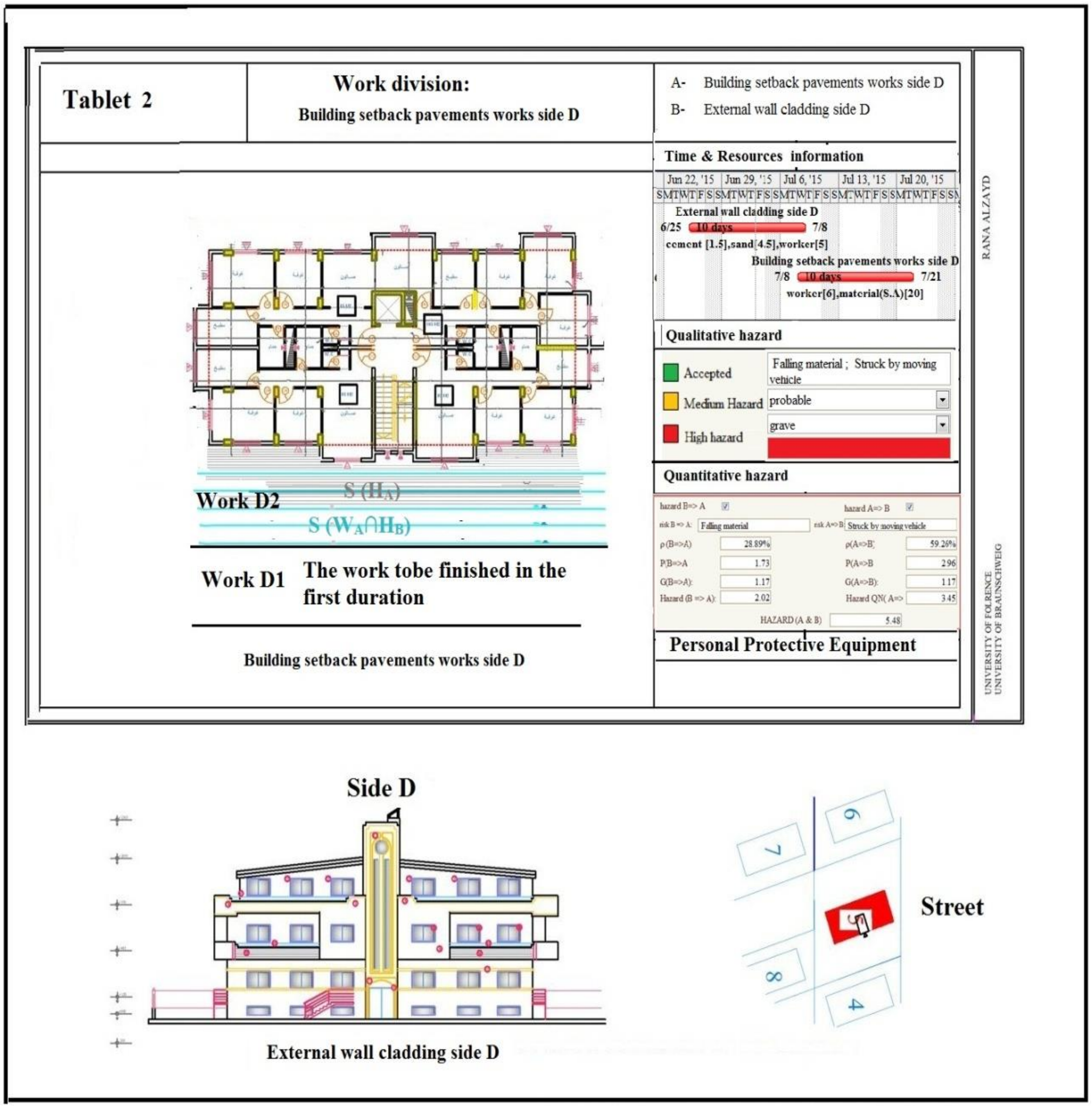

Figure 6-18 Example of the presentation of the work subdivision

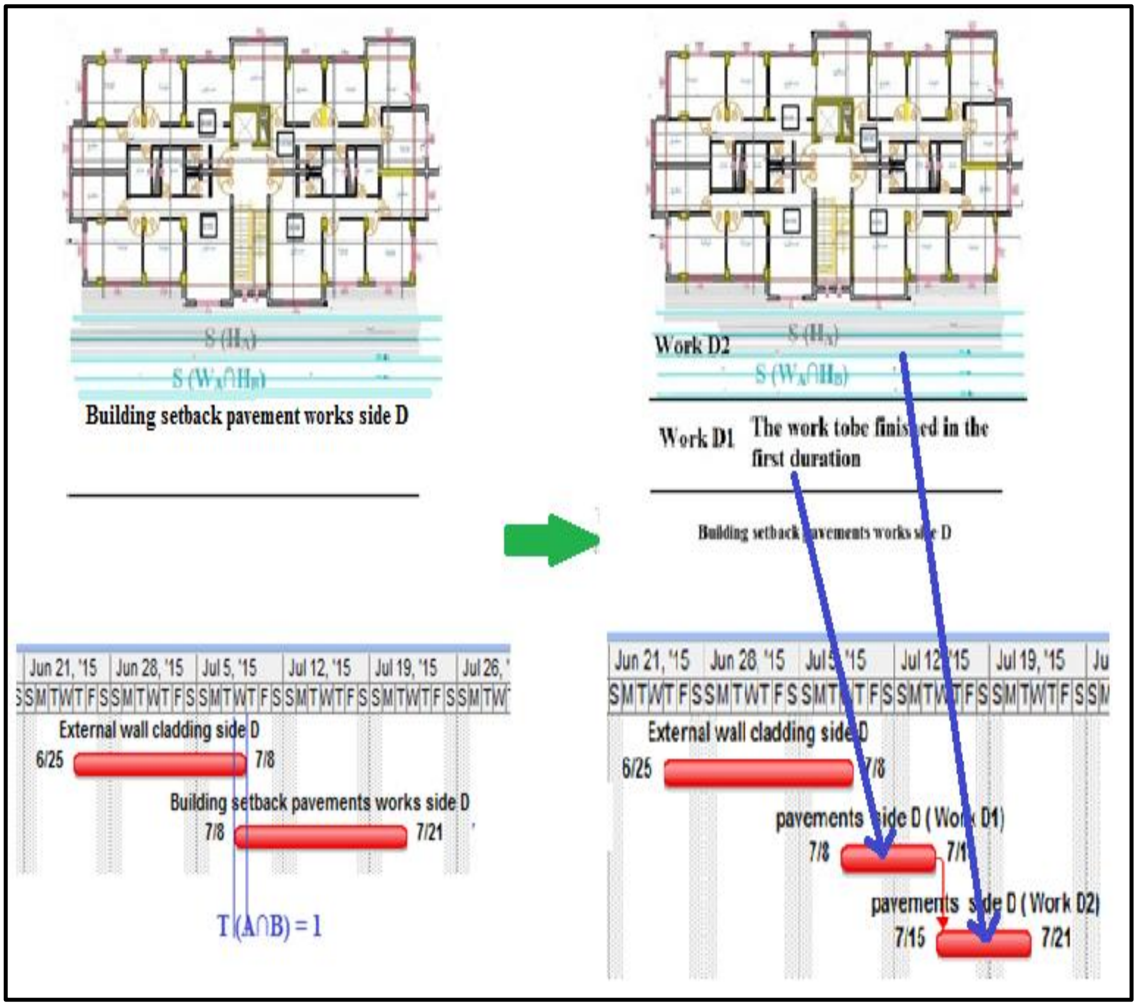

Figure 6-19 Explanation of the subdivision

6.3.6.3 Rescheduling

If a serious situation is threatened and the interface of the space is large (the two works take place close to one another i.e. occupy the same space, and the overlap of the time is equal to the duration of one of the two activities, re-scheduling the uncritical activity is the solution recommended by the framework.

