DEVELOPMENT OF AN ACTIVITY BASED RISK ASSESSMENT TOOL USING INTEGRATED DURATION – COST INFLUENCE NETWORK

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ABSTRACT

DEVELOPMENT OF AN ACTIVITY BASED RISK ASSESSMENT TOOL USING INTEGRATED DURATION – COST INFLUENCE NETWORK

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As the construction sector is becoming more competitive in recent years, it has become more important to estimate the duration and cost of the construction projects and to calculate the risks' effects correctly. The aim of this thesis is to estimate the duration and cost of construction projects accurately using an activity based risk assessment method which is based on the integrated duration – cost influence network diagram model proposed by Tah and Poh (2006).

Within the context of this thesis, a web based risk assessment tool using the integrated duration – cost influence network at an activity level is developed to estimate the possible cost overrun and delay in construction projects. Risk breakdown structure for construction projects is created which enables the evaluation of risk effects at an activity level. The developed tool uses Monte Carlo Simulation Technique and Risk Rating Method. The results of the developed tool are compared with those of traditional methods and the reliability of the developed tool is validated.

Keywords : Risk Assessment, Monte Carlo Simulation, Duration – Cost Estimation, Influence Network Diagram

ÖZ

BÜTÜNLEŞTİRİLMİŞ SÜRE –MALİYET ETKİ AĞI İLE AKTİVİTE BAZLI BİR RİSK DEĞERLENDİRME PROGRAMI GELİŞTİRİLMESİ

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Son yıllarda inşaat sektöründeki rekabet ortamının giderek artması, inşaat projelerinin maliyet ve sürelerinin gerçekçi olarak tahmin edilmesini ve risklerin etkilerinin doğru bir şekilde hesaplanmasını gerekli kılmıştır. Bu tez kapsamında geliştirilen programın amacı, Tah ve Poh (2006) tarafından geliştirilen bütünleştirilmiş süre-maliyet etki ağı ile aktivite bazlı risk değerlendirme yöntemini baz alarak, inşaat projelerinde gerçekçi bir maliyet ve süre tahmini yapılabilmesini sağlamaktır.

Bu tez kapsamında proje süresindeki ve maliyetindeki artışı tahmin etmek için aktivite bazlı süre – maliyet etkileşim ağı modelinin kullanıldığı web tabanlı bir risk değerlendirme programı geliştirilmiştir. İnşaat projelerine özel bir risk yapısı oluşturulmuş ve risk etkilerinin aktivite bazında incelenmesini sağlayacak bir yöntem geliştirilmiştir. Programda Monte Carlo benzetimi ve çok kriterli risk ölçüm yöntemleri kullanılmış, sonuçların güvenilirliği geleneksel yöntemlerle karşılaştırılarak, programın güvenilirliği doğrulanmıştır.

Anahtar Kelimeler : Risk Değerlendirmesi, Monte Carlo Benzetimi,
Süre – Maliyet Tahmini, Etki Diyagramları

Dedicated to my wife, mother, father and brothers

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EFFD	External Factors for Duration
EFT	Early Finish Time
EST	Early Start Time
FS	Finish to Start
FF	Finish to Finish
H	Lower Limit for the High Region
LFT	Late Finish Time
LST	Late Start Time
L	Upper Limit for the Low Region
M	Most Probable Value for the Change in the Given Parameter
MC	Monte Carlo
NA	Not Applicable
O	Optimistic Value for the Change in the Given Parameter
P	Pessimistic Value for the Change in the Given Parameter
PDM	Precedence Diagramming Method
P100	Productivity of Labour
P200	Unit Rate of Labour
P300	Quantity of Labour
P400	Unit Cost of Material
P500	Quantity of Material

P600	Productivity of Subcontractor
P700	Unit Rate of Subcontractor
P800	Unit Price of Subcontractor
P900	Quantity of Subcontractor
P1000	Productivity of Plant
P1100	Unit Rate of Plant
P1200	Quantity of Plant
P1300	External Factors for Duration Coefficient
RM	Risk Manager
R100	Delay in Bureaucracy
R200	Delay in Payment
R300	Delay in Delivery of Equipment
R400	Delay in Delivery of Material
R500	Delay in Site Handover
R600	Delay in Design
R700	Change in Scope
R800	Change in Design
R900	Change in Construction Technique
R1000	Change in Weather Conditions
R1100	Change in Geological Conditions
R1200	Change in Inflation
R1300	Change in Socio-Political Conditions
R1400	Change in Relations between Parties
SF	Start to Finish
SS	Start to Start

SP	Sample Project
TF	Total Float

CHAPTER 1

INTRODUCTION

In today's world, winning a bid of a construction project is more difficult for companies since the bids are more competitive due to increased number of construction companies, world globalization and improvements in construction techniques. In order for a construction company to win a bid with an appropriate offer, the increase in activities' durations and costs due to risk factors must be well estimated. Knowing the limits how much the construction activities' durations and costs may increase enables the company to estimate the varieties in the cash flow diagram, critical path, total project duration and cost. This will enhance the company to determine an appropriate bid offer.

Moreover, the success of construction projects depends on estimating durations and costs of the activities and plan accordingly. In order for a construction manager not to have a bad planning of the activities and a misleading cash flow diagram during the construction period, the effects of risk factors should be quantified to calculate risk adjusted durations and costs. This can be achieved by performing risk analysis for the project.

It is also important to monitor and record the risk effects in a project since this information is useful in minimizing the risk effects in other similar projects. Quantitative risk analysis quantifies the risk effects on the quantifiable performance measures of duration and cost (Tah and Poh, 2006).

Researches have been carried out for quantifying risk effects on duration and cost of activities. However, there is still an obvious need for a useful risk assessment tool.

In this thesis, the major aim is to develop an activity based risk assessment tool using integrated duration – cost influence network model. This tool enables users to record and monitor the risk data on the web, and gives graphical results which show how much durations and costs of activities and whole construction project may increase in a probabilistic manner.

In Chapter 2, the definitions of the terms used in the model, formulations used in the calculations are given. The basic characteristics and the limitations of the model proposed by Tah and Poh (2006) are described.

In Chapter 3, risk assessment procedure of the integrated duration – cost influence network diagram is defined in a systematic manner. The risk breakdown structure is given and the improvements are explained.

The developed tool is explained in Chapter 4 with its formwork and algorithm. The background of the software and the user interface is described. The assumptions while applying the methods are also described.

In Chapter 5, the developed tool is tested by using data of an implemented construction project. The project inputs used in the software for the case study is given and the results are discussed.

Finally, in Chapter 6, the risk assessment tool developed with this thesis work is discussed with its advantages and shortcomings. It is also discussed how the developed tool can be improved in further researches.

CHAPTER 2

RISK ASSESSMENT USING INTEGRATED DURATION – COST INFLUENCE NETWORK MODEL

Construction industry has become more competitive over the recent years. This brings a tough challenge between construction firms to win a bid. The costs and durations of construction projects usually exceed the planned costs and durations due to risks the effect of which were not taken into account during the planning stage. In order for a company to win the bid or to make a good planning of cash flow and schedule, the cost overrun and duration extension should be well estimated. This can be achieved by applying a proper and effective risk assessment methodology. The aim of this thesis is to develop a software tool to be used in the risk assessments of construction projects. The definitions and the characteristics of the risk assessment process of the tool are discussed in this chapter in detail by giving the structure of the model.

2.1 Definition of Risk and Risk Management

"Risk" is used in many different ways and with many different words, such as "hazard" or "uncertainty" (Jannadi & Almishari, 2003). Construction projects have many risks in their nature. Risks should be assessed taking into account their probability of occurrences and impacts on the activities in order to make a good contingency estimation and proper scheduling. Risk can be expressed mathematically as "the probability of occurrence of loss/gain multiplied by its respective magnitude" (Jaafari, 2001). Within the context of this thesis study, risk is defined as an event the occurrence of which causes either a delay in the planned duration or an increase in the planned cost of an activity or both. Therefore, it is needed to identify risks, evaluate their probability of occurrences and impacts and determine the duration extension and cost overrun.

Risk management methodology consists of three main parts; risk identification, risk assessment and risk response strategy. The identification of risks is an important step in risk management at tender preparation phase and planning phase. Risk classification is an important step in the risk assessment process, as it attempts to structure the diverse risks that may affect a project (Tah & Carr, 2001).

Hastak and Shaked used International Construction Risk Assessment Model (ICRAM) to classify risks. Risks are analyzed at three different levels in this model: Macro (or country) level, market level and project level (Hastak & Shaked, 2000). In this model, risk assessment is made in such a structured way that the impact of macro environment on market and project environment, and the impact of market environment on project environment are included in the risk analysis.

To make an activity based risk assessment, risks should be defined at an activity level. Risks can be named according to their sources or consequences. In this thesis study, risks are classified according to their sources and grouped in two main parts as "delay risks" and "change risks". Delay risks are the events the occurrences of which cause a delay in the activity due to changes in the parameters such as productivity, quantity etc. Similarly, change risks are the events the occurrences of which cause a change in the scope of an activity. The consequence of a delay risk or a change risk itself may be an increase in duration, cost or both. This brings the necessity to make an integrated duration – cost risk assessment. Risk assessment in this thesis study consists of three main parts; the evaluation of the probability of occurrences of risks, the association of them to the relevant parameters by introducing impacts, and quantification of risk effects to calculate risk adjusted durations and costs of activities.

There are two factors in assessing risks: probability of occurrence and impact. The probability and the impact are two different concepts which should not be used interchangeably. Impact is the effect of a risk on a parameter when it occurs, i.e. without considering the chance of occurrence. On the other hand, probability is the likelihood of occurrence without considering the impact of a risk on a parameter. A risk may have a high impact on a parameter but a low probability of occurrence or vice and versa. Therefore, it is wise to determine the effects of risks by considering both the probability of occurrence and the impact.

The aim of risk assessment in construction projects is to develop a risk response strategy by taking necessary actions and plan accordingly as required by the risk assessment results. Risk response strategy can be executed by either controlling a risk by minimizing the effect of a risk or financing a risk by supplying financial resource.

2.2 Integrated Duration Cost Influence Network Model

The primary objective during the construction process is completing the project on time and within the budget while meeting the established quality requirements and other specifications (Rasdorf & Abudayyeh, 1991). However, due to uncertainties, vagueness and hazards duration and cost of a project is subject to increase. The question is how much cost or duration of a project may increase. It is worthy for a construction company to know the answer of this question at the early stages of a project. This can be achieved by quantifying risk information using risk analysis techniques.

Influence diagrams are useful when there is an interrelation between the elements of risk analysis. These elements may be risks or parameters which are affected by risks.

One of the limitations identified is that conventional techniques can only analyse either duration or cost risks (Rao and Grobler, 1995). It is time-consuming to undertake two separate risk analyses due to the extra effort required for preparing the inputs of analysis. In addition, ignoring the correlation between duration and cost has raised concerns about the accuracy of the results (Isidore and Back, 2002). Although there have been attempts to integrate time and cost risks, they only integrate the results from two individual analyses, and the correlation is not examined in detail (Poh and Tah, 2006).

Duration of an activity can be affected by different risk factors, which results in the prolongation of that activity duration. This will in turn result in an increase in the cost of that activity as well. Besides, cost of the activity is affected by risk factors some of which may be different than those that affect the duration. Therefore it is needed that risk analysis on the duration and the cost of the activities are carried out taking into account the interrelation.

Activities include different types of works such as design works or concrete works. Different types of works are affected by various risk factors such as weather conditions or bureaucracy. Therefore associating risks to appropriate activities, instead of associating them to whole project, which can actually be defined as activity based risk analysis will give more reliable risk assessment results.

In order to have a model in which the interrelation between duration and cost parameters is included at an activity level, the integrated duration – cost influence network activity model proposed by Tah and Poh is used. This activity model is the basis of the developed tool.

Figure 2.1 shows the constituent components that determine the duration and cost measures of a construction task. The duration measure is subject to the duration – based resource components of plant, labour and subcontractor, which require time to complete works. Certain external factors such as authority approval, handover of job site and late delivery of material, are factors that will influence the task duration, but are beyond the control of the labour, plant and subcontractor components. (Tah and Poh, 2006).

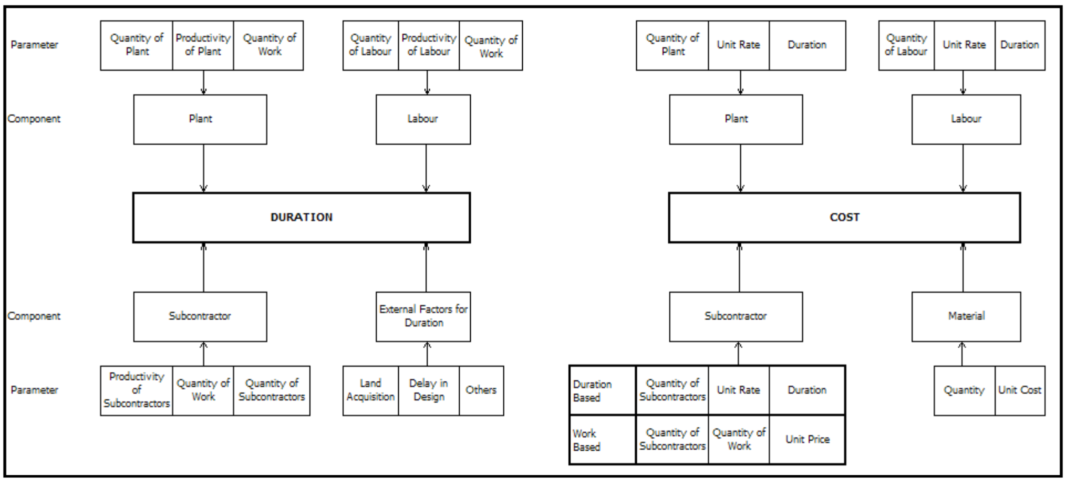

Figure 2.1 Components and Parameters of Task Cost and Duration Measures (Tah & Poh, 2006)

An integrated duration – cost influence network can be formed by rearranging and merging the parameters shown in Figure 2.1. (Tah and Poh, 2006). The formed integrated duration – cost influence network activity model is the basis for the mathematical formulations derived by Tah and Poh. This model and the mathematical formulations derived by Tah and Poh are the basis for the calculations used in the tool. The formulations and the integrated duration – cost model are given and discussed in detail in the following sections.

2.3 Structure of the Model

The main characteristic of this tool is to make an activity based risk analysis by integrating risk calculations of duration and cost. Duration and cost integration can be achieved by analysing duration and cost components and parameters simultaneously which can be achieved by a proper model with a well defined structure. The elements of the structure of the model are introduced in subsections.

2.3.1 Activities

Activity in a construction project can be defined as a task which requires cost and duration for its completion. Duration and cost of an activity can be affected by risks which results in a delay and/or an increase in the cost of the activity. The effect of risks on both duration and cost can be analyzed simultaneously by decomposing activities into components, and components into parameters. Such an activity model, which the developed risk assessment tool is based on, is suggested by Tah and Poh. Figure 2.2 shows the activity model used in this thesis study.

Activity ID, activity name, duration, cost, predecessor – successor activities with logical relationship types and lag times should be specified to define an activity. The use of duration, cost and logical relationships in the calculations will be discussed in Section 2.6.

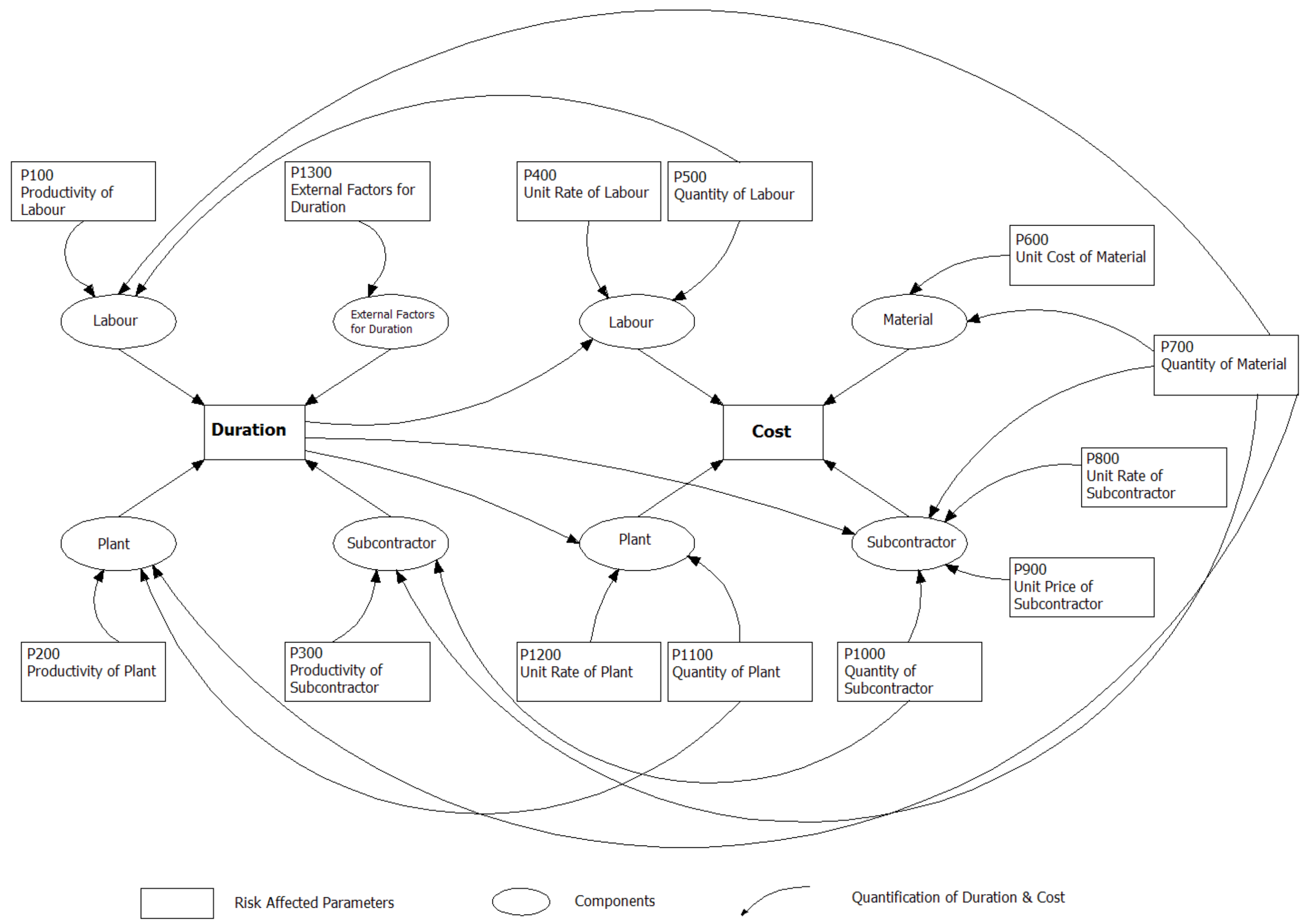

Figure 2.2 Activity Model (Tah & Poh, 2006)

2.3.2 Components

Duration and cost of an activity is dependent on the components which constitutes that activity. These components are defined as "plant", "labour", "material", "subcontractor" and "external factors for duration". A component has a duration and cost itself which in turn is used to calculate the duration and cost of an activity.

Duration and cost required by equipments and construction site is included within the ***Plant Component.*** If labours are working for that activity, the duration required by labours to complete the work defined with that activity and labour cost is included in the ***Labour Component.*** Material used for that activity is included in the *Material Component* which has only cost but no duration. If the activity is given to a subcontractor, duration required by the subcontractor and payments to the subcontractor is included in the ***Subcontractor Component. External Factors for Duration Component*** is defined for the factors which causes a delay in the duration of an activity which is not included in the other components of the duration such as "delay in delivery of material".

It can be observed from Figure 2.2 that two important property of an activity; duration and cost, have common and distinct components. This model requires the costs to be distributed over the components to distinguish the risk adjusted cost calculations. In other words, the cost of an activity is to be defined as the cost of labour component, material component, subcontractor component, and plant component of that activity. This provides to calculate the increases of costs of components separately. It is also needed to define the cost of subcontractor as either duration based or work based depending on the type of subcontractor.

2.3.3 Parameters

Duration and cost of a component is determined by its parameters the list and definitions of which are given below. This is the last sublevel that an activity is decomposed. Risk calculations are carried out through the parameters of an activity first. Changes in the parameters due to the risk factors result in an increase in the cost and a delay in the duration of an activity.

P100 – Productivity of Labour: Productivity of Labour is the measure of the work done within a unit time by one labour. A change in productivity of labour due to risk factors could be a decrease which has a negative value.

P200 – Unit Rate of Labour: Unit rate of Labour is the unit cost of a labour for a unit time. A change in unit rate of labour due to risk factors could be an increase which has a positive value.

P300 – Quantity of Labour: Quantity of Labour is the number of workers required to complete the task. A change in quantity of labour due to risk factors could be an increase which has a positive value.

P400 – Unit Cost of Material: Unit Cost of Material is the cost per one unit of material required for the activity. A change in unit cost of material due to risk factors could be an increase which has a positive value.

P500 – Quantity of Material: Quantity of Material is the amount of material required to complete the task. A change in quantity of material due to risk factors could be an increase which has a positive value.

P600 – Productivity of Subcontractor: Productivity of Subcontractor is used for the works given to the subcontractor to represent a measure of the work done within a unit time by subcontractor. A change in quantity of material due to risk factors could be a decrease which has a negative value.

P700 – Unit Rate of Subcontractor: Unit rate of Subcontractor is the cost of subcontractor per a unit time. This is used if the contract with the subcontractor is duration based; i.e. unit price contract. A change in unit rate of subcontractor due to risk factors could be an increase which has a positive value.

P800 – Unit Price of Subcontractor: Unit price of Subcontractor is the cost of subcontractor per a unit time. This is used if the contract with the subcontractor is work based; i.e. lump sum contract. A change in unit price of subcontractor due to risk factors could be an increase which has a positive value.

P900 – Quantity of Subcontractor: Quantity of subcontractor shows the number of workers of subcontractor required to complete the given activity. A change in quantity of subcontractor due to risk factors could be an increase which has a positive value.

P1000 – Productivity of Plant: Productivity of plant is the measure of the work done by a plant which includes equipments such as excavator, crane etc. within a unit time. A change in productivity of plant due to risk factors could be an increase which has a negative value.

P1100 – Unit Rate of Plant: Unit rate of plant is the cost of plant including equipment and site cost per unit time. A change in unit rate of plant due to risk factors could be an increase which has a positive value.

P1200 – Quantity of Plant: Quantity of plant is the amount of equipment and construction site needed for the completion of the activity. A change in quantity of plant due to risk factors could be an increase which has a positive value.

P1300 – External Factors for Duration Coefficient: External Factors for Duration Coefficient is used to modify the duration for the risks which do not have effects on other parameters. EFFD Coefficient is 1 under no risk condition. A change in external factors for duration coefficient due to risk factors could be an increase which has a positive value.

2.3.4 Mathematical Formulations

The model proposed by Tah and Poh (2006) derived mathematical formulations to be used in the quantification of the risk effects. The formulations are based on two assumptions.

Firstly, an assumption that the work scope will be handled by all the parties involved cooperatively and interactively is made. This assumption is generally true in practice. (Tah & Poh, 2006). This assumption yields an equation (1) given below.

$$Q_w = Q_{w,p} = Q_{w,l} = Q_{w,s} \quad (1)$$

where

Q_W = the total quantity of work of the activity;

$Q_{W,P}$ = the quantity of work to be completed by the plant component;

$Q_{W,L}$ = the quantity of work to be completed by the labour component;

$Q_{W,S}$ = the quantity of work to be completed by the subcontractor component.

Secondly, it is assumed that the duration required by a labor component, plant component, and subcontractor component is equal to the duration of an activity. This is, in practice, can be achieved by optimising the resources.

$T_a = T_p = T_l = T_s$ (2)

where

T_a = the duration of the activity;

T_P = the duration required by the plant component for the activity;

T_L = the duration required by the labour component for the activity;

T_S = the duration required by the subcontractor component for the activity;

The duration of an activity can be calculated by the following formulas;

Plant : $Tp = \frac{\mathrm{Qw}}{\mathrm{Pp} \times \mathrm{Qp}}$ (3)

Labour : $Tl = \frac{\mathrm{Qw}}{\mathrm{Pl} \times \mathrm{Ql}}$ (4)

Subcontractor : $Ts = \frac{\mathrm{Qw}}{\mathrm{Ps} \times \mathrm{Qs}}$ (5)

where

T_p = the duration required by the plant component;

P_p = the plant productivity;

Q_p = the quantity of plant required;

T_l = the duration required by the labour component;

P_l = the labour productivity;

Q_L = the quantity of labour allocated;

T_S = the duration required by the subcontractor component;

P_S = the subcontractor productivity;

Q_S = the quantity of resources allocated by the subcontractors;

The costs of the components can be calculated from the following formulas;

Plant : $C_p = Q_p \times UR_p \times T_a$ (6)

Labour : $C_l = Q_l \times UR_l \times T_a$ (7)

Material : $C_m = Q_m \times UC_m$ (8)

Subcontractor : $C_s = C_{sw} + C_{sd}$ (9)

$C_{sw} = Q_{sw} \times UP_{sw}$ (10a)

$C_{sd} = Q_{sd} \times UR_{sd} \times T_a$ (10b)

where:

Q_p = the quantity of plant;

UR_p = the unit rate of plant;

Q_l = the quantity of labour required;

UR_l = the unit rate of labour;

C_{sw} = the subcontract cost based on work done;

Q_{sw} = the quantity of work scope under the subcontractor;

UP_{sw} = the unit price for work under the subcontractor;

C_{sd} = the subcontract cost based on the duration of service performed;

Q_{sd} = the number of workforce provided by the subcontractor;

UR_{sd} = the unit rate of workforce provided by the subcontractor;

Q_m = the quantity of the material;

UC_m = the unit cost of the material.

The total cost of an activity can be represented by the following equation;

$$C_a = C_p + C_l + C_s + C_m \quad (11)$$

where

Ca = the total cost of the activity;

C_p = the plant cost of the activity;

C_l = the labour cost of the activity;

C_s = the total subcontractor cost;

C_m = the material cost of the activity.

The duration and cost of an activity is specified by the user directly in the developed risk assessment tool. The above formulations are given to form a base for the risk adjusted calculations.

Changes in the parameters; P_l, UR_l, Q_l, UC_m, Q_m, P_s, UR_s, UP_s, Q_s, P_p, UR_p, Q_p C_{effd}; result in changes in the durations and costs. Risk adjusted durations and costs can be calculated with the following formulas.

It is assumed that change in the work required by an activity is equal to the maximum of the changes of works completed by the components. This can be formulated as in the equation (12).

$$\Delta Qw = \max(\Delta Q_p, \Delta Q_l, \Delta Q_s, \Delta Q_m) \tag{12}$$

Then,

$$T_p' = T_a \times \frac{\left(1+\frac{\Delta Qw}{100}\right)}{\left(1-\frac{\Delta Pp}{100}\right) \text{x} \left(1-\frac{\Delta Qp}{100}\right)} \tag{13}$$

$$T_l' = T_a \times \frac{\left(1+\frac{\Delta Qw}{100}\right)}{\left(1-\frac{\Delta Pl}{100}\right) \text{x} \left(1-\frac{\Delta Ql}{100}\right)} \tag{14}$$

$$T_s' = T_a \times \frac{\left(1+\frac{\Delta Qw}{100}\right)}{\left(1-\frac{\Delta Ps}{100}\right) x \left(1-\frac{\Delta Qs}{100}\right)} \quad (15)$$

$$T_a' = \max\,(T_p', T_l', T_s') \quad (16)$$

where

T_p' = the risk adjusted duration required by the plant component;

T_l' = the risk adjusted duration required by the labour component;

T_s' = the risk adjusted duration required by the subcontractor component;

T_a' = the risk adjusted duration of the activity;

and Q_s is either Q_{sd} or Q_{sw} according to the type of subcontractor.

Since the duration cannot be a decimal value, it is rounded to an integer value after the calculations.

Changes in the duration of an activity results in a change in the cost of an activity as well as the changes in the parameters of the components related with the cost of that activity. The integrated duration – cost calculations takes place for the risk adjusted cost calculations.

$$C_p' = C_p \times \left(1 + \frac{\Delta Qp}{100}\right) \times \left(1 + \frac{\Delta URp}{100}\right) \times \left(\frac{Ta'}{Ta}\right) \quad (17)$$

$$C_l' = C_l \times \left(1 + \frac{\Delta Ql}{100}\right) \times \left(1 + \frac{\Delta URl}{100}\right) \times \left(\frac{Ta'}{Ta}\right) \quad (18)$$

$$C_m' = C_m \times \left(1 + \frac{\Delta Qm}{100}\right) \times \left(1 + \frac{\Delta UCm}{100}\right) \times \left(\frac{Ta'}{Ta}\right) \quad (19)$$

$$C_s' = C_{sd}' + C_{sw}' \quad (20)$$

$$C_a' = C_p' + C_l' + C_m' + C_s' \quad (21)$$

$$C_{sd}' = C_{sd} \times \left(1 + \frac{\Delta Qs}{100}\right) \times \left(1 + \frac{\Delta URs}{100}\right) \times \left(1 + \frac{\Delta Qw}{100}\right) \times \left(\frac{Ta'}{Ta}\right) \quad (22a)$$

$$C_{sw}' = C_{sw} \times \left(1 + \frac{\Delta Qs}{100}\right) \times \left(1 + \frac{\Delta UPs}{100}\right) \times \left(1 + \frac{\Delta Qw}{100}\right) \times \left(\frac{Ta'}{Ta}\right) \quad (22b)$$

where

C_p' = the risk adjusted cost of the plant component;

C_l' = the risk adjusted cost of the labour component;

C_m' = the risk adjusted cost of the material component;

C_s' = the risk adjusted cost of the subcontractor component;

C_a' = the risk adjusted cost of the activity.

2.3.5 Limitations of the Model

The proposed model is useful in the quantification of the risk effects at an activity level. However, the proposed model does not have a risk assessment part. Therefore, how the selection of a parameter % change which is used in the risk adjusted calculations is provided by the risk assessment used in the developed tool. Furthermore, calculations using the derived mathematical equations cannot be made by hand practically. The possible increase in the indirect cost of the project due to a delay is ignored in the proposed tool as well. Hence, the proposed model is improved to overcome these limitations. The improved model is used as the basis of the developed tool.

CHAPTER 3

THE PROPOSED RISK ASSESSMENT METHOD

The model proposed by Tah and Poh (2006) is improved and used as the basis of the developed tool. Firstly, a risk breakdown structure is created and risk assessment part is added to the model. Then, Monte Carlo Simulation technique is used in the determination of percent changes in the parameters to create scenarios. A web based software tool with simplified rules is developed which can be used for overall project.

The equations derived by Tah and Poh (2006) are used in the developed tool. As explained in Chapter 2, it is assumed that the duration required by a labor component, plant component, and subcontractor component is equal to the duration of an activity. This assumption is extended to assume that the duration required by the external factors for duration (EFFD) is also the same as that required by the other components.

$$T_a = T_p = T_l = T_s = T_{effd} \tag{23}$$

where

T_a = the duration of the activity;

T_P = the duration required by the plant component for the activity;

T_L = the duration required by the labour component for the activity;

T_S = the duration required by the subcontractor component for the activity;

T_{effd} = the duration required by the EFFD component for the activity;

EFFD : $T_{effd} = (C_{effd}) \times T_a$ (24)

C_{effd} = External Factors for Duration Coefficient which is 1 under risk free case.

Then,

$$T_{effd}' = T_a \times C_{effd} \quad (25)$$

$$T_a' = \max (T_p', T_l', T_s', T_{effd}') \quad (26)$$

where

T_p' = the risk adjusted duration required by the plant component;

T_l' = the risk adjusted duration required by the labour component;

T_s' = the risk adjusted duration required by the subcontractor component;

T_{effd}' = the risk adjusted duration required by the EFFD component;

T_a' = the risk adjusted duration of the activity;

3.2 Risk Breakdown Structure

Risk breakdown structure is an important stage in the quantitative risk analysis since the duration and cost is adjusted according to the risks defined for activity parameters. Within the context of this thesis study, risk can be defined as an event which has an uncertainty and causes a delay in the duration and/or an increase in the cost of an activity if it occurs. A risk may be a delay or a change in the events related with the construction activities. Considering the causes, risks can be categorized in two parts as delay or change. The risk list prepared for the development of this tool and the definitions of the risks are given below.

R100 – Delay in Bureaucracy: Construction projects have relations with different disciplinary which requires necessary permissions to be taken from the governmental organizations and institutions. The documentation and getting permissions may sometimes require a longer time which is not thought to be likely to happen.

R200 – Delay in Payment: It is important to have a proper cash flow and sufficient equity and/or credit for the completion of the construction projects on time. However, it is a common problem which is very likely to happen in some projects due to the contractor or owner that the payments are not done on time. This has a negative effect on duration and cost of an activity which is to be determined with the calculations used in the tool.

R300 – Delay in Delivery of Equipment: Equipment such as excavation, crane should be available on site on time. In some projects like tunnel construction, availability of equipment is vitally important and a delay in the delivery of equipment may result in extra cost and longer project duration.

R400 – Delay in Delivery of Material: Material needed for the completion of a task in construction works may not be available on time due to insufficient storage area, late procurement or transportation etc. The effect of delay in delivery of material will be a delay in the completion of activity. In addition, there will be extra cost for that labour or subcontractor will wait for the material.

R500 – Delay in Site Handover: To begin the mobilization and other following activities in construction projects, site handover is to be completed. Site handover is usually a critical activity which means that a delay in site handover results in a delay in project duration.

R600 – Delay in Design: In construction projects, design work is an important stage which has a great effect on the project plan. Usually, the design company is a 3rd company hired by the contractor or the owner of the project. The submission of the design may be a prerequisite for the construction works to be started. Besides, purchase orders for the material and equipment are finalized after design.

R700 – Change in Scope: Although the scope of work in construction projects is defined at the beginning, it may change due to changes in the requests of the owner, extra structures needed to be built like access roads or bridges etc. This results in extra cost and requires extra duration for the completion.

R800 – Change in Design: It is known that as built drawings have lots of differences from the design drawings due to further investigations on site. The problems occurred during the construction can only be realised after the construction starts. They can be solved by changing the initial design which requires extra cost and duration.

R900 – Change in Construction Technique: As the technology is improving day by day, new techniques are introduced in the construction sector. According to the project needs and availability of necessary technology, construction technique is subject to change.

R1000 – Change in Weather Conditions: Depending on the project location, size of the project and project type, change in weather conditions may have a great importance on the duration required by activities. In some projects, severe weather conditions may result in rework which means extra cost.

R1100 – Change in Geological Conditions: Although preliminary investigations are done before the construction starts, unpredicted adverse soil conditions might be faced with. Changes in geological conditions sometimes may prevent the construction works to be continued.

R1200 – Change in Inflation: In today's world, economical conditions may be changed dramatically. Considering the construction projects the duration of which are even more than 5 years, change in inflation may be critical by affecting the cost of the project.