For the pair of activities;

- External wall cladding side D,
- Place windows side D,

Figure 6-20 offers an explanation of this example.

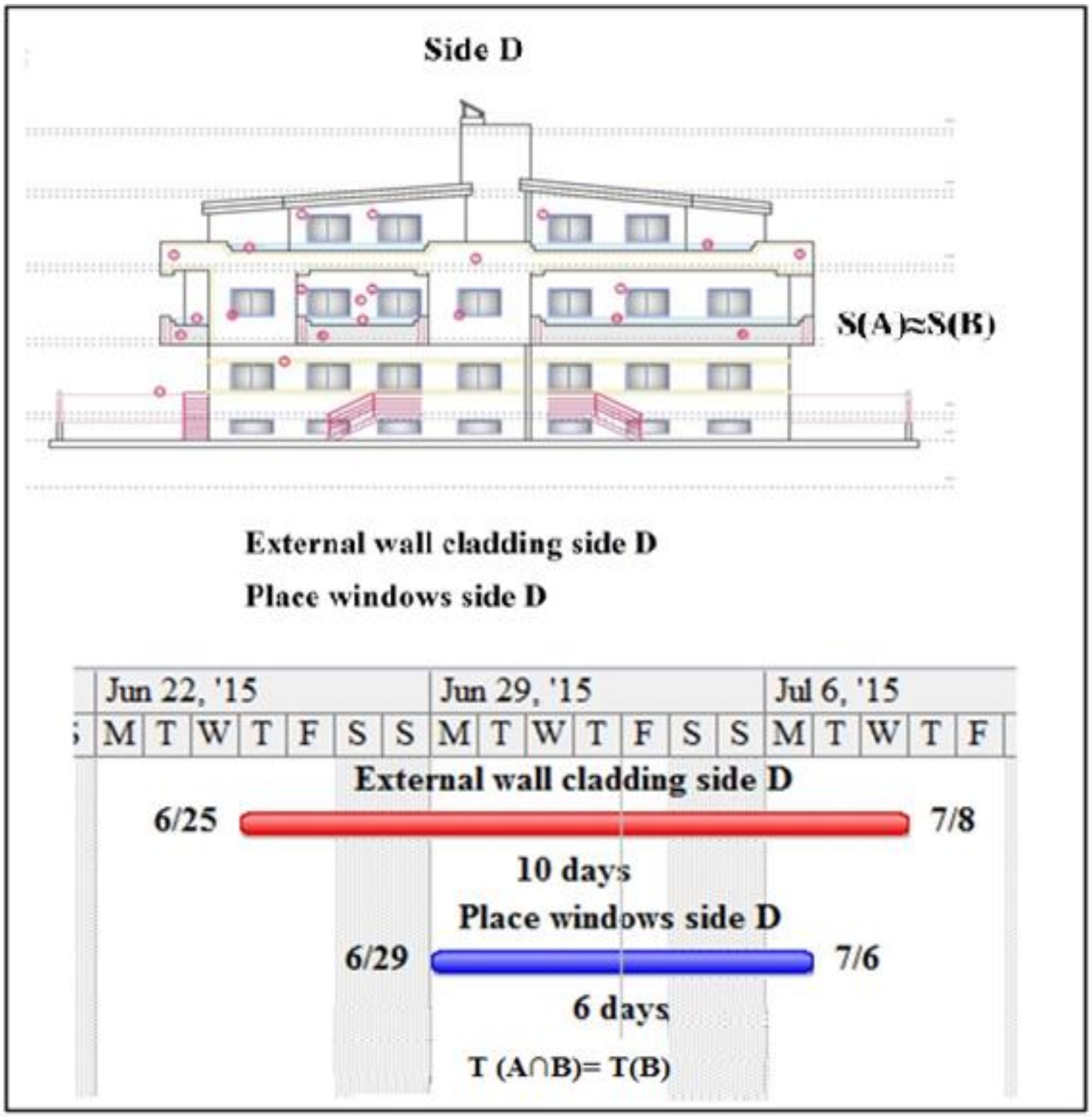

Figure 6-20 Example of rescheduling

Figure 6-21 shows the result of the hazard estimate of this pair of activities, while Figure 6-22 shows the solution proposed by the framework.