R1300 – Change in Socio-Political Conditions: Responses and reactions of the community, public organizations and governmental organizations to the project is an important issue. The payments or permissions are highly dependent on the socio-political conditions in some projects.

R1400 – Change in Relations between Parties: Construction projects consist of many parties such as owner, contractor, subcontractor, designer, manufacturer etc. A good communication and coordination between these parties is important for the continuation of activities without stoppage.

3.2 Risk Assessment Criteria

Risk assessment in this thesis study can be defined as evaluating probability of occurrences of risks, associating risk to relevant parameters and quantifying the effects of risks on the activities' duration and cost for the determination of risk adjusted durations and costs.

3.2.1 Probability Assessments of Risks

The question; "What is the probability that a risk occurs during the project?" should be answered by a risk manager using the probability ratings given in Table 3.1. Uncertainties exist in the nature of risks. Risk manager rates the probability of risks according to project type, location of the project, duration and size of the project.

Table 3.1 Rating Table for Risk Assessments

Rating Scale	Probability	Impact
1	Very Rare	Very Low
2	Rare	Low
3	Medium	Medium
4	Likely	High
5	Very Likely	Very High

3.2.2 Activity – Parameter Matching

Not all the parameters have to exist in every activity. According to the type of work, the needs of activity and the involvement of subcontractor, related parameters are selected for every activity.

3.2.3 Assessment of Changes in Parameters

As described in section 2.3.3, changes parameters are the key factors that cause changes in activities' durations and costs. Percent changes of parameters are estimated for two cases; pessimistic case and most probable case by the risk manager. Pessimistic case is considered as the condition when all risks occur. Most probable case is considered as the normal condition where expected risks occur. Optimistic case is considered as the condition where no risks occur. Thus, all % change values for optimistic case are set to "0".

The assessment of changes in parameters is a critical issue since it has a direct effect on the risk adjusted duration and cost calculations. A parameter may be affected by one risk factor or more. Furthermore, the effect of a risk on a parameter is not represented by single values of pessimistic and most probable cases. Therefore, the changes in parameters are represented with a normal distribution, which is fit into a triangular shape. Figure 3.1 shows the distribution of changes over the low, medium and high regions for parameters. % Change value for pessimistic case is considered as the highest value, and that for most probable case is considered as the mode which is the most frequent value.

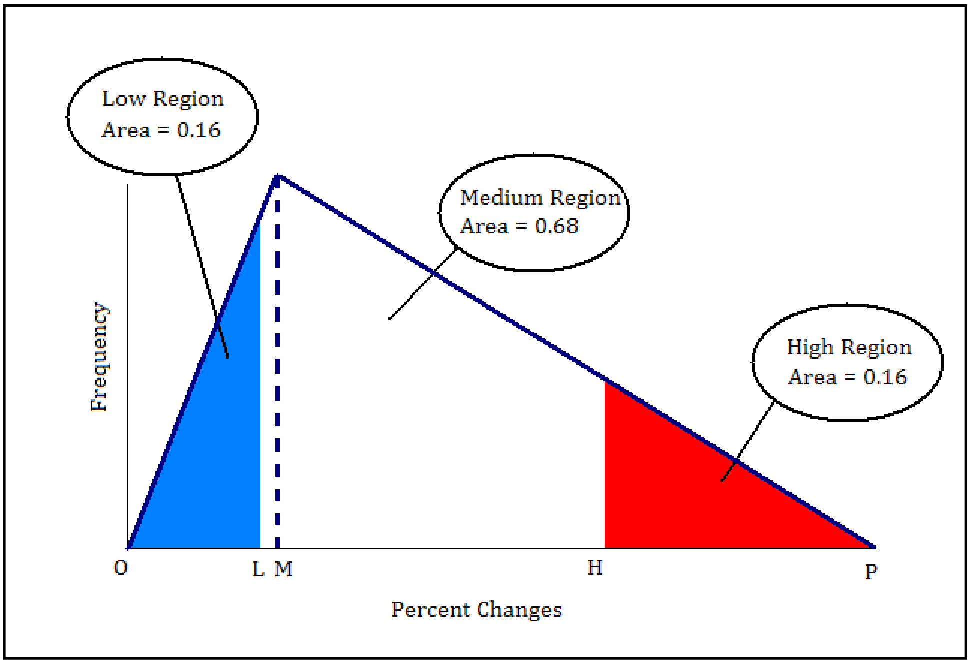

Figure 3.1 Distribution of Regions of Parameter % Changes

O: Optimistic value for the change in the given parameter;

P: Pessimistic value for the change in the given parameter;

M: Most probable value for the change in the given parameter;

L: Upper limit for the low region;

H: Lower limit for the high region.

The total area under the triangle shown in Figure 3.1 is 1. As described in Chapter 2, 68% of the data fall within 1 standard deviation of the mean. This region is assumed to be medium region in the parameter changes distribution. It is also assumed that, if the calculated upper limit for low region is more than the most probable value or the calculated lower limit for high region is less than the most probable value, they are equated with the most probable value. The calculations of the limits for high region and low region, the unionization of the risk effects on parameters and the selection of % changes for parameters will be discussed in section 3.3.2.

3.2.4 Assessment of Risk Impacts

After the selection of risks that are related to the activities, risk impacts are evaluated using risk – parameter pairs. This brings the advantage of evaluating risk impacts in one table for all activities, instead of making a risk impact evaluation for all activities. The impacts of risks are assessed using the rating scale shown on Table 3.1. “NA” is typed for irrelevant risk – parameter pairs to state that the evaluation is “Not Applicable”. Risk – parameter matrix with default NA values is given in Table 3.2. Defaults shown in the table can be changed for each project by RM. Names and definitions of Parameter and Risk ID’s given in the tables are explained in sections 2.3.3 - 3.1 respectively.

What is the impact of a risk factor on the corresponding parameter for the given project?

Table 3.2 Parameter – Risk Impact Matrix with Default Values

Par./ Risk	P100	P200	P300	P400	P500	P600	P700	P800	P900	P1000	P1100	P1200	P1300
R100		NA	NA	NA	NA		NA	NA	NA	NA	NA	NA	NA
R200		NA	NA	NA	NA		NA	NA	NA	NA	NA	NA	NA
R300	NA	NA	NA	NA	NA	NA	NA	NA	NA		NA	NA	NA
R400		NA	NA	NA	NA		NA	NA	NA		NA	NA	NA
R500	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
R600	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	
R700	NA	NA		NA		NA	NA			NA	NA		
R800		NA		NA			NA	NA			NA		NA
R900				NA	NA			NA					NA
R1000		NA	NA	NA			NA	NA	NA		NA	NA	NA
R1100		NA	NA	NA			NA	NA	NA		NA		NA
R1200	NA		NA		NA	NA		NA	NA	NA		NA	NA
R1300		NA	NA	NA	NA		NA	NA	NA	NA	NA	NA	NA
R1400	NA	NA	NA	NA	NA				NA	NA	NA	NA	NA

3.3 Calculations

Completing the assessments of risks, the risk adjusted calculations are done by the developed tool according to the formulas introduced in the following subsections.

3.3.1 Determination of Project Duration and Cost Using PDM

First of all, the risk free calculations are carried out to calculate the project duration and cost under no risk condition. This is accomplished by using precedence diagramming method; forward and backward calculations.

Precedence Diagramming Method (PDM) is used for the determination of critical path(s) and thus duration of a project using the logical relationships between activities. PDM was first introduced Professor John W. Fondahl of Stanford University in 1961. PDM is very useful in computer applications since it has a systematic approach. Figure 3.2 shows a visualization of PDM.

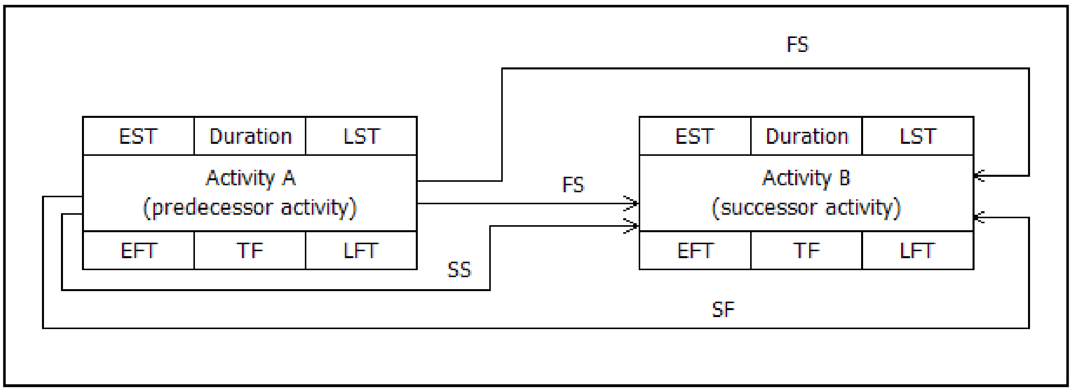

Figure 3.2 Activity and Relationship Representation in PDM

EST – Early Start Time

LST – Late Start Time

EFT – Early Finish Time

LFT – Late Finish Time

EFT of an activity = the previous day of EST of that activity + activity duration

LST of an activity = the next day of LFT of that activity – activity duration

TF of an activity = difference between LFT and LST or EFT and EST of the activity

There are four types of logical relationships; Finish to Start Relationship (FS), Start to Start Relationship (SS), Start to Finish Relationship (SF), and Finish to Finish Relationship (FF). When there is an FS relationship between activities A and B shown in Figure 3.2, activity B may start after activity A is finished. When there is an SS relationship between activities A and B shown in Figure 3.2, activity B may start after activity A is started. When there is an SF relationship between activities A and B shown in Figure 3.2, activity A may start after activity B is finished. When there is an FF relationship between activities A and B shown in Figure 3.2, activity B may finish after activity A is finished.

Lag is the duration by which the start or finish of a succeeding activity is delayed according to the logical relationship type. When lag is negative, it is called lead. Total float is the amount of time that an activity may delay without causing a delay in the project duration. It is used to determine the critical activities and project duration. Critical activity is the activity with zero float. Critical path is the continuous path on which there are only critical activities.

In PDM, forward and backward calculations are carried out to find total floats as described below.

Forward Calculations

Forward calculations start with a start activity EST and EFT of which are 1 and 0 respectively.

- **FS Type of Relationship**

EST of successor activity = the next day of the EFT of predecessor activity + the amount of lag

- **SS Type of Relationship**

EST of successor activity = the day of the EST of predecessor activity + the amount of lag

- **SF Type of Relationship**

EFT of successor activity = the previous day of the EST of predecessor activity + the amount of lag

- **FF Type of Relationship**

EFT of successor activity = the day of the EFT of predecessor activity + the amount of lag

Backward Calculations

Backward calculations start with a finish activity EFT of which is equal to LFT.

- **FS Type of Relationship**

LFT of successor activity = the previous day of the EFT of predecessor activity – the amount of lag

- **SS Type of Relationship**

LST of successor activity = the day of the LST of predecessor activity – the amount of lag

- **SF Type of Relationship**

LST of successor activity = the next day of the LST of predecessor activity – the amount of lag

- **FF Type of Relationship**

LFT of successor activity = the day of the LFT of predecessor activity – the amount of lag

An activity may be a predecessor of another meaning that the start or finish of a successor activity is dependent on the start or finish of a predecessor activity. A logical relationship between two activities shows predecessor – successor relation which is used to in the calculation of the total project duration. To determine the critical path using precedence diagramming method, a start and a finish activity whose durations are set to 0 are assigned to all projects.

According to the logical relationship type between the activities, the developed tool chooses appropriate formula among the formulas given in section 2.3.1 to calculate the Early Start Time (EST), Early Finish Time (EFT), Late Start Time (LST), Late Finish Time (LFT) and Total Float (TF) of the activities. Lag durations are taken into consideration in these calculations. The activities with "0" TF are determined and recorded as critical activities. Once the critical activities are determined, the duration of the project can be calculated using the equations (27) and (28) given below.

Project RF Duration=∑RF Durations of Critical Activities on One Path (27)

Project RF Cost=∑All Activity RF Costs + Indirect Cost x Project RF Duration (28)

RF: Risk Free

When the risk adjusted calculations are finished, the risk adjusted durations and costs of activities are determined. Changing the durations of the activities may change the critical path. Therefore, critical activities are determined at each run and project risk adjusted duration and risk adjusted cost are calculated using the following equations.

Project RA Cost=∑All Activity RA Costs + Indirect Cost x Project RA Duration (29)

Project RA Duration=∑RA Durations of Critical Activities on One Path (30)

RA: Risk Adjusted

3.3.2 Risk Adjusted Calculations

Duration and cost of an activity is determined by the components which are affected by the changes in the parameters. Activity model used as the basis for the duration and cost calculations is shown on Figure 2.2. The duration components are plant (p), labour (l), subcontractor (s) and external factors for duration (e). The cost components are plant (p), labour (l), subcontractor (s) and material (m). The related parameters are illustrated in the figure as well.

Adding the risk factors to the activity model and relating with the parameters, Figure 3.3 can be obtained. Figure 3.3 is created using defaults used by the developed tool. The relation between risks and parameters can be defined and rearranged by a user while using the developed tool.

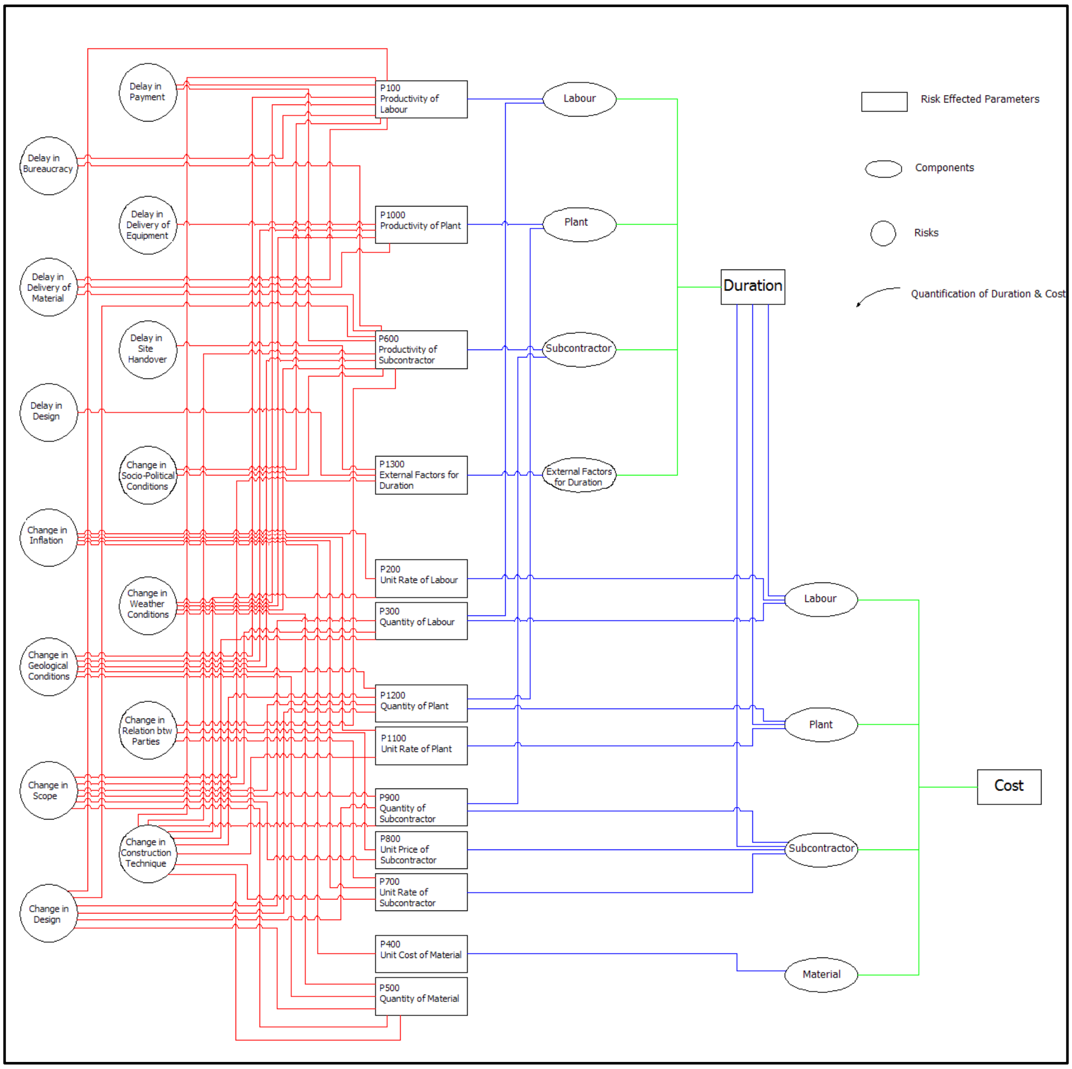

Figure 3.3 Activity Model with Risks

Decision table given in Table 3.3 is defined for the determination of ranges for changes in parameters. The ranges in the table can be modified by the user for each project.