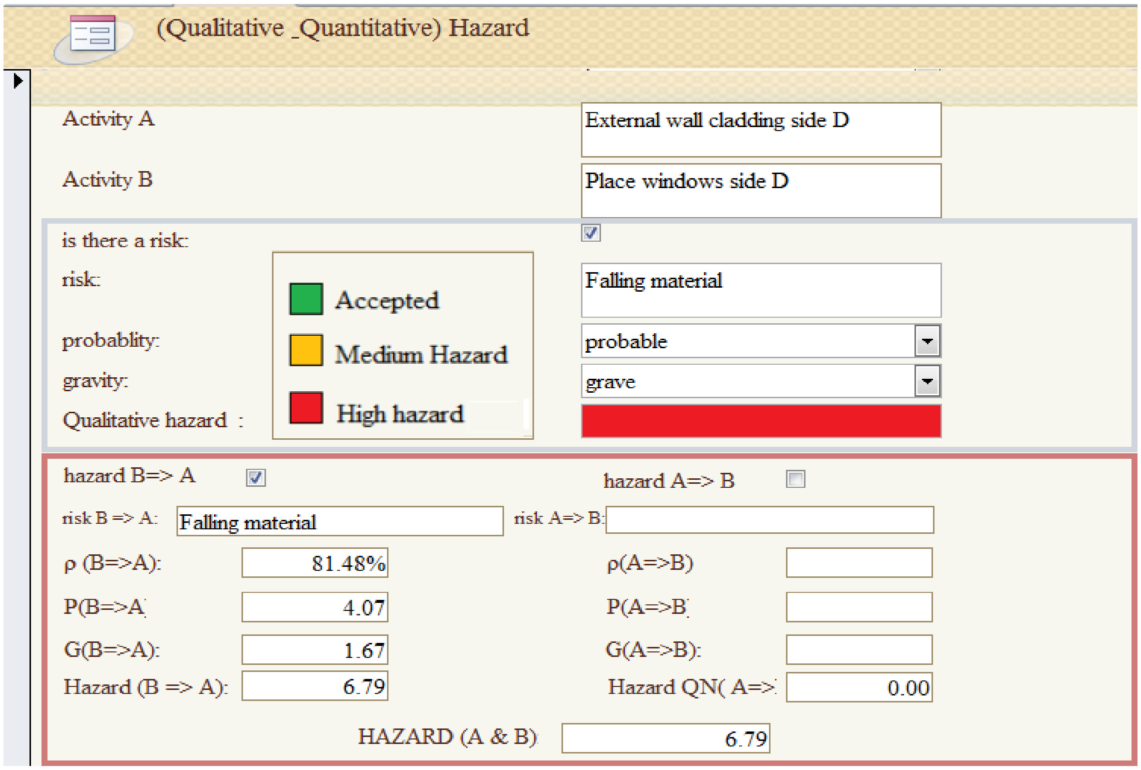

Figure 6-21 Risk of the third example (rescheduling)

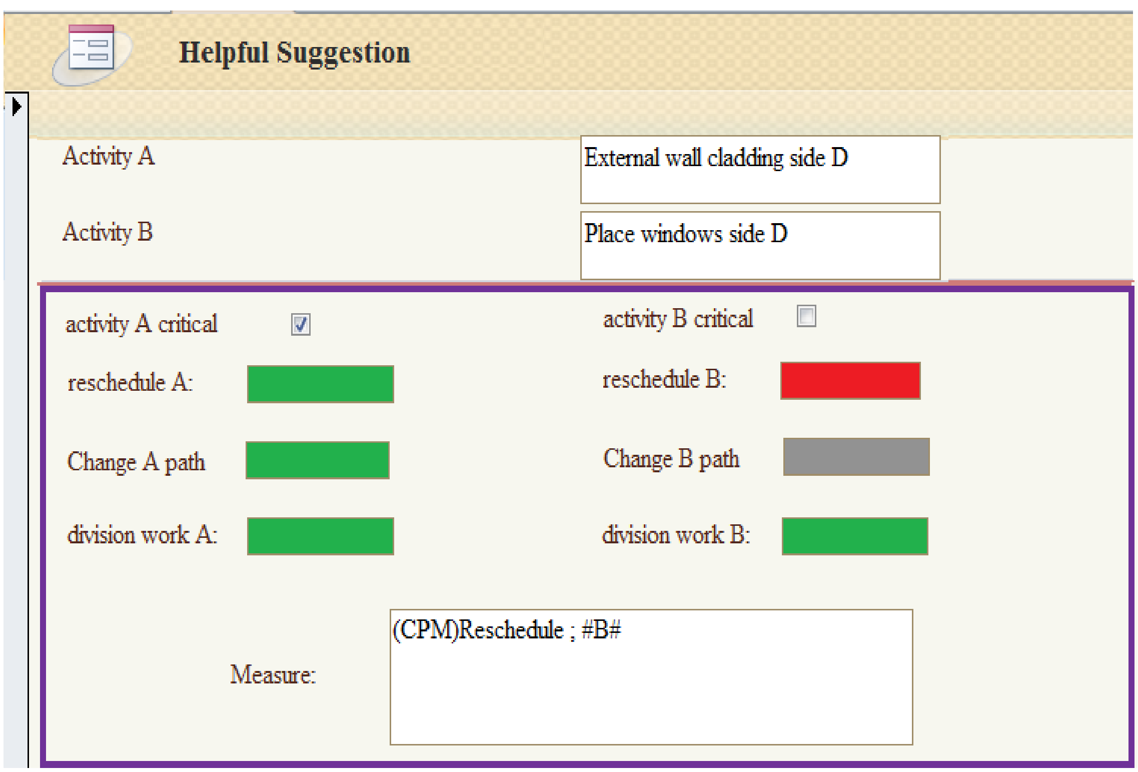

Figure 6-22 Suggestion of the framework for the third example (re-scheduling)

6.4 Comparing the result with the previous methods

The methods HSP (health and safety plan) and WHS (work health and safety) plan were applied in the project, these methods were in use all over the world in the period of the project 2007-2010, and they are used until now. Updated versions of these methods were published in 2011 and 2013 and templates of them are available online.
Figure 6-24 shows the results of these methods taken from the archives of the project, for logical comparisons we have taken the results of the group of activities of the same example mentioned above, in relation to the conflicts.
Therefore, only 11 hazards were found in these results, some of which were difficult to determine through previous methods, which fail to integrate the design with the schedule. For example, the fire causing a hazard, which had occurred when the painting and electricity works were performed simultaneously, was not discovered early. In contrary, the WSiCPM framework identified 15 hazard situations including the fire and other possible hazards since it analyses all intersections of the work.
The measures recommended through the previous methods were: "prevent other works, keep away from other works". However, it was not specified which works it is referring to. This is due to the fact that the schedule is not taken into consideration. For example, in the case of falling material in the lay roof zone D, it was stated that "the supervisor must organize the work so that no other works are done under this work". In addition to the shortages above, there are three shortages in this statement, when compared to the WSiCPM framework:

1. It is difficult for the traditional methods to detect the hazardous conflict situations through brainstorming, meeting, experience, and discussion since the design and schedule are treated separately.
2. Since the schedule is not considered, the works which must not be performed parallel to another work cannot be determined, even the safety engineer will be unable to distinguish them.
3. Dealing with the resolution of conflicts at the construction phase is the main reason leading to fatalities in the construction industry. This is the main concern in this field, which is considered by many researchers all over the world, see 1.2.

The construction site is not the most suitable place to resolve such conflicts, they must be avoided in the pre-construction phase, in the design and schedule. Otherwise the threat cannot be overcome while the probability of accidents remains high, this is because it becomes too late to control the hazard. The cost of resolving the hazard will increase, while a change will be expensive and lead to delays in the project; see Figure 6-23.

4. The previous methods do not provide a solution, it merely suggest measures, such as not allowing another work to take place. Preventing other works from being performed will result in a delay of the project, congestion in the construction site, and increased cost of the project.
5. In the previous methods, the hazard is only estimated qualitatively based on a record of accidents. Since there is no number to assess the hazard, only a ranking, the hazard cannot be measured.

Contrary to that, the WSiCPM framework has the following advantages:

1. The overlap-time conflict is automatically identified in the framework to aid the user in discussing the overlapping pairs. The overlap matrix ensures that no conflict situation is ignored as it studies all possible intersections of the works one by one. As seen in the previous example, the framework identified 15 hazards.
2. The works that take place at the same time in the hazard zone of another work have been determined. E.g. For the same work (lay roof zone D), all the works which take place in the hazard zone of this activity have been recognised.
3. This framework has the potential to resolve the problem in the field of workers' safety successfully since it introduces a method to address safety early in the project life cycle and includes the workers' safety in the design and schedule.
4. This framework suggests suitable solutions to hazard conflicts. These solutions can be applied early on in the design and schedule when the possibility of improving safety is still high, cost of the solution low, while the change does not yet lead to a delay in the project, see Figure 6-23. Similarly, for the problem mentioned previously (falling material in the lay roof zone D) the solution proposed by the framework was to subdivide the work "building setback pavements side D", which takes place under this work. For example, if the work "building

setback pavements side D" is performed in the safe place, while the hazardous work (lay roof zone D) is running, then it will be executed in the second part once the hazard work has ended. This solution ensures the workers' safety, does not add any cost, nor lead to a delays.

5. The qualitative method in the framework assesses the risk with a measurable number allowing differentiation and analysis, which can be transferred to an estimated monetary value.

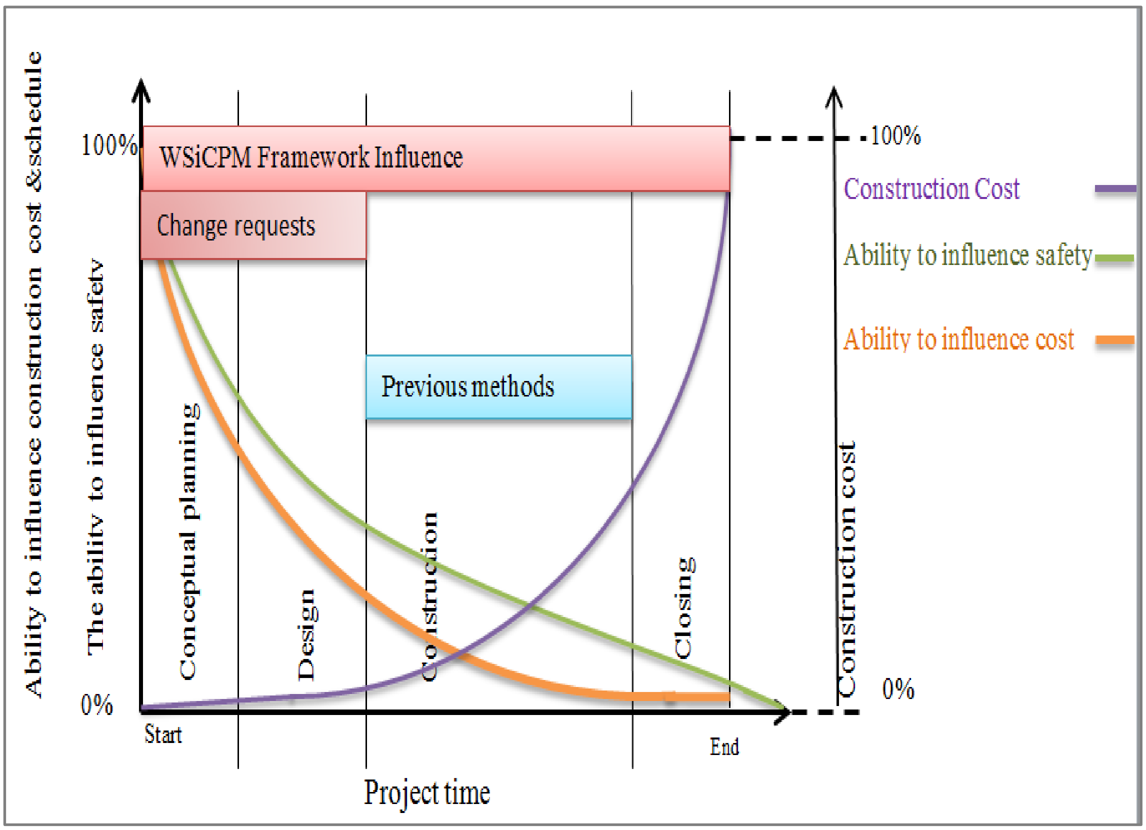

Figure 6-23 Modified from the ability to influence safety (Szymberski, 1997) and the ability to influence construction cost over time (Hendrickson & Au, 1989)

Task	Activity	Hazards	Hazard ranking	Mitigation, Reduction	Comment
Place windows					
	Place windows side C	Falling materials, resulting in personnel injury,	medium	Keep personnel away from falling materials zone; Keep non-essential personal out of work area; wear the helmet.	
	Place windows side D	Falling materials, resulting in personnel injury,	medium	Keep personnel away from falling materials zone; Keep non-essential personal out of work area; wear the helmet and proper PPE.	
Setback pavements					
	Building setback pavements works side C	Stuck by vehicles, resulting in personnel injury	high	Clarify the road, put signs ,arrange with other works,	
	Building setback pavements works side D	Stuck by vehicles, resulting in personnel injury	high	Clarify the road, put signs ,arrange with other works,	
External wall cladding					
	Set up scaffolding	Stuck by moving or fixed parts, resulting in personnel injury.	low	Put Signs, wear proper PPE	
	External wall cladding side C	Falling materials, resulting in personnel injury,	medium	Subcontractors to advise site upervisor where and when is to be done above ther workers. This must be discussed in pre work meetings with subcontractors Site supervisor to schedule work so that height work is not done above others. Barricading of exclusions zone.	
	External wall cladding side D	Falling materials. resulting in personnel injury.	medium	Subcontractors to advise site supervisor where and when is to be done above other workers. This must be discussed in pre work meetings with subcontractors. Site supervisor to schedule work so that height work is not done above others . Barricading of exclusions zone.	
Interior Siding					
	Painting floor 1	Flammable materials, resulting in burns.	medium	Material and plant to be safely stored	
	Electricity work floor 1	Contact with electricity.	high	Signs, color the cables , warn the other workers	
Lay roof					
	Lay roof zone C	Falling materials, resulting in personnel injury.	high	Subcontractors to advise site supervisor where and when is to be done above other workers. This must be discussed in pre work meetings with subcontractors. Site supervisor to schedule work so that height work is not done above others. Barricading of exclusions zone.	
	Lay roof zone D	Falling materials, resulting in personnel injury,	high	Subcontractors to advise site supervisor where and when is to be done above other workers. This must be discussed in pre work meetings with subcontractors. Site supervisor to schedule work so that height work is not done above others . Barricading of exclusions zone.	

Figure 6-24 Traditional HSP method application

6.5 Example of incorporating safety into CPM

Using the same group of activities in the first example, we will explain addressing safety in the baseline schedule, as introduced in 5.3.

Referring back to the updated schedules and reports of accidents and lost days, these were accomplished during the progress of the project mentioned above, as well as accessing the data of the same group the activities. The developed safety indicators see 0, will be applied to this group of activities, to verify their link with the earned value measures, and to test the software.

6.5.1 *The baseline schedule*

This step covers all types of hazards, not only those caused by conflicts. This process is preferably performed after the framework application to recognise all the hazards, either related to the job itself or conflicts.