Table 3.3 Decision Table

P/I	1	2	3	4	5
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25

Region Index
Low
Medium
High

P: Probability, I: Impact

The area under the triangle shown in Figure 3.1 is 1. It is divided into three parts as low region, medium region and high region. It is assumed that, if the calculated upper limit for low region is more than the most probable value or the calculated lower limit for high region is less than the most probable value, they are equated with the most probable value. It is known that in normal distribution, 68% of the data fall within 1 standard deviation of the mean. The region having 68% area is assumed to be medium region in the parameter changes distribution. The formulas giving the limits for the regions are as follows:

$$L = \begin{cases} \sqrt{0.16 \times \mathrm{P} \times \mathrm{M}}, & \sqrt{0.16 \times \mathrm{P} \times \mathrm{M}} < M \\ \mathrm{M}, & \sqrt{0.16 \times \mathrm{P} \times \mathrm{M}}, \geq \mathrm{M} \end{cases} \quad (31)$$

$$H = \begin{cases} \mathrm{P} - \sqrt{0.16 \times \mathrm{P} \times (\mathrm{P} - \mathrm{M})}, & \mathrm{P} - \sqrt{0.16 \times \mathrm{P} \times (\mathrm{P} - \mathrm{M})} > M \\ \mathrm{M}, & \mathrm{P} - \sqrt{0.16 \times \mathrm{P} \times (\mathrm{P} - \mathrm{M})} \leq \mathrm{M} \end{cases} \quad (32)$$

Once the region limits for the parameters are determined, a random value is selected from the determined region of the parameter. To determine the region of a parameter, risk scores are calculated first by multiplying "probability" and "impact" values. The risk score is used in the decision table given on Table 3.3. A random value is selected from the corresponding region. The selected value is the % change of the parameter.

For every risk – parameter pair, the products of "probability" and "impact" values which are determined by the user in steps 1 and 4 are found. The corresponding region is selected from the decision table defined by the user and is used in the determination of the changes in parameters shown in Figure 3.1. Selection of the changes in the parameters is done randomly between the limits of the determined region at each run. Using MC simulation for random selection of the changes in parameters within the corresponding region enables the developed tool to create scenarios.

Usually a parameter is affected by more than one risk factor. Unionization of risk effects on a parameter has an effect on the selected change value of a parameter. For such cases where there is more than one risk effecting on a parameter, the risk scores are calculated separately. The first random selection for % change is done according to one of the risks affecting that parameter. The most probable value of a parameter % change is changed to the first selected random value. The random selection is repeated until all risks affecting the parameter are considered. The last selected random value is considered as the change value of the parameter for that activity at that run. The result is sensitive to the order of risks while repeating the random selection. For example, if the selection starts according to risks with the higher risk scores, probably the last selected random value is selected from a low region or vice and versa. Therefore, the order of risks are determined randomly at each run. This will provide to create scenarios which shows both pessimistic and optimistic results.

3.4 Example Calculations

In this section, risk assessment of a project which consists of 3 activities is explained by following the developed risk assessment methodology in order to show the calculation steps clearly. The name of the project is called "Sample Project".

3.4.1 Step 1 – Defining Activities of SP

The project is assumed to have 3 activities. The activity names, durations, costs and predecessors are given in Table 3.4.

Table 3.4 Activities of Sample Project

Activity ID	Activity Name	Duration (days)	Cost ($)	Predecessor
A100	Excavation	18	300.000	-
A200	Concrete Works	64	500.000	A100
A300	Painting	28	200.000	A200

Durations and costs given in Table 3.4 are risk free durations and costs. Using Precedence Diagramming Method, duration of the project can be determined. In this sample application, there is only one path as shown at Figure 3.4.

Duration of a project is the sum of the durations of critical activities in the project. Therefore, total duration of the Sample Project is 110 days. Cost of a project is the sum of the costs of all activities. Therefore, the cost of the Sample Project is 1.000.000 $.

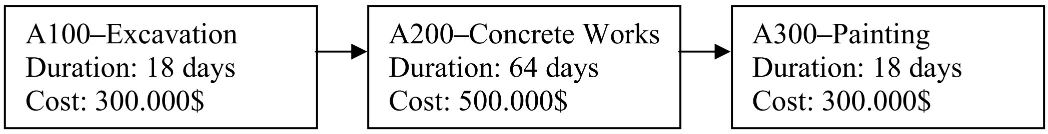

Figure 3.4 Critical Path Diagram of the Sample Project

3.4.2 Step 2 – Probability Assessment of Risks of SP

The risks are pre-defined for the used tool and cannot be changed. Probability assessment varies from one project to another. In this part, risk manager should answer what would be the probability of occurrence of each risk factor for the Sample Project. The probability assessments are filled using 1 – 5 rating scale (5 being most probable) and given onTable 3.5.

3.4.3 Step 3 – Activity – Parameter Matching of SP

For each activity, parameters which determine duration and cost of that activity should be determined by RM. The activity – parameter matrix is a YES/NO matrix. Some of the parameters must be excluded from the calculations of risk adjusted duration and cost for some activities. Excavation and concrete works activities are to be completed by labour, whereas painting activity will be done by a subcontractor. Consecutively, subcontractor parameters are marked as "NO" for excavation and concrete works activities. Similary, labour parameters are marked as "NO" for painting activity. Once the activity – parameter pair is signed as "NO", the parameter is not included in the influence network through which all the calculations are carried out. Table 3.6 shows activity – parameter pairs for the Sample Project.

Table 3.5 Probability of Occurrences of Risks for the Sample Project

Risk ID	Risk	Probability of Risk (1 – 5 Scale)
R100	Delay in Bureaucracy	1
R200	Delay in Payment	5
R300	Delay in Delivery of Equipment	4
R400	Delay in Delivery of Material	2
R500	Delay in Site Handover	3
R600	Delay in Design	1
R700	Change in Scope	1
R800	Change in Design	1
R900	Change in Construction Technique	1
R1000	Change in Weather Conditions	5
R1100	Change in Geological Conditions	4
R1200	Change in Inflation	2
R1300	Change in Socio-Political Conditions	2
R1400	Change in Relations between Parties	3

Table 3.6 Activity – Parameter Matrix for the Sample Project

Activity/ Parameter	P100	P200	P300	P400	P500	P600	P700	P800	P900	P1000	P1100	P1200	P1300
A100	Y	Y	Y	N	N	N	N	N	N	Y	Y	Y	Y
A200	Y	Y	Y	Y	Y	N	N	N	N	Y	Y	Y	Y
A300	N	N	N	Y	Y	Y	Y	N	Y	Y	Y	Y	Y

3.4.4 Step 4 – Changes in Parameters for Sample Project of SP

Parameters are subject to change due to risk factors. In this part, RM estimates % changes of parameters for most probable case and pessimistic case. % changes are "0" in optimistic case by default since when a parameter is affected by none of the risk factors, it does not change. Estimated % changes are given in Table 3.7.

Table 3.7 Parameter – Risk Matrix for Sample Project

Par. ID	Parameter Name	Change for Opt. Case (%)	Change for Most Prob. Case (%)	Change in Pes. Case (%)
P100	Productivity of Labour	0	5	14
P200	Unit Rate of Labour	0	2	7
P300	Quantity of Labour	0	2	4
P400	Unit Cost of Material	0	10	20
P500	Quantity of Material	0	5	9
P600	Productivity of Subcontractor	0	2	5
P700	Unit Rate of Subcontractor	0	3	9
P800	Unit Price of Subcontractor	0	2	4
P900	Quantity of Subcontractor	0	4	8
P1000	Productivity of Plant	0	2	4
P1100	Unit Rate of Plant	0	1	3
P1200	Quantity of Plant	0	6	15
P1300	Ext.Factors for Duration Coef.	0	5	12

3.4.5 Step 5 – Parameter – Risk Impact Matrix of SP

In this part, the evaluation of the risk impacts on the parameters should be made by RM. The evaluation of parameter – risk matrix is filled using 1 – 5 rating scale. "NA" is typed for a parameter – risk pair stating that the evaluation is "Not Applicable" so as not to associate for irrelevant pairs. Impact evaluation is made to quantify how a risk factor affects on the given parameter. Parameter – Risk impact matrix of the Sample Project is given on Table 3.8.

It can be observed from the Table 3.8 that, Unit Rate of Labour (P200) is lowly affected from Change in Construction Technique (R900) and very highly affected from Change in Inflation (R1200) for the Sample Project.

3.4.6 Step 6 – Decision Table of SP

In this part, decision table for risk probability and impact values are defined. The regions defined in the decision table are used to classify the risk ratings for the parameters. The selected change value for a parameter is to be selected according to the corresponding region in the decision table. The default values are used in the calculations for sample project.

Table 3.8 Parameter – Risk Impact Matrix for the Sample Project

Par./ Risk	P100	P200	P300	P400	P500	P600	P700	P800	P900	P1000	P1100	P1200	P1300
R100	2	NA	NA	NA	NA	2	NA	NA	NA	NA	NA	NA	NA
R200	5	NA	NA	NA	NA	5	NA	NA	NA	1	NA	NA	NA
R300	NA	NA	NA	NA	NA	NA	NA	NA	NA	4	NA	NA	NA
R400	3	NA	NA	NA	NA	3	NA	NA	NA	3	NA	NA	4
R500	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	5
R600	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4
R700	NA	NA	3	NA	5	NA	NA	2	4	NA	NA	3	NA
R800	3	NA	3	NA	5	3	NA	NA	3	2	NA	3	NA
R900	3	2	2	NA	NA	3	NA	NA	2	4	3	3	NA
R1000	4	NA	NA	NA	1	4	NA	NA	NA	4	NA	NA	NA
R1100	2	NA	NA	NA	4	2	NA	NA	NA	5	NA	4	NA
R1200	NA	5	NA	5	NA	NA	NA	NA	NA	NA	3	NA	NA
R1300	4	NA	NA	NA	NA	4	NA	NA	NA	NA	NA	NA	NA
R1400	NA	NA	NA	NA	NA	4	NA	4	NA	NA	NA	NA	NA

3.4.7 Sample Calculation for SP

After the completion of the risk assessment evaluation for the project, the calculations are carried out to determine % changes in the parameters. For every parameter in every activity, [probability] x [impact] is calculated first. The result is found in the decision table to determine the % change range for that parameter. Calculations are shown on Table 3.9.

Table 3.9 Calculations for P200

Risk	(P)	(I) on P200	(P) x (I)
R100	1	NA	-
R200	5	NA	-
R300	4	NA	-
R400	2	NA	-
R500	3	NA	-
R600	1	NA	-
R700	1	NA	-
R800	1	NA	-
R900	1	2	2
R1000	5	NA	-
R1100	4	NA	-
R1200	2	5	10
R1300	2	NA	-
R1400	3	NA	-

The change in "Unit Rate of Labour" parameter for pessimistic and most probable cases can be found in Table 3.7 as 2% and 7% respectively. Using the equations (27) and (28) will give the L as 1.50% and H as 4.63%. One of the [P] x [I] values from Table 3.5 is 10. The region of P200 for R1200 is selected from the decision table; Table 3.3 as "Medium". A random value in the "Medium" region (between 1.50% and 4.63%) is selected. The selected value for this run is 2.06%. The value of M (Most Probable Case) is changed from 2% to 2.06%. Using the equations (27) and (28) will give the new L as 1.52% and H as 4.65%. Another [P] x [I] value in Table 3.5 is 2. The region of P200 for R900 is selected from the decision table; Table 3.3 as "Low". A random value in the "Low" region (between 0% and 1.52%) is selected. The selected value for this run is 1.05%. Therefore, the selected change value for P200 in A100 at this run is 1.05%. Similar calculations are done for the other parameters and activities. Note that, since A300 is not associated with P200, the change of P200 for A300 is 0%. Determining the %changes for the other parameters and making the risk adjusted calculations will give the results given in Table 2.10. Increasing the "run" value will give graphical results from which a risk manager can interpret the boundaries. User interface screenshots and all the selected change values for the Sample Project at this run are given in Appendix A.

Table 3.10 Results of Sample Project

Act. ID	Activity Name	Duration (days)	Cost ($)	Risk Adjusted Duration (days)	Risk Adjusted Cost ($)
A100	Excavation	18	300.000	19	318.826
A200	Concrete Works	64	500.000	69	548.226
A300	Painting	28	200.000	30	231.277

CHAPTER 4

THE DEVELOPED RISK ASSESSMENT TOOL

The developed risk assessment tool is used to store project information, activity information and risk assessment evaluations to calculate risk adjusted durations and cost. The developed tool is composed of a database, a web container and an application which are introduced in this chapter with the used technologies to develop the risk assessment tool.

4.1 Database Model

Database is a set of information formed in an organized and structured way to achieve easy data store, access and manipulation. Each data entity in a database is kept in a table, which is a two-dimensional array of rows and columns. Rows in a table represent a data set whereas columns represent attributes of data. Several models have been proposed to keep data. Most commonly used database models are "Hierarchical Model", "Network Model" and "Relational Model".

Hierarchical Model uses a tree like structure to group data using parent – child relationship in which a parent entity may be related to many child entities whereas a child entity can have only one parent entity relation. Network model extended this structure by supporting multiple parents for a child entity. However, both of these models require the data to be predefined with its relations which makes the database specific for used application. The internal structure of the database needed to be known in order to retrieve, update, insert and delete records from the database.

This limitation has been overcome by Relational Model, in which the data can be accessed in a uniform way without knowing the database structure. With the growth of relational model came the development of SQL (Structured Query Language) which standardized database access. In addition to being relatively easy to access, relational database model made it possible to extend the database. New data groups can be added and even related to an existing relational database without any effect on applications using the database.

4.2 Preferred Technologies

Over the recent years, web-based applications have emerged as the most preferred software application development platform. Some of the advantages of web based applications over traditional software are high availability, ease of access, high reliability and centralized configuration. The need to install, update and configure software on each client has been removed in this platform.

These advantages and increasing features of modern web browsers made web based applications the most preferred development platform for new applications. It is a well known term; "LAMP" in Information Technology referring to applications using Linux operating system, Apache web server, MySQL database and Perl/PHP programming language. The developed risk assessment tool is created by using three of these technologies which are MySQL, PHP and Apache.

4.2.1 MySQL Database

MySQL is one of the most widely used relational database management system. Being an open-source alternative to major database management systems and performing well on both small and large scale applications, MySQL has emerged to be the world's most popular database software. In addition to vital features of a MySQL database management system such as reliability, scalability and performance, easy integration of MySQL with PHP made it preferable especially for web applications.

4.2.2 PHP Programming Language

PHP is a scripting language especially used for web development. Although it was first created as a basic language for simple rapid web application development purposes, its capability has extended to support modern programming language features like object-orientation. Having PHP code interpreted on the fly by the web server -without the need to compile and deploy the application on each update- makes development very rapid.

4.2.3 Apache Web Server

The performance of a web based application is primarily determined by the performance of the web container. Thus, it is crucial to choose a suitable web server that meets the requirements of the application.

Apache is the most widely used web server used since 1996 with almost %46 of market share measured in the last year. It is also the best choice to be used with PHP programming language and MySQL database.

4.3 Structure of the Developed Tool

The developed tool is implemented in PHP programming language running on an Apache Web Server on a Linux Operating System. The application is connected to a MySQL database which is also located on the same Linux Server.

4.3.1 Database Model of the Developed Tool

The database of the developed tool is designed to allow multiple projects to be managed at the same time. Each project is stored with a unique identifier which is used to relate all project specific data to the project. Project specific data include activities, activity relations and risk values entered for the calculations. There are some tables storing project independent information like the list of risks, parameters and project components, which are stored without project reference to be used with all projects. The tables used in the developed tool are described below. Database schema is shown in Figure 4.1.

"projects" table: The developed tool is designed to support multiple projects. Each project defined must be saved into this table with its name, definition and indirect cost. Also each project is given an identifier stored as *id* field in this table which is used by all project specific data stored in other tables. The id field is preferred to be a string rather than integer to allow users to give logical short names to define projects.

"activities" table: This table stores all activities with their relation to the projects. Each activity defined is given an identifier entered by the user similar to the projects. Also activity duration and costs are stored here. The duration of an activity is stored as integer to represent number of days, while the cost values for labor, material, plant and subcontractor (for both duration based and work based) are stored as floating point numbers with 2 digits of precision.

"activity_relations" table: Predecessor and successor relations between project activities are stored in this table with lag time for the relations and relationship types. Lag time is stored as integer to represent number of days.

"decision_tables" table: Project based probability – impact values are stored in this table. A range value is to be set for each value as low, medium or high. This table is populated for each new project when the project is created with pre-defined range values for each probability – impact value.

"parameter_changes" table: Changes in the parameters due to risk factors are used in the risk adjusted calculations. Project specific most probable and pessimistic case values for each parameter is stored in this table.

"risk_parameter" table: The impact values for each risk parameter pair are stored in this table. Either ratings from 1 to 5 or NA can be entered to this table.

"project_stat" table: Calculations performed during the output of the developed tool is stored here. Duration and cost values for each activity in a project calculated at each iteration are saved as a new record. The statistics for the project are overwritten at each run of the tool to prevent being affected from the values from previous runs during calculations.

In addition to the tables described above, there are a few small tables to keep additional data. ***"activity_parameter"*** table keeps track of which activity is affected from which parameter. ***"components"*** table keeps the five components of a project: labor, material, subcontractor, plant and external factors for duration. ***"parameters"*** table keeps the list of parameters. ***"risks"*** table keeps the list of risks in two groups: change risks and delay risks. Parameters and risk definitions is same across all defined projects. For each project, the probability of each risk is stored in ***"risk_probabilities"*** table.

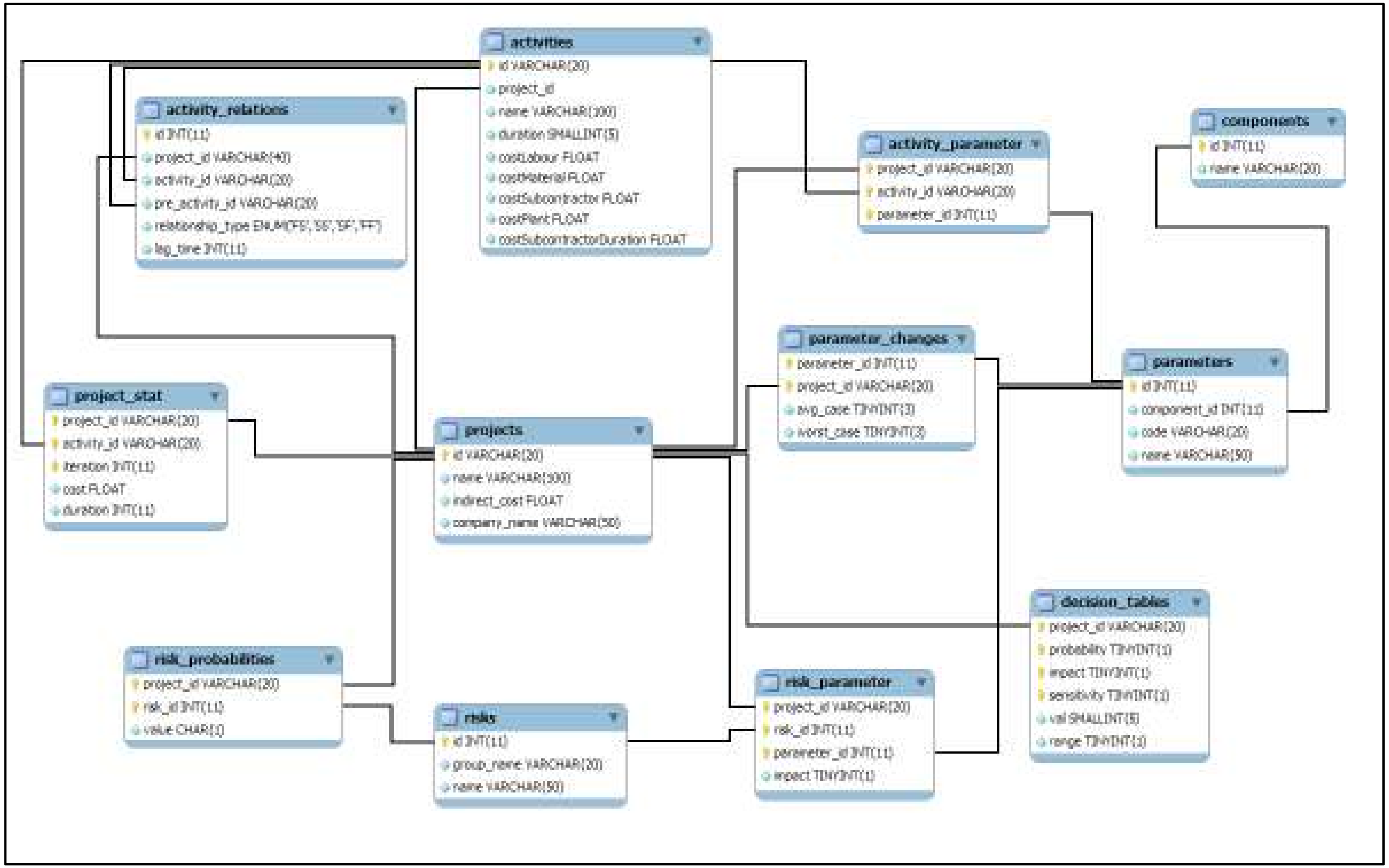

Figure 4.1 Database Schema

4.3.2 Process Model

Risk assessment process has subsequent functions which should be followed in a systematic manner in order to make a proper risk analysis. Integration Definition Function Modelling (IDEF0) is used to illustrate functions and its input, output, control and mechanism.

It can be observed from the Figure 4.2 that the input of the first function is risk free durations and costs of the activities. The output of the last function is the risk adjusted durations and costs of the activities. The process followed by the developed risk assessment tool to calculate risk adjusted calculations is summarized with the function boxes. The first function is to define project. Project ID, name of the project and the company, indirect cost of the project, activities with their durations, costs and relations are defined. Project management department, planning engineers and project manager takes place in creating work breakdown structure. The output of the first function is "activities" which is the input of the second box. Activity durations and costs are determined by the parameters of labour, plant, subcontractor, material and external factors for duration components. The parameters related to the activities are selected which is represented by the second function. Risk management team chooses the relevant parameters in coordination with the site engineer who knows the activity needs. The third function represented with a box numbered as "3" is assessing parameters. It is vitally important to define realistic values for the changes in parameters. Those in pessimistic and most probable cases are estimated by risk management team using previous knowledge and quality of work done by that company. The forth function is to select the appropriate risks for the corresponding parameters. The output is risk resources which is the input of the fifth function; "assess risks". The operation of this function includes assessing probabilities of occurrences, impacts and sensitivities of the risks. Using the decision tables which can be modified by the risk manager, the output "probability x impact" is used to determine % changes in parameters which is used in the risk adjusted calculations. This is the last function and the output is risk adjusted durations and costs.

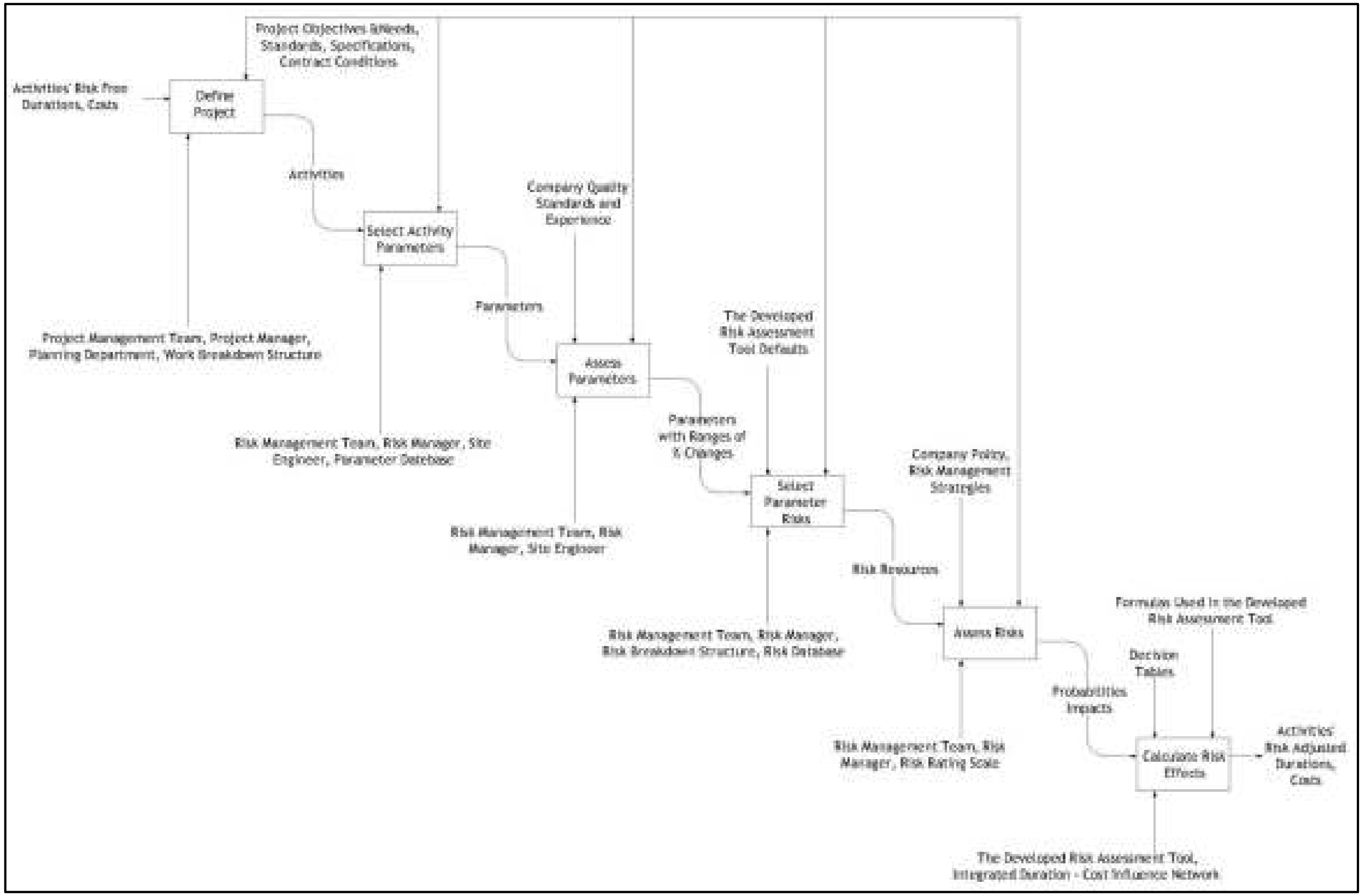

Figure 4.2 Process Model

4.3.3 UML

UML is a collection of methods to visualize and document software-intensive systems. UML combines the best practices from previous data modeling concepts, thus aiming to be the standard modeling language. It has evolved to keep up with the changes in software development since 1996 when UML was first proposed as a modeling specification. Currently UML 2.0 has 13 different types of diagrams for different needs.

Use case diagram is one of the diagrams in UML, which is used to describe the functionality in a system using the actors, their goals (use cases) and the interaction between them. Instead of showing the details of individual features, use case diagrams show all available functionality with all possible interaction. It can be considered as a summary of scenarios for a single task. The following components are displayed in use case diagrams.

Actors are the users of the system which interact with system components. They are represented by stick figures in use case diagrams.

Use cases can be described as discrete units of interaction between the user and the system. They are represented by ovals in use case diagrams.

Interactions in a use case diagram are connections between actors and use cases and dependencies between use cases themselves. Thus interactions between actors are not displayed in use case diagrams. There is only one type of connection between actors and use cases which represent the action to perform the use case. On the other hand, the connections between use cases may show extension, generalization and inclusion. Dashed arrows with labels <<include>> and <<extend>> are used to represent inclusion and extension relationship whereas the notation for generalization relationship is represented by a solid line ending in a triangle at the more general use case.

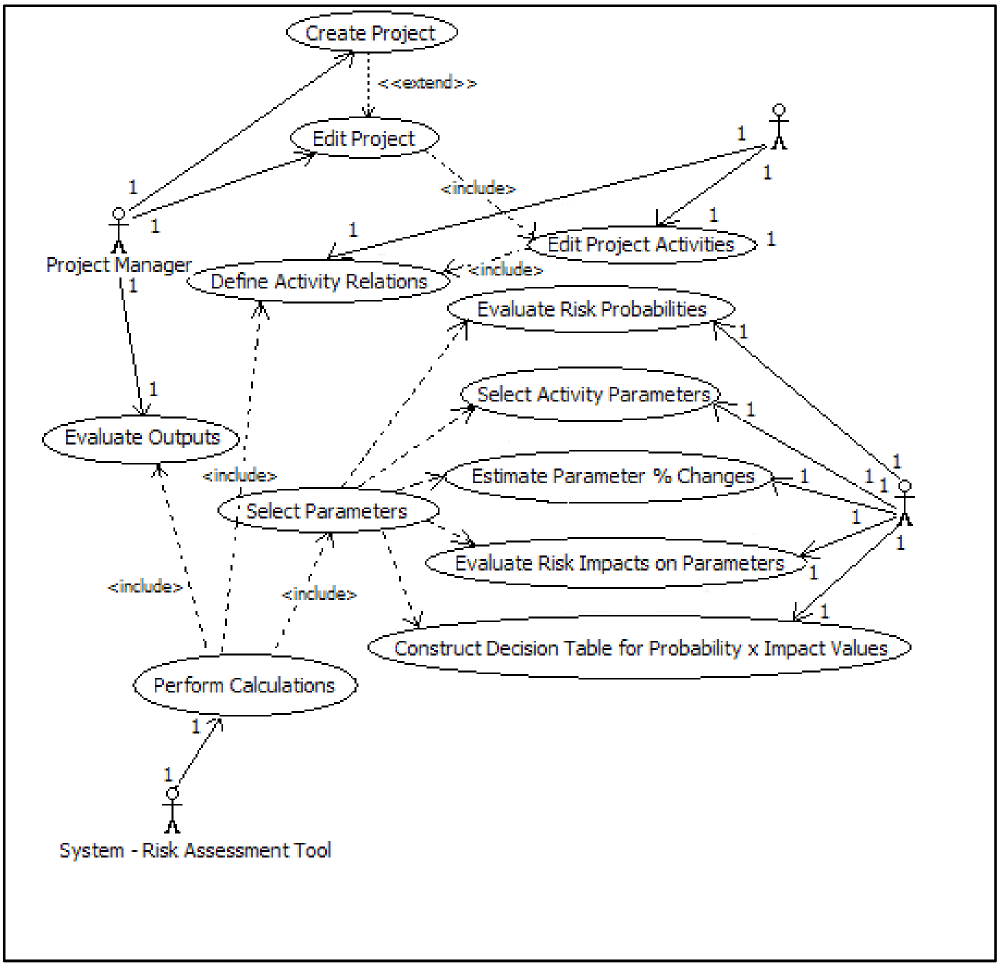

Figure 4.3 Use Case Diagram of the Developed Tool

Use Case Diagram for the Developed Tool: To describe the functionality of the developed tool in a use case diagram, four actors are identified. The first actor is the Project Manager who is responsible for defining projects and who is going to evaluate the output of the tool. The second actor is Planning Engineer who is responsible for identifying the activities and the relations between them in a given project. All the risks and risk related definitions are managed by the Risk Manager actor. Finally, the internal calculation module of the developed tool is considered as an actor to perform calculations and prepare the output. According to these actors and roles, use case diagram of the developed tool is shown in Figure 4.3.

4.3.4 User Interface

A web-based application is preferred because of its high availability. The user interface is composed of project definition page, six steps of input pages and the output page.

Project Definition Page: After selecting an existing project or creating a new one from the main page, user is edirected to this page. Project name, definition and indirect cost values are entered in this page along with activity definitions belonging to the project. Project ID is not permitted to be updated since it is used in relations in the database to reference the project from other tables. Project Definition Page can be observed form the Figure 4.4.

Activity Definition Page: The activities of the project are managed in this page which is accessed via "edit activity" links at project definition page. In addition to activity duration and cost, the predecessor – successor relations are also defined here. Although only the predecessor relations are kept in the database for an activity, successor activity entry is also allowed here to give more freedom to the user. Activity Definition Page can be observed form the Figure 4.5.

Step 1: Risk Assessment – Probability: The probability assessments of the risks for the project is made using 1 – 5 rating scale. The user marks the values of probability of occurrences before clicking "Save & Next" button. Risk Assessment – Probability page is shown on Figure 4.6.

Step 2: Activity Parameter Matching: Next step is to select the parameters for the activities defined for the project. Parameters which are irrelevant to the corresponding activities should be marked as "NO". User can change the activity – parameter situation by clicking on the cells. Activity Parameter Matching page is shown on Figure 4.7.

Step 3: Estimate % Changes for Parameters: It is critical to determine the % changes of parameters for pessimistic and most probable cases since these values have great effect on the risk adjusted duration and cost results. RM should estimate the changes of the parameters due to the risk factors. The page of this step is given on Figure 4.8.

Step 4: Parameter Risk Matrix – Impact Evaluation: The next step is the assessment of impacts on the parameters for the project. RM should type "NA" for the irrelevant risk – parameter pairs. 1 – 5 rating scale given on the page is used for the evaluation of the impacts. This page is shown on Figure 4.9.

Step 5: Decision Tables: Decision tables are used to determine the ranges of the % changes in the parameters. The user is free to change the default decision tables by selecting the ranges and clicking on the values in the tables. Decision tables page is shown in Figure 4.10.

Output Page: The output page shows the results of calculations both in tabular format and in graphs. When the output page is first entered, the results from the last run is displayed. The calculations can be re-run here by entering required number of iterations. Figure 4.11 shows the output page.

The table in the output page summarizes the results for the project and activities. The risk free duration and cost of the project is displayed for comparison with the risk adjusted ones. The pessimistic result considering the duration case corresponds to the maximum duration calculated at the runs whereas the optimistic one corresponds to the minimum one. Similarly, the pessimistic result considering the cost case corresponds to the maximum cost calculated at the runs whereas the optimistic one corresponds to the minimum one. The average case gives the average of the calculated durations and cost at the runs. The risk adjusted durations and costs given for the activities are the average ones.

Results are also displayed in graphical form in order for the user to see the results of the scenarios, the distribution of the results. The axes of the duration graph are y: frequency and x: duration. The axes of the cost graph are y: frequency and x: cost. These graphs are useful to see where the results are centered.

The tabs available at the top of the output page is used to see the useful project information like, project information, risks and their probabilities, parameters with % change limits.