Figure 6-25 shows the proposed additions (milestone, tasks, recurring task, etc.) to include the workers' safety in the CPM.

These additions are:

- A recurring task for safety meetings,
- A recurring task for housekeeping,
- A milestone for safety approval of the scaffold,
- A milestone for checking vehicles,
- A task for setting up a safety decking before the beginning of the work in external wall cladding of the side C to protect workers from falling into the building during the side cladding works,
- A task for setting up safety decking prior to the external wall-cladding site D, as the one described above.

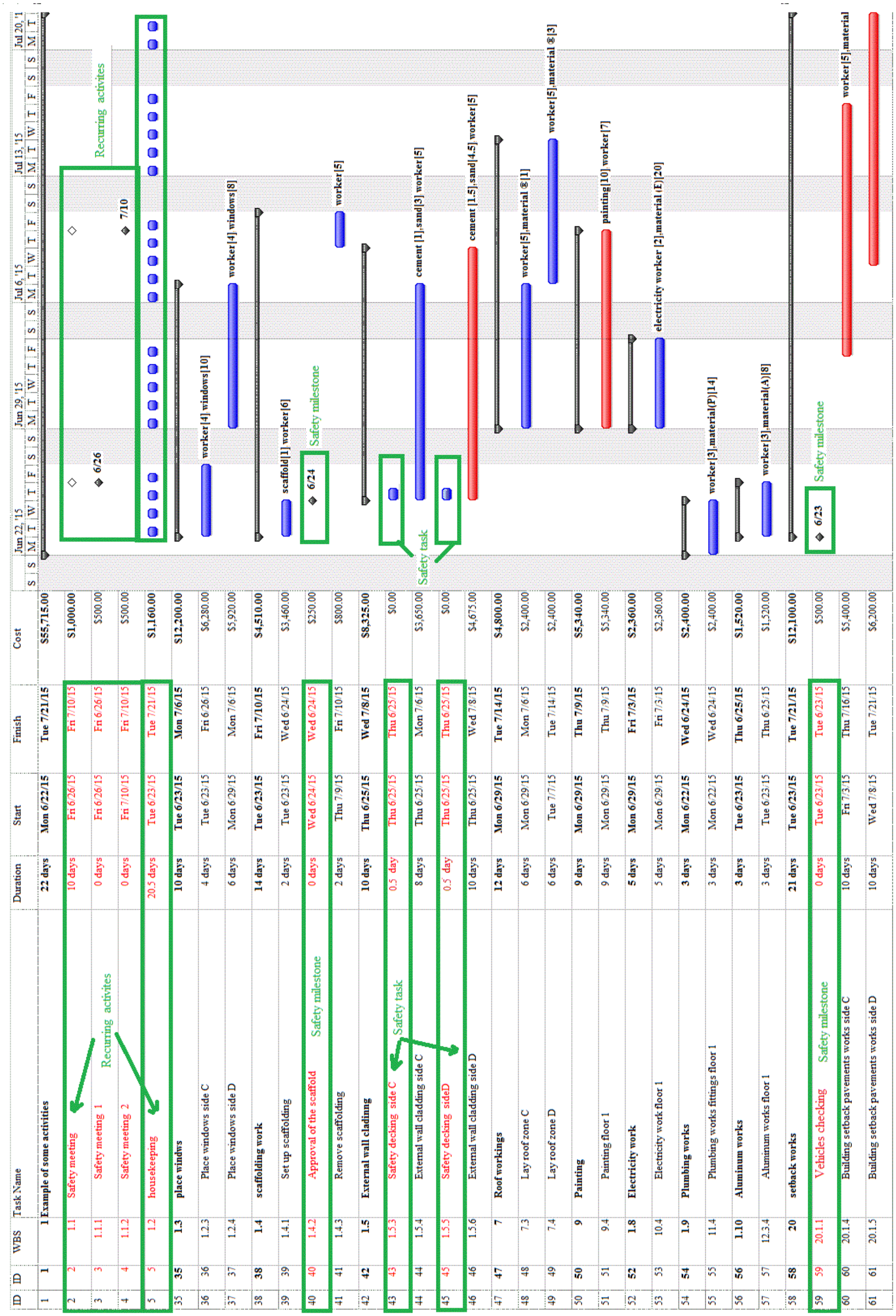

Figure 6-25 Example of the baseline schedule

6.5.2 *The safety indicators*

These safety indicators and all required fields, tables, views, windows, icons, commands, forms and additional toolbar have been developed in this research. They have been programmed by the use of VBA in the MS Project environment, and have been included as additional software for workers' safety purposes to the original MS Project program, which did not previously contain this concept.

These indicators keep track of the level of accidents in the construction phase while the project progresses, and must be applied to the update version of the schedule.

This refers to the actual ratio of the accidents in the project construction phase, as well as the closing phase and delivers an idea on the effect of accidents to the cost variance (the difference between the actual cost and planned one) for each activity, and the whole project.

Figure 6-26 shows the results when the safety indicators software is applied to the example above, after the project has progressed (the data are taken from the update versions of the project and the reports of the accidents as well as lost days). The result demonstrates the activities with high ratio of accidents through red symbols, yellow symbols represent the medium ratio of accidents, and green symbols the low ratio, while the grey means no accident has occurred.

The ratio of accidents is calculated for the complete activity, and the portion of activities in progress to measuring date.

If the percentage of completed activity is 0%, then the ratio of the accident will also be 0%.

In this example, we note that the percentage of completion of the whole group of activities is 30%, while the ratio of the accidents is 7%..While the DVC is 39%, accidents contribute to 39% of cost variance (CV: The difference between the actual cost and the planned one, noting that the accident cost is a part of it). Cost variance is 18,433.39 €; while the cost of accidents is 7,215.00 € which makes 39% of CV.

WBS	task name	work%	Cost	Lost Days	Compensation	Accident Cost	ratio	costvarience (with accident)	DCV	failure
1	Example of some activities	36%	$87,691.00	19.7	$5,245.00	$7,215.00	0.07	$18,433.93	0.39	
1.1	Safety meeting	0%	$1,000.00	0	$0.00	$0.00	0	$0.00	0	
1.1.1	Safety meeting 1	100%	$500.00	0	$0.00	$0.00	0	$0.00	0	grey
1.1.2	Safety meeting 2	0%	$500.00	0	$0.00	$0.00	0	$0.00	0	grey
1.2	housekeeping	35%	$2,088.00	0.7	$0.00	$70.00	0.08	$394.80	0.18	
1.3	place windws	61%	$17,136.00	1.2	$600.00	$720.00	0.05	$4,384.53	0.16	
1.2.3	Place windows side C	80%	$8,880.00	1	$600.00	$700.00	0.08	$3,313.33	0.21	red
1.2.4	Place windows side D	45%	$8,256.00	0.2	$0.00	$20.00	0.01	$1,071.20	0.02	green
1.4	scaffolding work	55%	$5,918.00	0.5	$435.00	$485.00	0.04	$1,253.00	0.39	
1.4.1	Set up scaffolding	100%	$4,228.00	0.5	$435.00	$485.00	0.07	$1,253.00	0.39	yellow
1.4.2	Approval of the scaffold	0%	$250.00	0	$0.00	$0.00	0	$0.00	0	grey
1.4.3	Remove scaffolding	0%	$1,440.00	0	$0.00	$0.00	0	$0.00	0	grey
1.5	External wall cladinng	46%	$14,373.00	9	$1,830.00	$2,730.00	0.16	$5,578.00	0.49	
1.5.3	Safety decking side C	100%	$144.00	0	$0.00	$0.00	0	$144.00	0	grey
1.5.4	External wall cladding side C	50%	$6,210.00	5	$850.00	$1,350.00	0.21	$2,630.00	0.51	red
1.5.5	Safety decking sideD	100%	$144.00	0	$0.00	$0.00	0	$144.00	0	grey
1.5.6	External wall cladding side D	40%	$7,875.00	4	$980.00	$1,380.00	0.13	$2,660.00	0.52	red
7	Roof workings	22%	$9,360.00	3	$920.00	$1,220.00	0.08	$1,540.00	0.79	
7.3	Lay roof zone C	35%	$4,320.00	3	$920.00	$1,220.00	0.17	$1,540.00	0.79	red
7.4	Lay roof zone D	10%	$5,040.00	0	$0.00	$0.00	0	$0.00	0	grey
9	Painting	40%	$10,380.00	1	$480.00	$580.00	0.02	$2,092.00	0.28	
9.4	Painting floor 1	40%	$10,380.00	1	$480.00	$580.00	0.02	$2,092.00	0.28	yellow
1.8	Electricity work	40%	$2,360.00	3	$980.00	$1,280.00	0.5	$1,280.00	1	
10.4	Electricity work floor 1	40%	$2,360.00	3	$980.00	$1,280.00	0.5	$1,280.00	1	red
1.9	Plumbing works	75%	$3,408.00	0	$0.00	$0.00	0	$756.00	0	
11.4	Plumbing works fittings floor 1	75%	$3,408.00	0	$0.00	$0.00	0	$756.00	0	grey
1.10	Aluminum works	100%	$2,528.00	0.8	$0.00	$80.00	0.11	$785.60	0.1	
12.3.4	Aluminum works floor 1	100%	$2,528.00	0.8	$0.00	$80.00	0.11	$785.60	0.1	red
20	setback works	17%	$19,140.00	0.5	$0.00	$50.00	0.01	$370.00	0.14	
20.1.1	Vehicles checking	100%	$500.00	0	$0.00	$0.00	0	$0.00	0	grey
20.1.4	Building setback pavements works sic	25%	$8,600.00	0.5	$0.00	$50.00	0.01	$370.00	0.14	green
20.1.5	Building setback pavements works sic	10%	$10,040.00	0	$0.00	$0.00	0	$0.00	0	grey

The additional software developed by this research (safety indicators)

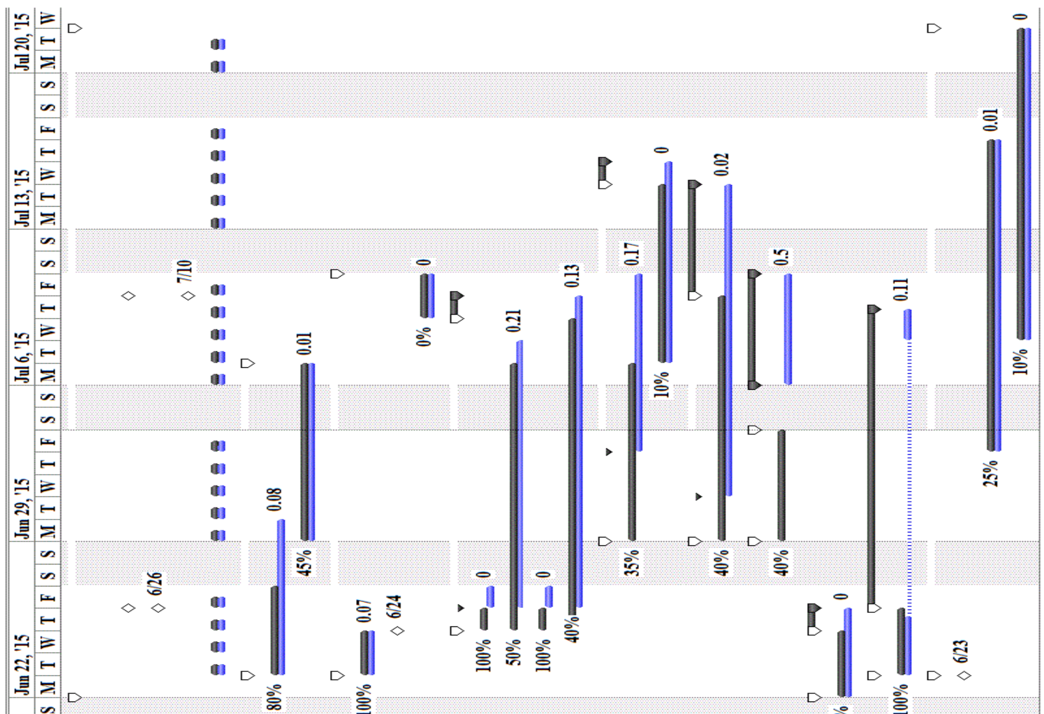

Figure 6-26 Safety indicators

6.6 **Discussion**

The advantages of the developed methodology compared to previous methods are:

- The baseline schedule for safety conveys the start date of each safety measure, safety guard, etc. It also reminds project participants of these measures at the convenient time, while most of the other safety methods, including safety in design tools do not take time into consideration.
- This framework achieves the integration of the safety in the design and the schedule, two concepts that are traditionally treated separately. The safety in design tools fail to consider the time attributes of activities. While methods depending on the schedule do not consider the design and the spatial attributes of them.
- Identifying all conflict situations by brainstorming, experience, or by examining numerous designs and the Gannet charts is difficult, while there is no guarantee that no conflicts are forgotten. In fact, this framework ensures the detection of all hazardous conflict situations, since it studies all the possibilities of intersection between activities one by one.
- An advantage of this method in comparison with other tools is the solutions suggested by the framework, which is more than the measures typically relying on experience. These are decisions which have been made by analysing several calculated parameters, taking into account each individual condition.
- The quantitative risk measure is a vital, as it allows the hazard to be measurable, while enabling analysis, differentiation, and cost estimates. Another valuable attribute is its ability to be transferred to an estimated money value.
- When other methods consider activities running simultaneously with an activity mentioned in the measure, they are referred to as "other works" without identifying them in detail. In this framework, activities are affected by the hazard of an activity specifically identified and analysed.
- Safety indicators are a significant feature of this method as they allow safety tracking, measuring accident levels, and analysing the impact of accidents on the cost of the project. Furthermore, their link with earned value measures increases

the importance of such indicators and makes them even more valuable and effective.