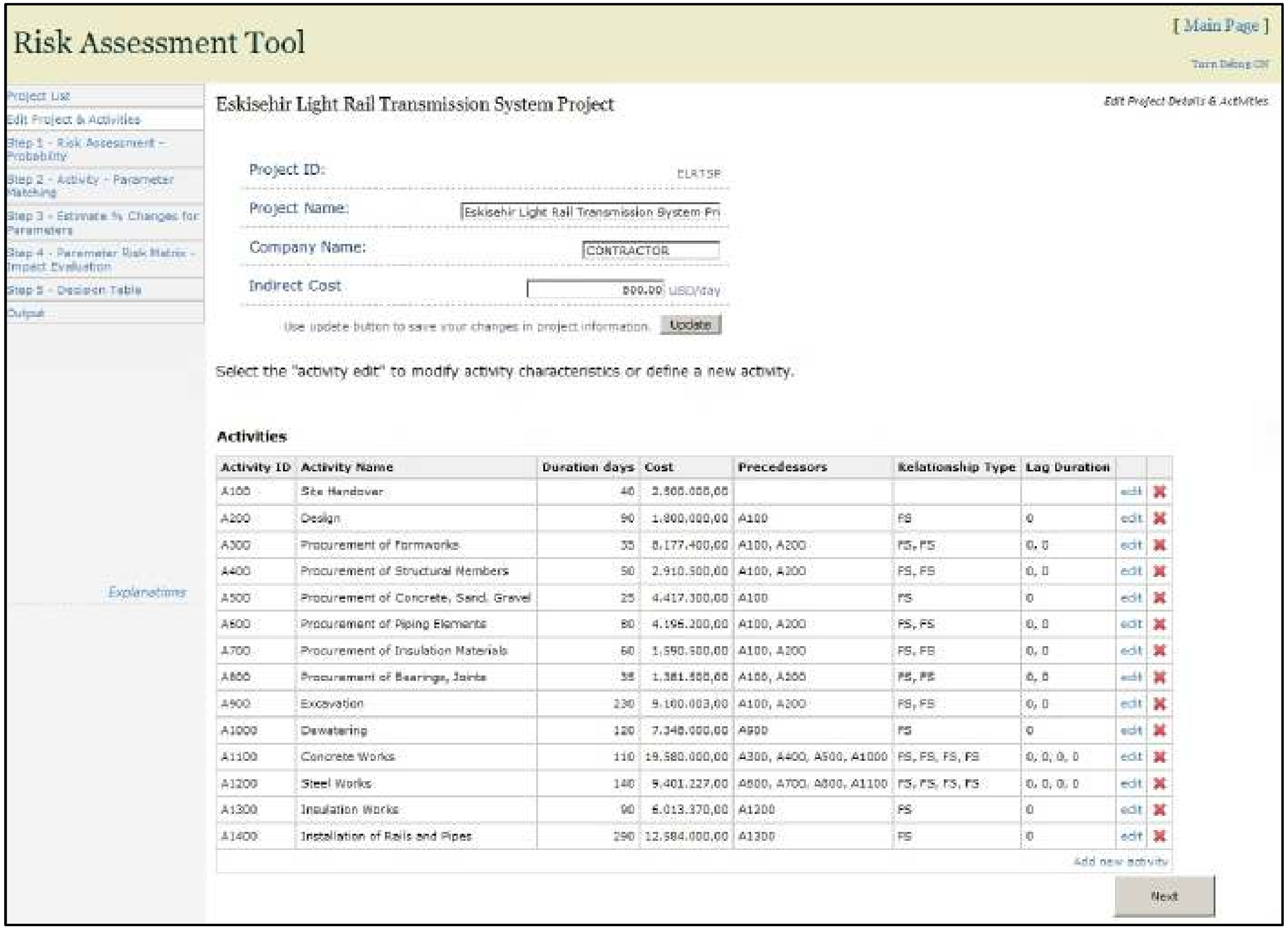

Figure 4.4 Project Definition Page

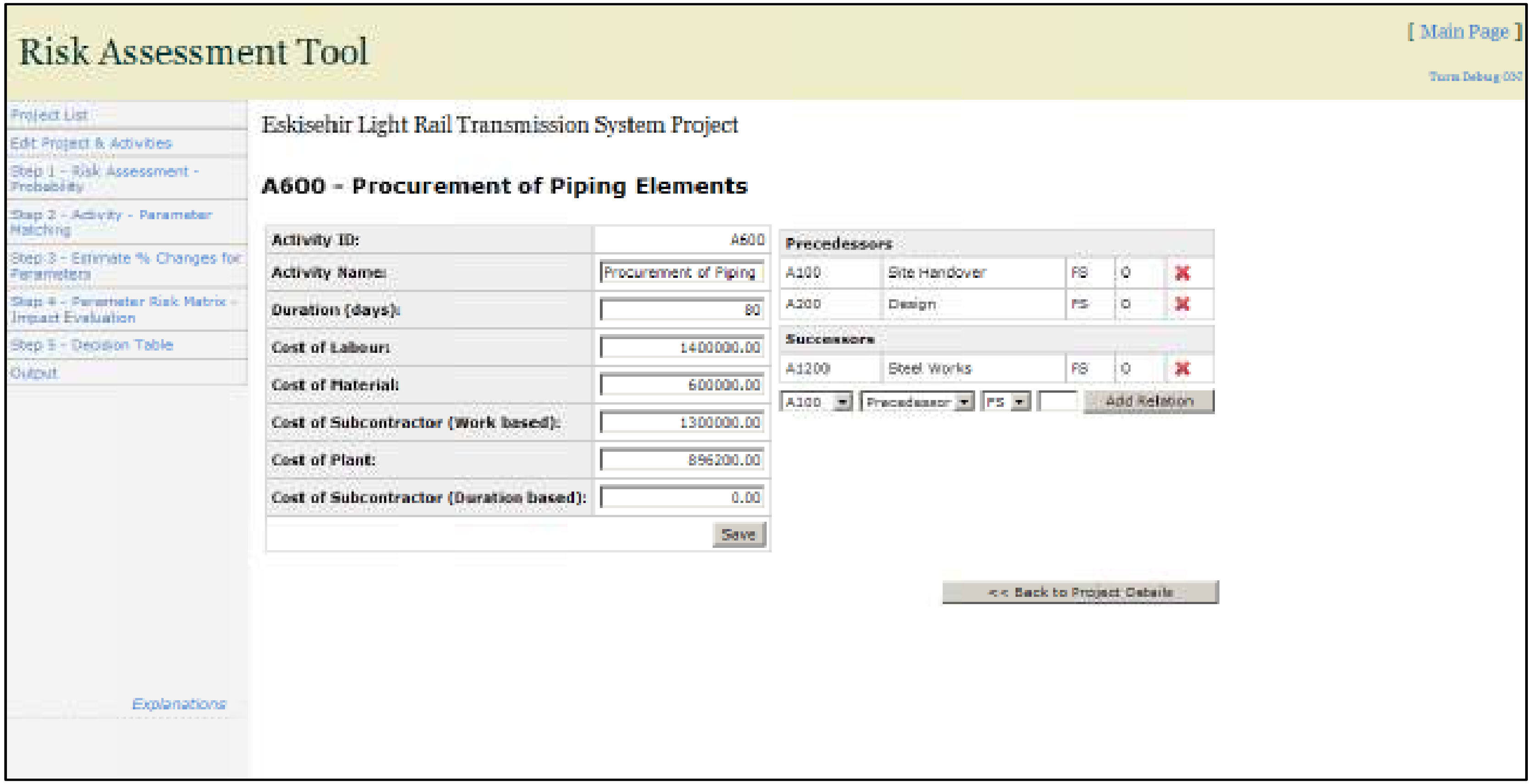

Figure 4.5 Activity Definition Page

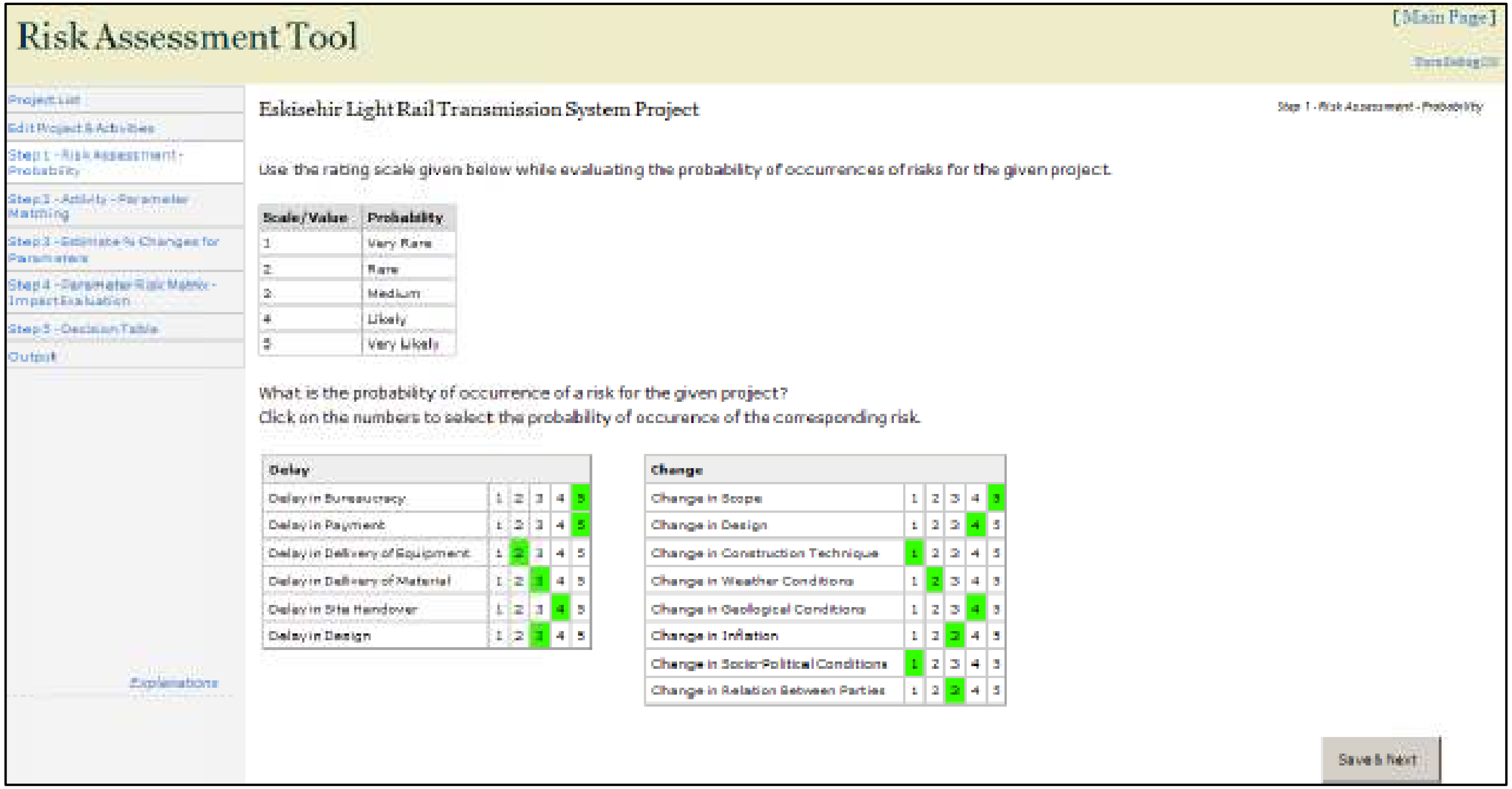

Figure 4.6 Risk Assessment – Probability Page

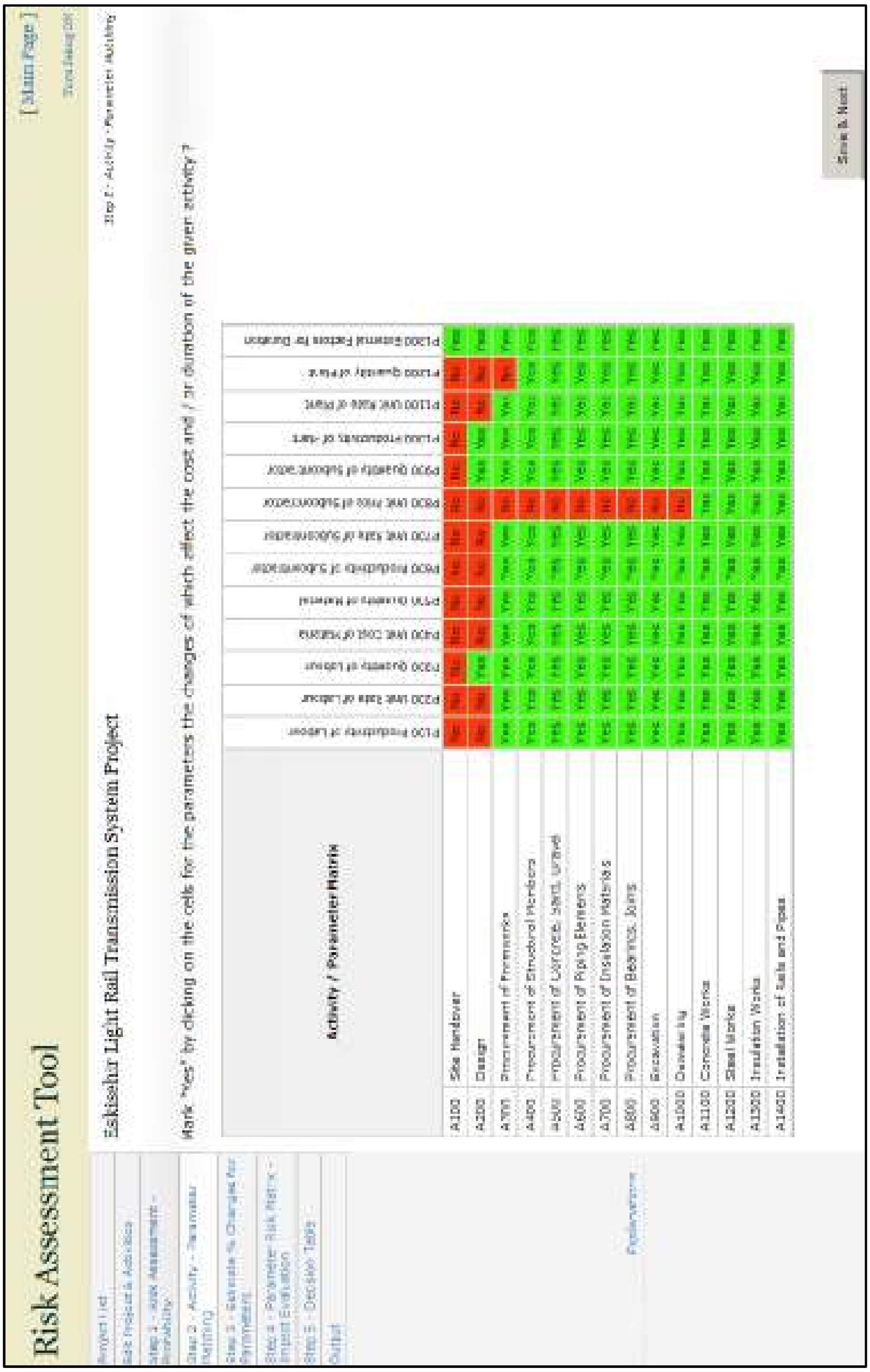

Figure 4.7 Risk Activity Parameter Matching Page

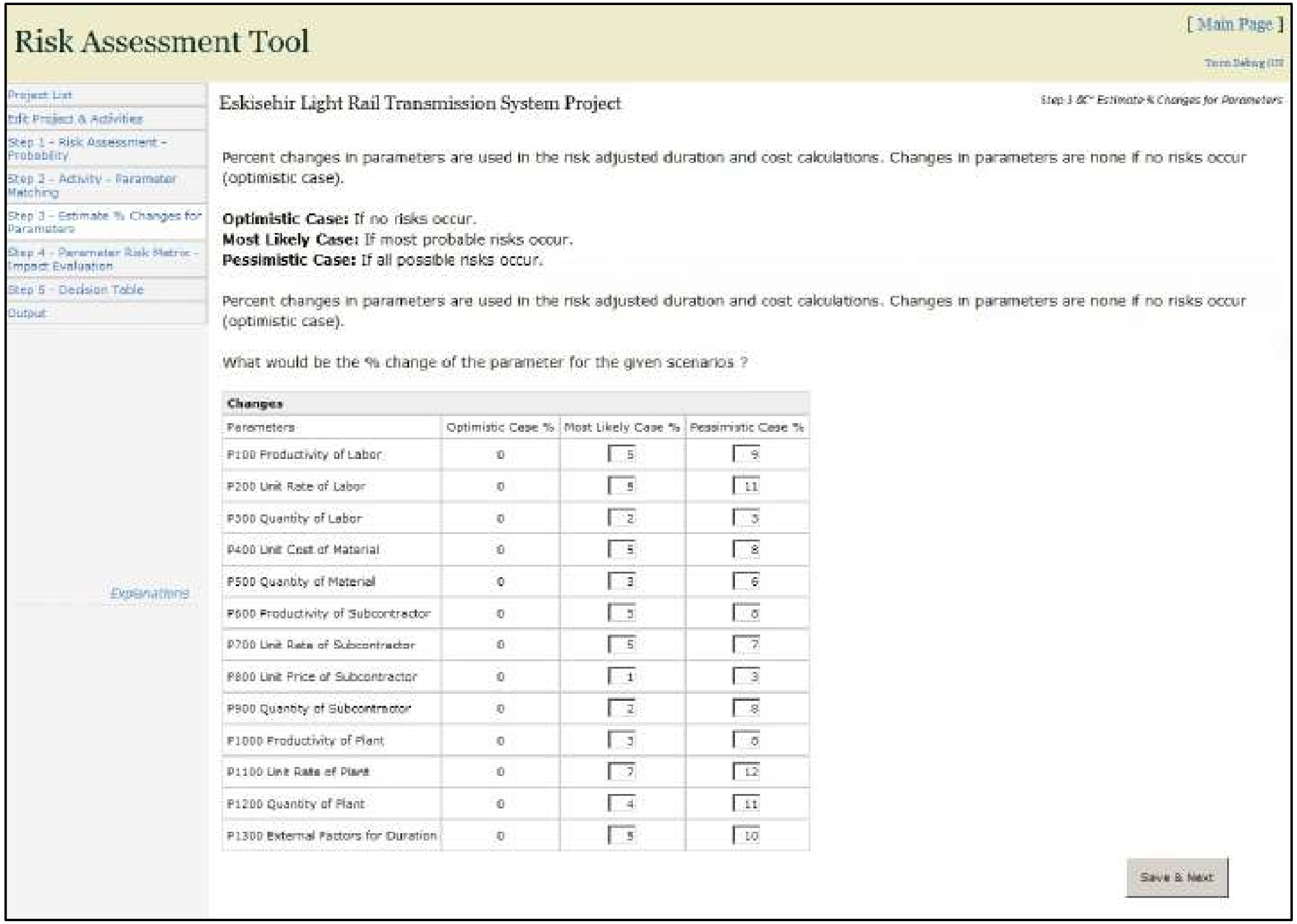

Figure 4.8 % Changes for Parameters Page

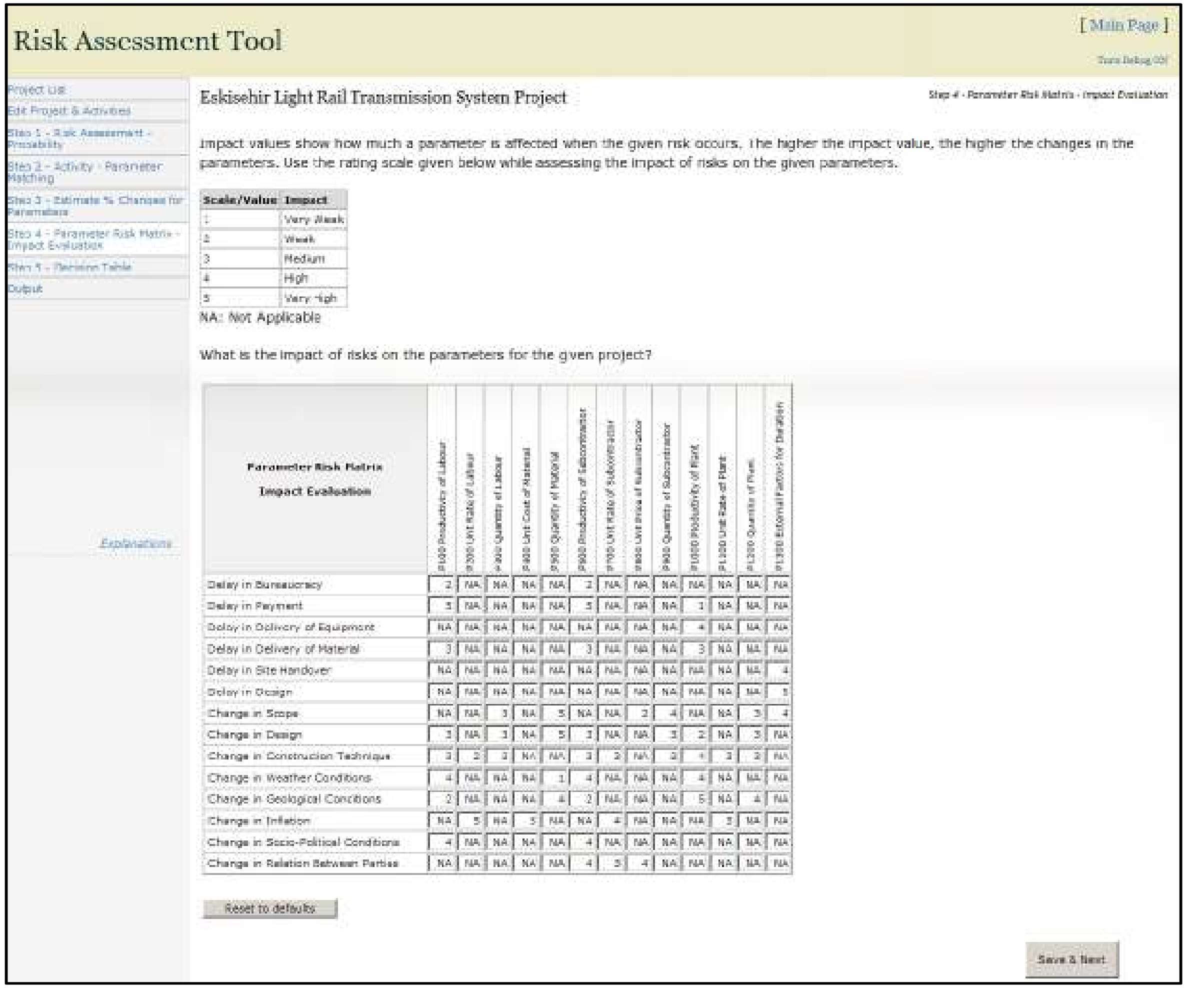

Figure 4.9 Parameter – Risk Impact Evaluation Page

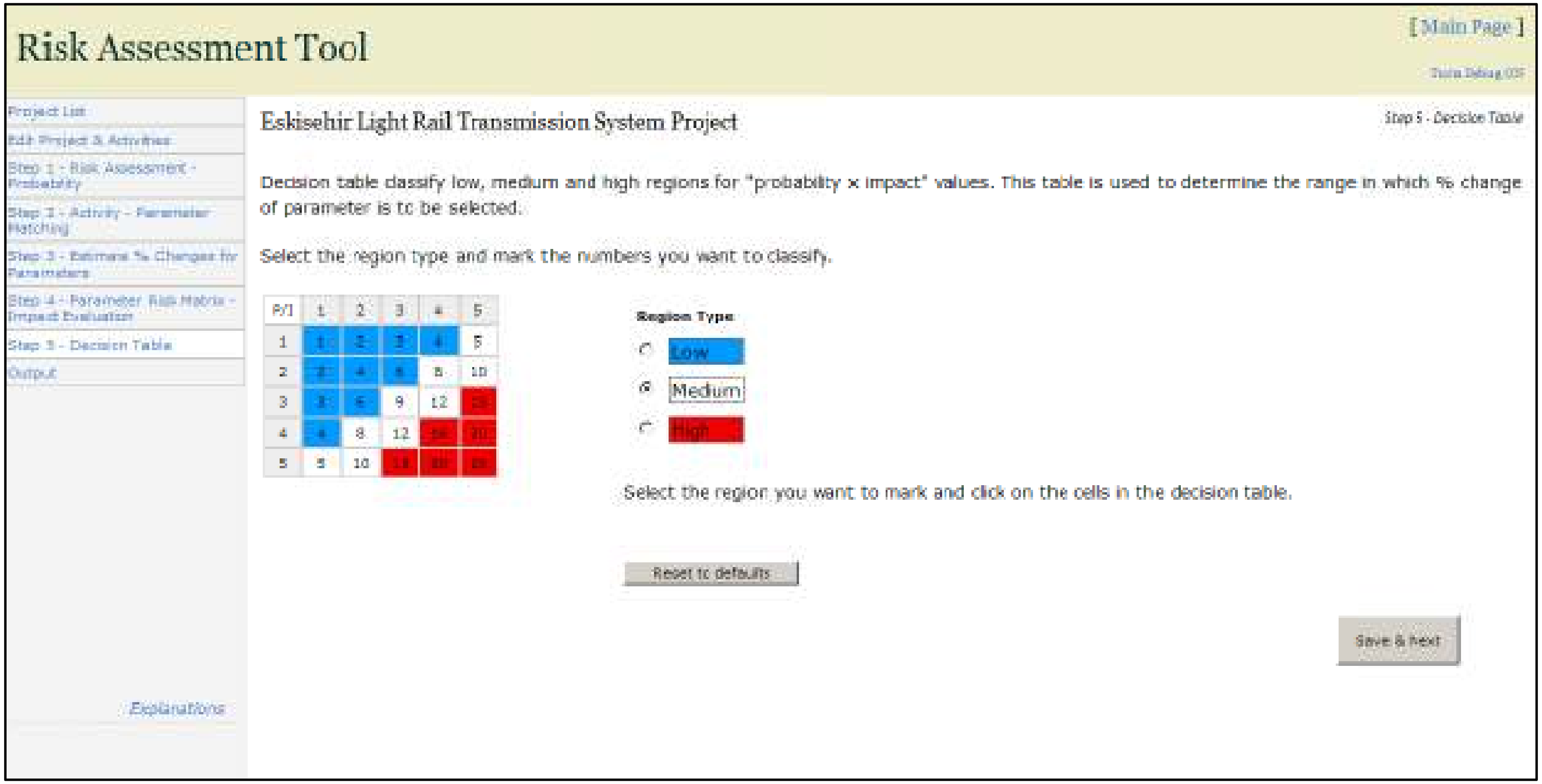

Figure 4.10 Decision Tables Page

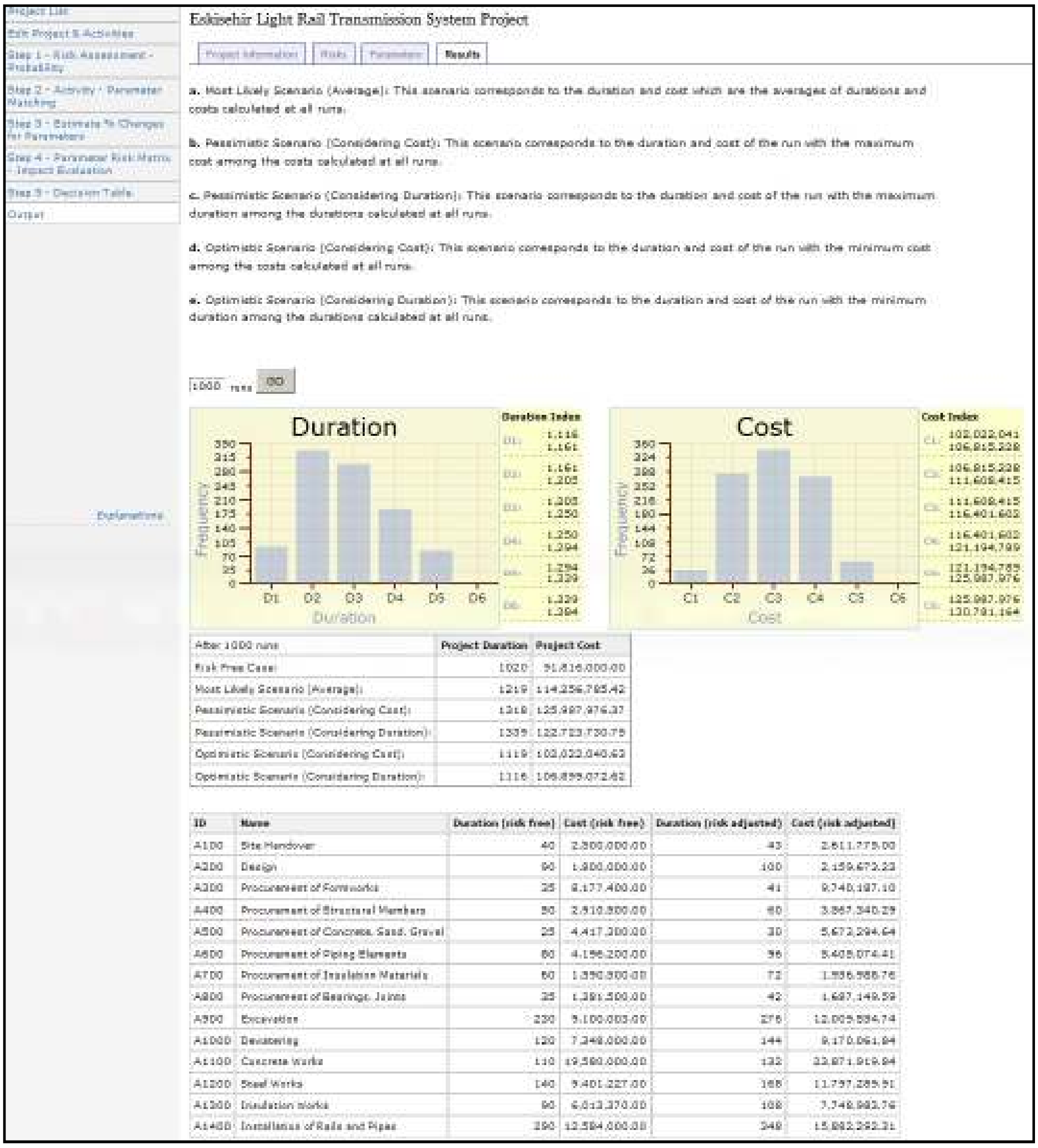

Figure 4.11 Output Page

CHAPTER 5

VALIDATION OF THE DEVELOPED TOOL

The developed risk assessment tool is used to estimate cost overrun and duration extension due to risk factors in construction projects. A proper validation test is performed to check if the developed tool meets the requirements and needs. Moreover the developed software is tested if it is functional and easy to use.

5.1 Validation Test

The validation of the developed software tool is accomplished by applying Charrette Test Method. The Charrette Test Method is a comparative method used to measure the effectiveness of a tool. The term "effectiveness" refers to the changes in speed and quality of processes (Clayton, Kunz and Fischer, 1998).

Performing the Charrette Test Method provides to check the developed tool against an existing technique. The effectiveness of the developed tool can be measured against a traditional technique by observing the statistics such as the time spent and the accuracy of the results.

The developed software is used to make a risk assessment of a construction project in order to estimate risk adjusted duration and cost. Before making risk adjusted calculations, the software finds out the risk free duration and cost of a project using CPM logic. The traditional method used as an alternative way for the determination of risk free duration and cost of a project is to use MS Project tool.

The used risk assessment methodology in the tool is as follows. The risk manager is asked to enter probability of occurrences and impacts of risks. (Probability) x (Impact) values are calculated for every risk – parameter pair. The risk rating calculated for each pair is used in the decision table to determine the level of risk effect. Once the level is determined as High, Medium or Low, corresponding change value for a parameter is selected randomly. The random selection enables the tool to create scenarios. The changes in the durations and costs due to the changes in the parameters such as productivity of labour, unit cost of material etc. are calculated in an integrated manner using mathematical formulations. The graphical results are displayed with which the most likely, pessimistic and optimistic results are given.

The traditional method used as an alternative way for risk assessment is "Risk Rating Method". It is one of the most widely used methods to estimate the cost overrun and duration extension in construction projects. In this method, first RM rates probability of occurrences and impacts of risks. Total "Probability x Impact" value is used to determine the level of risk effect for the project as High, Medium or Low. The increases in the duration and cost are estimated by the risk manager according to the concluded risk level. This method can be applied on activities to make an activity based risk assessment. The integration of duration and cost in this risk assessment technique can be achieved by integrating the risk adjusted results. The total indirect cost is calculated using the risk adjusted duration. The new indirect cost is added to risk adjusted costs of the activities to find total risk adjusted cost of the project.

To perform the Charrette Test on the developed software, a hypothetical project is defined with activities, durations and costs. The details of the hypothetical project are given in section 5.2. The probability and the impacts of risks are given. Civil Engineers performed a risk assessment using traditional techniques first. The calculated duration, cost, risk adjusted duration, risk adjusted cost and the time spent for the risk assessment of the project using traditional techniques are recorded. The users then asked to use the developed software to make risk assessment of the hypothetical project. The questionnaire given in Table 5.1 is used for the validation testing of the tool.