- Recognising the workers' safety as the sole responsibility of contractors and the concern of the site is the true cause of accidents. Since the ability to influence the safety in the construction phase is insignificant, the hazard cannot be controlled. Although the cost of any change in this phase would be a considerable amount, it will result in delays. This framework resolves this problem by addressing safety early in the project in both the design and the schedule,
- The links between the safety in design tool BDS and CPM allows workers' safety to be considered in all project phases, and strengthens the impact of BDS on all the phases of the project.
- The supervisory model enables safety controls during the construction phase.
- This method can be performed manually, however building the overlap matrix is indubitably a difficult job (e.g. for 10 activities you must study 90 pairs and analyse 90 possible intersections). Moreover, calculating the duration of overlapping pairs, number of workers, area parameters, hazard, as well as choosing the suitable formulas according to the hazard and examining all parameters to find the suitable solution are all difficult to be accomplish manually. All of these emphasise the significance of the automation discussed in this study.
- This method is a complete one, containing all steps of the risk management tool established by the PMBOK School, with clear inputs, outputs and tools, as illustrated in **Figure 6-27**.

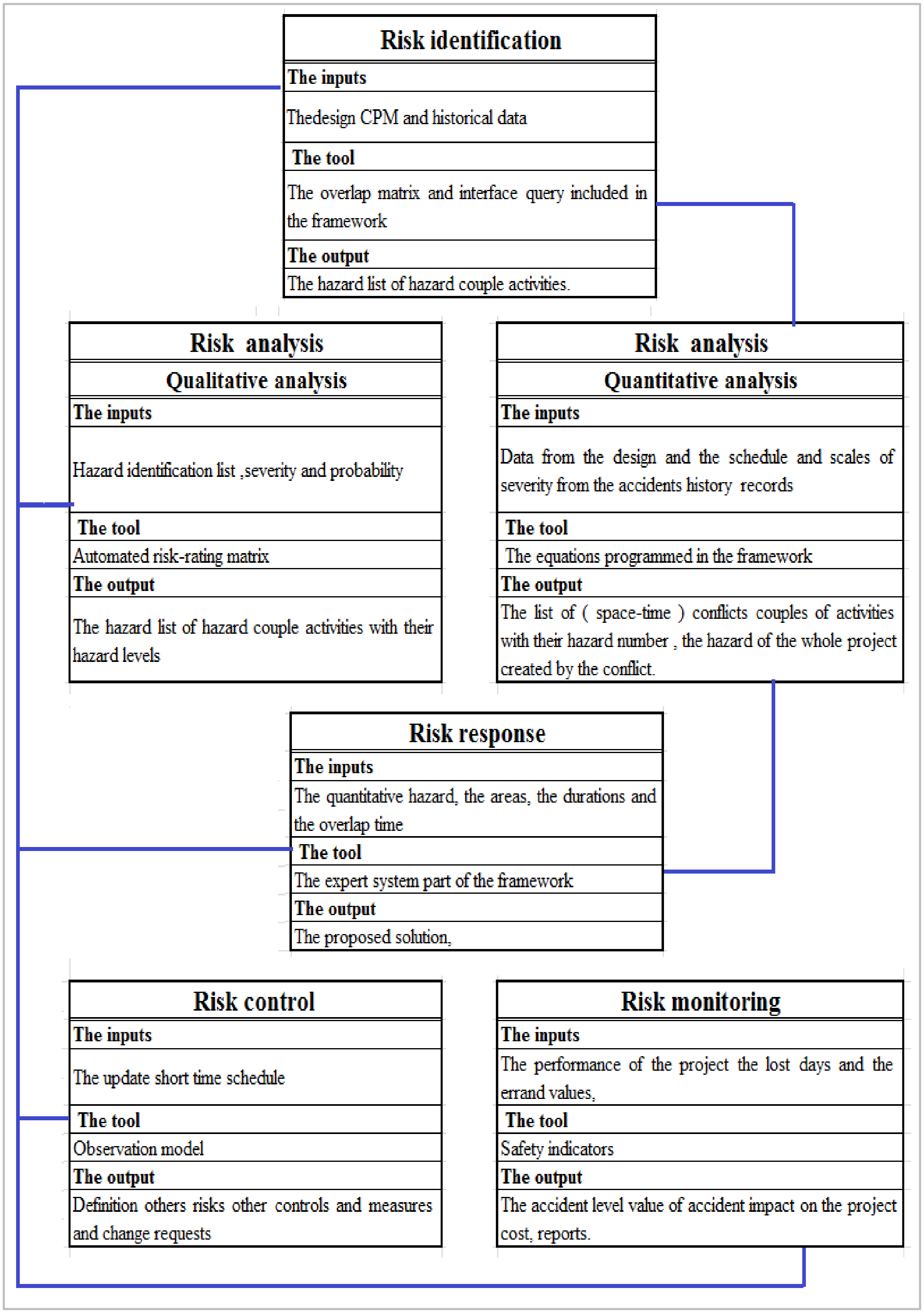

Figure 6-27 Comparison with the risk management definition of PMBOK school

6.7 Conclusion

This chapter aims to demonstrate that the method introduced in this study is fully operational. The second part provides a description of the examples it presented, the WSiCPM framework was later applied to illustrate how this framework works, and to assess its results as well as the proposed solutions. The individual and general reports of this framework have been discussed; while the results were examined to prove their rationality.

Three proposed solutions have been examined with the result that they are suitable and highly valuable.

The results were also compared to previous methods that were applied during the project, thus the benefits of this framework were identified.

In the fifth paragraph, the safety indicators software suggested by this research through the use of VBA in the MS Project environment was applied to the example (after a progress in the project). The results were discussed, and the applicability of these indicators was verified, while their link with the earned value measures was examined mathematically and logically. It became evident that this software would be worthwhile as additional software to the MS Project for the purpose of workers' safety.

However, these indicators must be applied in different projects during several points of progress and at the end, to demonstrate how they represent the actual accident ratio in the project.

The advantages of this framework in comparison to other methods, including safety in design tools, have also been studied and proven to be a complete method compared with the definition of the risk management introduced by the PMBOK School.

In conclusion, the method functions as it is intended to do and delivers countless benefits in comparison with previous methods, and it has the potential to recommend suitable solutions for identified conflicts with various parameters.

CHAPTER 7

Conclusion

7.1 Introduction

This study was set out to reduce the level of accidents on construction sites by resolving the space-time-conflicts, and through integrating design for safety into the critical path method and the workers' safety into scheduling and design.

Fundamentally, conflicts and the lack of safety aspects in the schedule and design are evident as the main issues affecting workers' safety.

Since the projects contain hundreds of overlapping contracts, finding the hazard conflicts by studying the paper schedule and hundreds of design drawings is challenging and almost impossible.