The Charrette Test is applied to 3 Civil Engineers first. A revision is done on the tool according to the evaluations, recommendations and comments of the 3 engineers. Then the revised version is also tested by another 3 Civil Engineers.

A software tool must have a good documentation which presents the calculation methodology. This will give high level of confidence to the user which provides to have more realistic inputs. A software tool should also have satisfactory instructions which guide the users to follow the steps. The developed tool is to be checked if the documentation and instructions are well defined. This will show the functionality and traceability of the tool. To measure the functionality and traceability of the developed tool, Evaluation Form given in Table 5.2 is created. The recommendations from the users are taken into consideration and necessary modifications have been done.

The forms filled by the users are given in the Appendix – B. The results are discussed in section 5.3.

Table 5.1 Charrette Test Form

Step – 1: Use traditional methods described above for the calculation of project duration and cost, activities' risk adjusted durations and costs.	
What is the risk free cost and risk free duration calculated using the traditional method?	RF Cost: RF Duration:
What is the risk adjusted cost and risk adjusted duration using the traditional method?	RA Cost: RA Duration:
How much time did you spend for the calculation of project duration and cost, activities' risk adjusted durations and costs?	…… minutes
Step – 2: Use the developed tool for the calculation of project duration and cost, activities' risk adjusted durations and costs.	
What is the risk free cost and risk free duration calculated using the traditional method?	RF Cost: RF Duration:
What is the risk adjusted cost and risk adjusted duration using the traditional method?	RA Cost: RA Duration:
How much time did you spend for the calculation of project duration and cost, activities' risk adjusted durations and costs?	…… minutes
Which method gives more reliable results?	

Table 5.2 Evaluation Form

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The instructions were helpful.					
Mathematical Calculations were clearly defined.					
I did not face with any difficulties while using the software?					
The software is easy to use.					
Recommendations and Comments:					

5.2 Implementation of the Hypothetical Project

There are 3 types of blocks named as A, B, C which only differs in the number of floors. Block A has 3, Block B has 4 and Block C has 9 floors. The project consists of 5 blocks; 2 Blocks of type A, 2 Blocks of type B and 1 Block of type C. The project is assumed to be implemented in Turkey. The indirect cost of the project is 300 $/day.

Each floor will be poured in 2 sections each of for which a tunnel formwork will be used in the construction. There are 2 cranes and 2 tunnel formwork available. A crane will cover 2 blocks maximum. Movement of a crane from will last for 2 days with a cost of 2000$. For foundation works crane is not needed. After foundation works, 3 days will be waited for curing. Crane – 1 will be used in the construction of Blocks A1, B1 and B2. It will be moved when the construction of Block A1 and B1 is finished. Crane – 2 will be used in the construction of Blocks A2 and C1. Excavation works are given to a subcontractor with a unit price contract. The activities, resources, durations are given in Table 5.3.

Using the hypothetical project information given, activities of the hypothetical project are defined with the activity codes. The logical relations are defined between activities. The costs of the activities are decomposed into subcontractor cost, material cost, plant cost and labour cost components. All activities of the project are given in Appendix – C with their codes, logical relations, costs and durations.