The fact that the CPM scheduling software, like MS Project, remains the market leader for larger projects, highlights the importance of this study, making it more accessible and ensures its wide spread.

This study has successfully improved the planning and coordination for workers' safety purposes.

Moreover, this study has closed the gaps in this field as stated in the introduction and other chapters of this research, which are:

- The workers' safety is not considered in the schedule,
- The lack of integration of design with schedule,
- The concept of schedule for safety rarely exists,

- The schedule does not consider the spatial attributes of activities,
- The design for safety fails to consider the time attributes of activities,
- The design for safety is limited to the pre-construction phase,
- The control of the safety in design during the construction phase hardly exists,
- The lack of the measures preventing accidents,
- Although the conflict was proved as a significant cause of accidents, yet not analysed thoroughly.

7.2 The position of this research

To clarify the position of this study, we have compared it with the general risk management identified by the most important school in construction management (PMBOK).

We find that this study contains all the elements, which make it a complete framework, as it goes along with the risk management procedure which consists of the following steps:

- Risk plan in is the CPM, the input is WBS, the output is the plan.
- Risk identification in this study is a vital step, the inputs for this step are the design, CPM, and historical data. The tool is the overlap matrix and interface query included in the framework, while the output is the list of hazard pairs of activities.
- Qualitative risk analysis step is also included in the study, the inputs are the level of severity and probability, while the tool is a risk-rating matrix, and the output is a list of space-time-conflict pairs of activities with their risk level.
- Risk quantification is the most essential step in this study, the inputs for this step are the data from the design and the schedule, and scales of severity. The tools are the equations developed in this study and programmed in the framework, while the output is the list of space-time-conflicts pairs of activities with their risk calculation.

- Risk response planning is an unequalled attribute of this study among the tools in this field. It is presented by the recommended solutions of the framework. The inputs of this step are the result of the quantitative risk, areas, and the overlap time, the tool is the formula that functions as an expert system, the technics are elimination, mitigation, or acceptance. The output is the proposed solution (alternative strategies), the outputs are the inputs of the change requests.
- Risk control and monitoring, this study presents two types of the control.
  - First, since the risk is not a one-time event, it must be monitored regularly in construction phase, this study has developed the observation model as a tool of risk control, the inputs are the changes, the work progress, the updated short time schedule, while the outputs detect other risks, control measures and change requests.
  - Second, the safety indicators in the additional workers' safety tool in the MS Project environment. The inputs are the progress, the lost days, the errand values measures, and the performance of the project, while the outputs are the accident ratio in each (completed or in progress) activity and in whole project, level values of the accidents, the impact of the accidents on the project cost and other reports.

This framework proved to be vital for determining the hazardous situations, while it is difficult in the previous methods to determine all the hazard conflicts, it aids in the process of risk estimating by dividing this process, and by automating it as well as suggesting reasonable solutions to eliminate or reduce the hazard.

While other methods depend on experience to estimate the hazard and require an expert to do so, this method instead has the potential to help even new engineers to discover hazardous situation, estimate the risk and find a rational solution.

This framework resolves the problems of workers' safety, as stated in the introduction: "the workers' safety issues are not well considered in design, planning and scheduling, they are often believed to be the concern of the site and contracts, not of the planners and designers". It addresses workers' safety in the design and in the schedule early in the project.

This framework offers a solution to each hazardous conflict situation, these solutions were shown to be reasonable.

Through referring back to the records and reports of the accidents, we can find that many accidents would not have occurred if such a framework was applied.

7.3 Contribution

The contributions of this research include:

- Eliminate or reduce the accidents caused by space-time-conflicts on construction sites,
- Find the pairs of activities with time-overlap through the use of the overlap-matrix developed in this research,
- Identify all hazardous situations created by space-time-conflicts,
- Automate the traditional safety matrix,
- Calculate the risk quantitatively, and make the hazard fully measurable, enabling further studies the analysis and the priority classification,
- Develop a method to calculate the severity, relying on the damage, simulating the way in which the compensation of the casualty is calculated by the insurance companies in the actual accidents,
- Enable the conversion of the risk measured to an expected monetary value; this is due to the severity, which is calculated depending on the damage,
- Add the time concept to the BDS tool,
- Enable the control of the safety in the design during the construction phase,
- Develop additional tools in CPM scheduling software for workers' safety purpose,
- Enable the design for safety in construction, control and monitoring phases,
- Automate the procedure of hazard estimation,
- Discuss possible solutions for each space-time-conflict pair, to help the decision maker to find a suitable solution,

- Enable accident tracking during the construction phase using the safety indicators introduced in this research,
- Allow studying the impact of the accidents on the project cost,
- Link the safety indicators to the earned value measures,
- Analyse the unequal distribution of the work on the duration,
- Achieve the linking between several concepts traditionally analysed separately, they are constructability, safety in design, and scheduling,
- Help the non-expert user to estimate the hazard and find a solution,
- Enable analysis and differentiation by applying the safety indicators in the project,
- Study the impact of accidents on the project cost,
- Resolve the problems early in the project when the ability to influence safety is still high, without additional cost and without delay in the project,
- This framework is not costly and does not require much time nor an expert, as other methods such as 4D simulations,
- This framework does not demand additional work, it relies on the process followed throughout the project.

7.4 Further studies

The research in this field continues all over the world, the awareness of the importance of integrating time and space attributes, design and schedule, and constructability to achieve workers' safety is increasing.

This section introduces several recommendations for future studies stemming from the scope and the results of this research.

- The formulas can be more effective, if added to BIM (Building Information Modelling).
- Since the research in the BDS method continues towards the automation of the risk estimation process, these formulas could be useful.

- Other solutions can be added to the framework, which now offers eight types of the solutions.
- The formulas and the program of the framework can be further developed as an expert system.
- Since the VBA works in the AutoCAD environment, linking the database with Auto CAD to attain the areas automatically can be a significant improvement of the framework.
- The framework can be developed to resolve also other risks, not only the conflict situation.
- The impact of the solutions on the time and cost of the project should be studied.

7.5 **Limitation**

This study is one of the first to integrate different variables, addressing workers' safety in several phases and processes, to combine several fields and to close several gaps. It also contains several shortcomings:

- The framework only resolves the space-time-conflicts.
- The overlap-time pairs are countless, in comparison with the number of hazard conflict pairs.
- The framework is only applicable to measurable areas; it is difficult if the areas related to the activity are not clear.
- The framework does not contain all possible solutions for the detected hazard situations.

7.6 **Conclusion**

This chapter presented how this study successfully achieved its aims, listing the objectives, and referring to the gaps in previous studies that were overcome in this research.

It then presents the position of this study by comparing its elements with the steps of the risk management as identified by the PMBOK School, proving its validation and its distinctive attributes, which are the recommended solutions and safety indicators.

It finally highlights the importance of this study and its contributions, illustrating that it could become available and significant since it has been performed in the environment of CPM software, which is extensive, later suggesting the directions of further studies and revealing the present limitation of the study.

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