The users are asked to use the traditional techniques described in section 5.1 and the developed tool to determine risk free cost and duration, risk adjusted cost and duration of the project. Risk adjusted calculations should be activity based, and the risk effects on duration and cost should be integrated in both techniques used so as to have a good comparison.

Table 5.3 Activities of the Hypothetical Project

No	Description (activity/resource)	Duration (days)	Quantity	Unit Price
1	Excavation	2	980 m^3	1 $/m^3
2	Lean concrete	1	2.2 m^3	64 $/m^3
3	Foundation	4		
	Formwork	....	125 m^2	11 $/m^3
	Rebar	....	2 tons	630 $/m^3
	Concrete	....	150 m^3	77 $/m^3
4	Backfill	5	300 m^3	1 $/m^3
5	X Floor X Section Tunnel	1		
	Concrete	....	95 m^3	77 $/m^3
	Rebar	....	5 tons	630 $/ton
	Wire Mesh	....	3.5 tons	800 $/ton
6	Movement of Crane	2	1 ea	2000 $/ea

Using the activities listed in the Appendix – D, the users are asked to calculate the total duration and cost of the project. Probability of occurrences of the risks and their impacts on the parameters are given in Appendix – D as well. The users are asked to evaluate risk ratings for the activities so that they can estimate the risk adjusted durations and costs of the activities and the project. Then the users are asked to use the information given in Appendix – D in the developed tool to find the estimated risk adjusted durations and costs of the activities.

5.3 Results and Discussion

The developed tool is checked against traditional methods considering both risk free and risk adjusted duration – cost calculations. Although, the mathematical model used in the tool is logical and consistent, there may be errors, miscoding or the results may not seem reliable.

In the first part of the validation test, the Charrette Test is performed by three civil engineers using the developed too. The evaluation results were unexpected but helpful. Three main problems were realized owing to the users' recommendations and comments.

The first problem was about the risk free calculations. The risk free duration and cost calculated by the developed tool were different than those calculated by traditional methods. The reason why the risk free duration of a project is calculated wrong by the developed tool was simple. Fortunately, the hypothetical project used in the validation test of the tool has 2 critical paths. The developed tool was calculating the risk free duration of a project by adding all the critical activities' risk free durations. However, the risk free duration of a project should have been calculated by adding risk free durations of activities on the same critical path. The adjustment in the code has been made by correcting the project duration formula. The difference between risk free costs calculated by the developed tool and by the traditional methods was due to the difference in the indirect costs which was based on the duration. The cost calculation has been automatically corrected by correcting the duration calculation.

The second important problem was about pessimistic and optimistic risk adjusted results. All of the users were agree with that the pessimistic and optimistic results were too close to each other where there is no certain distinction. This was due to the assumption used for the determination of % change of the parameters which were affected by more than one risk. When there is more than one risk affecting on a parameter, the highest risk score (probability x impact) was used first to determine the new most probable % change value of that parameter. In this case, most of the time the last and therefore the lowest risk score was corresponding to the low region. Both the pessimistic and the optimistic calculations were done using this order which resulted in that % change value of a parameter was selected from the same region, which is usually the low region. This problem is resolved by omitting the assumption that the calculations start with the highest risk score first. Making the order of risks random at each run creates scenarios. The pessimistic scenario is based on % change values selected from the high region last which is achieved by starting the calculations with risks having low risk scores. The optimistic scenario is based on % change values selected from the low region last which is achieved by starting the calculations with risks having high risk scores.

The third problem was about the explanations and guidance provided in order to make the use of software easy and the calculations clear. An "Explanations" link is provided on the left frame by which the users can examine how the calculations are done, and what the terms mean. Besides, "Turn Debug On - Off" link is provided which lists the selected % change values for the parameters at a run. Finally, guidelines are presented at each step. It was also noticed that the impact evaluation is not easy for a user since it is a 13 x 14 parameter risk matrix. The default values are defined for the parameter – risk impact evaluation matrix for the irrelevant pairs. This provides user to make fast evaluation. For the advanced and detailed calculations, the default values can still be changed.

After the first test performed by the 3 civil engineers, the revisions mentioned above have been made. The revised version of the tool was tested again by another 3 civil engineers. The summary of the test results are given on Table 5.4 and 5.5. It can be observed from the results that the evaluations of the revised version have better results. Nearly all of the problems realized in the first test have been resolved. The second test results show that the users are still found the explanations about mathematical calculations inadequate. The software uses a good mathematical model in which an activity is decomposed into components, and components into parameters. Besides risks are defined and related with parameters. The calculations start with the risk item and continue through the parameters, components, activities and duration. Although the necessary explanations about the calculations are provided, it is not possible for a user to understand how all the calculations are carried out by the software. However a user can have more knowledge about the calculations by using the software several times. One of the users who performed the second test suggested that the impact evaluation could be simplified by grouping the parameters according to the components. This is achieved by grouping the parameters as labour, subcontractor, material and plant.

It was also observed that the users find the risk free results of the traditional methods more reliable. This is due to the fact that traditional methods used in the risk free calculations such as MS Project, have more features and better visualization. Although the risk free duration and cost calculated by the developed tool are correct, the developed software tool does not show the critical path(s) and activities. Since the aim of the developed software is making risk adjusted calculations, new features were not needed to be included in the risk free calculations and results.

The evaluation forms filled by the users are given in Appendix – B.

Table 5.4 The Charrette Test Results

No	Question	Method	Item	User	User	User
1	What is the risk free cost and risk free duration calculated using the corresponding method? (TM: Traditional Method, DT: Developed Tool)	**Before Revision**		**User 1**	**User 2**	**User 3**
		TM	RF Cost	$702,519.00	$702,519.00	$702,519.00
			RF Duration	41 days	41 days	41 days
		DT	RF Cost	$706,419.00	$706,419.00	$706,419.00
			RF Duration	54 days	54 days	54 days
		After Revision		**User 4**	**User 5**	**User 6**
		TM	RF Cost	$702,519.00	$702,519.00	$702,519.00
			RF Duration	41 days	41 days	41 days
		DT	RF Cost	$702,519.00	$702,519.00	$702,519.00
			RF Duration	41 days	41 days	41 days
2	What is the risk adjusted cost and risk adjusted duration using the corresponding method? (TM: Traditional Method, DT: Developed Tool)	**Before Revision**		**User 1**	**User 2**	**User 3**
		TM	RA Cost	$810,551.85	$769.205.00	$843.262.80
			RA Duration	56 days	70 days	50 days
		DT	RA Cost	$968,298.51	$890,274.24	$974,521.03
			RA Duration	89 days	89 days	89 days
		After Revision		**User 4**	**User 5**	**User 6**
		TM	RA Cost	$878,973.75	$951,295.00	$1,156,698.00
			RA Duration	54 days	65 days	62 days
		DT	RA Cost	$1,193,399.21	$935,793.79	$944,111.00
			RA Duration	74 days	69 days	68 days
3	How much time did you spend for the calculation of project duration and cost, activities' risk adjusted durations and costs? (TM: Traditional Method, DT: Developed Tool)	**Before Revision**		**User 1**	**User 2**	**User 3**
		TM	Time Spent (minutes)	45 mins	50 mins	40 mins
		DT		30 mins	45 mins	35 mins
		After Revision		**User 4**	**User 5**	**User 6**
		TM	Time Spent (minutes)	40 mins	45 mins	90 mins
		DT		35 mins	40 mins	40 mins
4	Which method gives more reliable results? (Traditional Method, TM or Developed Tool, DT)		**Before Rev.**	**User 1**	**User 2**	**User 3**
			RF Case	TM	TM	TM
			RA Case	TM	DT	TM
			After Rev.	**User 4**	**User 5**	**User 6**
			RF Case	TM	TM	TM
			RA Case	DT	DT	DT

Table 5.5 The Evaluation Results

	Strongly Disagree		Disagree		Neutral		Agree		Strongly Agree	
The instructions were helpful.			1		2	1		2		
Mathematical Calculations were clearly defined.			2	1		2	1			
I did not face with any difficulties while using the software.			1			1	2	1		1
The software was easy to use.			1		1		1	1		2

Recommendations and Comments

BEFORE THE REVISION

* The duration calculation of the developed tool for risk free case is not realistic.
* The pessimistic and optimistic risk adjusted results are too close to each other. There is not clear distinction between pessimistic and optimistic results.
* Irrelevant risk - parameter pairs may be marked as "Not Applicable" by defaults.
* Explanation for the definitons of the terms may be helpful.
* More clear instructions may be helpful.

AFTER THE REVISION

* Mathematical Calculations and Explanations may be given in more detail.
* In order to make parameter – risk matrix step easier, this step can be divided into sub steps according to the parameter types such as labour, plant, or subcontractor.
* Top Row text can be aligned horizontally. It is hard to read.
* Impact of risks on parameter should be easier to understand.

CHAPTER 6

CONCLUSION

An activity based risk assessment using integrated duration – cost model proposed by Tah and Poh has several advantages over the other risk assessment methods. First of all, risks are directly related to the activities instead of overall project which gives more reliable results. Furthermore, an activity is decomposed into components and parameters. This increases the level of confidence of the calculations since the risk effects on the activities are quantified through the parameters. This enables to reflect varied effects of a risk on different parameters. Moreover, this model has the advantage of integrating risk calculations of duration and cost. Overall effect of risks on duration and cost of an activity is quantified simultaneously.

On the other hand, the risk assessment model has several limitations, which were overcome by the developed tool within the context of this thesis study. Firstly, the model proposed in the article written by Tah and Poh in 2006 do not have a risk assessment part. Therefore, how the selection of a parameter % change which is used in the risk adjusted calculations is provided by the risk assessment used in the developed tool. To do this, risk breakdown structure was created by grouping risks as "delay risks" and "change risks". Risk assessment methodology is developed using risk probabilities and impacts. Risk score is used to determine the region for a parameter % change. The % change value for a parameter is selected randomly using MC simulation.

Secondly, making the calculations by hand using the proposed model was a crucial and tedious work. For each activity of a project, creating the model is almost impossible without using simplified rules and software tool. Developing a web based software tool with simplified rules enabled users to use the model in the risk assessments of construction projects. This also provided users to record the data of the projects on a web.

Thirdly, since the proposed model can be used on a single activity only, the indirect cost of the project cannot be included in the calculations. Defining logical relations and using PDM, the indirect cost of construction projects was taken into account in the developed tool.

Finally, it is almost impossible for a user to create scenarios using the proposed model when a software tool is not used. Using the MC simulation in the selection of % changes in the parameters enabled the developed tool to create scenarios which yields graphical results. Graphical results are helpful to see the distributions and the limits to which duration or cost of a project may reach to.

In conclusion, the aim of the developed software tool was to estimate the risk adjusted durations and costs of construction projects using an activity based integrated duration – cost influence diagramming method. The developed risk assessment tool was tested for validation. The necessary revisions have been made. It is a useful tool which has an easy access on the web and can be utilized to determine the pessimistic, most likely and optimistic risk adjusted duration and cost of a project.

However, there are some limitations of the developed tool. The risk adjusted calculations are based on the changes in the parameters such as productivity. The amount of change in the parameters is determined subjectively. Prediction of the changes in the parameters such as productivity using statistical methods can be integrated to the tool and this can be a part of a forthcoming research study. The developed tool may be improved so as to enable users to select types of parameter % change curves. Shapes other than triangular shape can as well be selected by the users. Another forthcoming study for the improvement of the developed tool may be performing sensitivity analysis to investigate which parameters affect the results most.

The risk free case which is defined as optimistic case in the developed tool may have negative values as cost and time reductions are also possible in construction projects due to successful management or favourable changes in external conditions (such as exchange rates etc.). In this thesis, positive side of risk is ignored. The developed tool may be extended to include the positive impact of changes in the forthcoming studies.

REFERENCES

Anaç, C., 2007. Development of a risk assessment tool for post-project appraisal, M.Sc. thesis, Middle East Technical University, Graduate School of Natural and Applied Sciences, Ankara.

Arikan, A. E., 2005. Development of a risk management decision support system for international construction projects, M.Sc. thesis, Middle East Technical University, Graduate School of Natural and Applied Sciences, Ankara.

Carr R. I. (1993), Cost, Schedule and Time Variances and Integration, Journal of Construction Engineering and Management, 119(2), 245-265.

Chao L. (2007), Fuzzy Logic Model for Determining Minimum Bid Markup, Computer-Aided Civil and Infrastructure Engineering, 22, 449-460.

Choi H. and Mahadevan S. (2008), Construction Project Risk Assessment Using Existing Database and Project-Specific Information, Journal of Construction Engineering and Management, 134(11), 894-903.

Isidore L. J. and Back W. E. (2002), Multiple Simulation Analysis for Probabilistic Cost and Schedule Integration. Journal of Construction Engineering and Management, 128(3), 211-219.

Jaafari, A. (2001), Management of Risks, Uncertainties and Opportunities on Projects: Time for a Fundamental Shift, International Journal of Project Management 19(2), 89-101.

Jannadi O. A. and Almishari S. (2003), Risk Assessment in Construction. Journal of Construction Engineering and Management, 129(5), 492-500.

Mulholland B. and Christian J. (1999), Risk Assessment in Construction Schedules. Journal of Construction Engineering and Management, 125(1), 8-15.

Nasir D., McCabe B. and Hartono L. (2003), Evaluating Risk in Construction-Schedule Model (ERIC-S): Construction Schedule Risk Model, Journal of Construction Engineering and Management, 129(5), 518-527.

Ozdogan, I.D. (1996) "Risk Management of BOT Projects in developing countries", M.Sc. thesis, Middle East Technical University, Graduate School of Natural and Applied Sciences, Ankara.

Rasdorf W. J. and Abudayyeh O. Y. (1991), Cost and Schedule Control Integration: Issues and Needs, Journal of Construction Engineering and Management, 117(3), 486-502.

Sachs T. and Tiong R. L. K. (2009), Quantifying Qualitative Information on Risks: Development of the QQIR Method. Journal of Construction Engineering and Management, 135(1), 56-71.

Skorupka D. (2008), Identification and Initial Risk Assessment of Construction Projects in Poland, Journal of Management in Engineering, 24(3), 120-127.

Tah J. H. M. and Carr V. (2000), A Proposal for Construction Project Risk Assessment Using Fuzzy Logic, Construction Management and Economics, 18, 491-500.

Tah J. H. M. and Carr V. (2001), Knowledge-Based Approach to Construction Project Risk Management. Journal of Computing in Civil Engineering, 15(3), 211-219.

Tah J. H. M. and Poh Y. P. (2006), Integrated Duration-Cost Influence Network for Modelling Risk Impacts on Construction Tasks, Construction Management and Economics, 24, 861-868.

APPENDIX A

USER INTERFACE SCREENSHOTS OF SAMPLE PROJECT

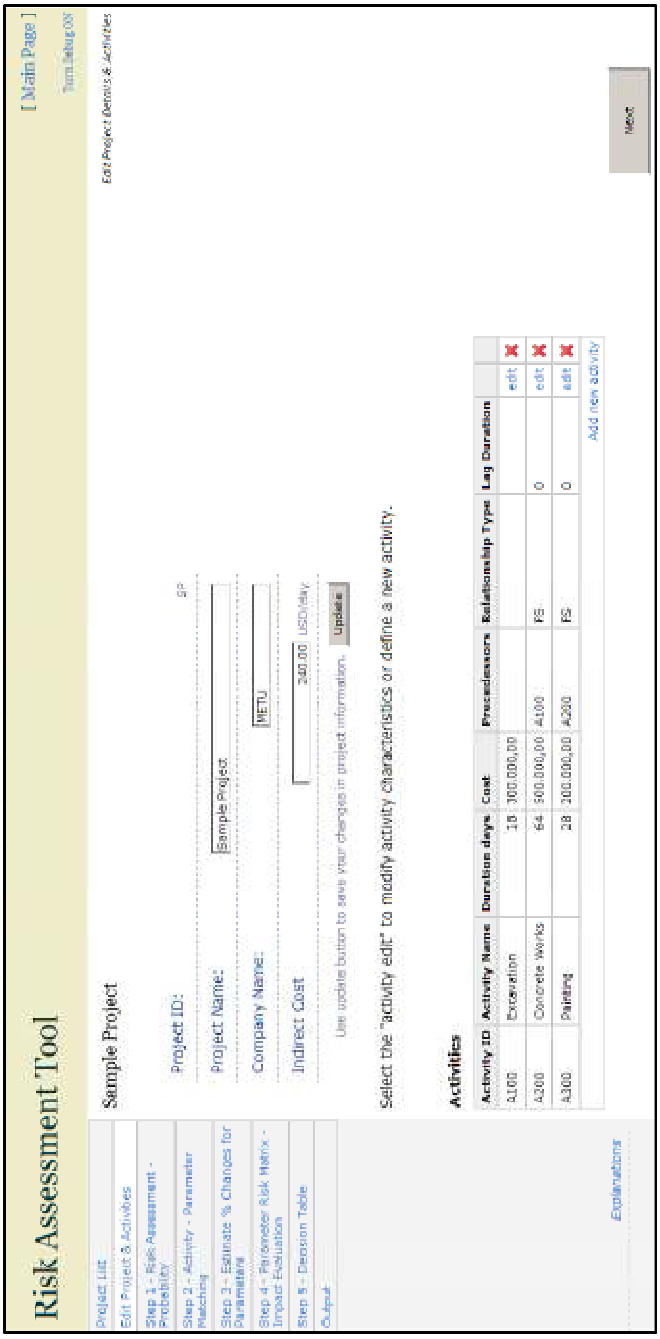

Figure A.1 Project Definition Page of Sample Project

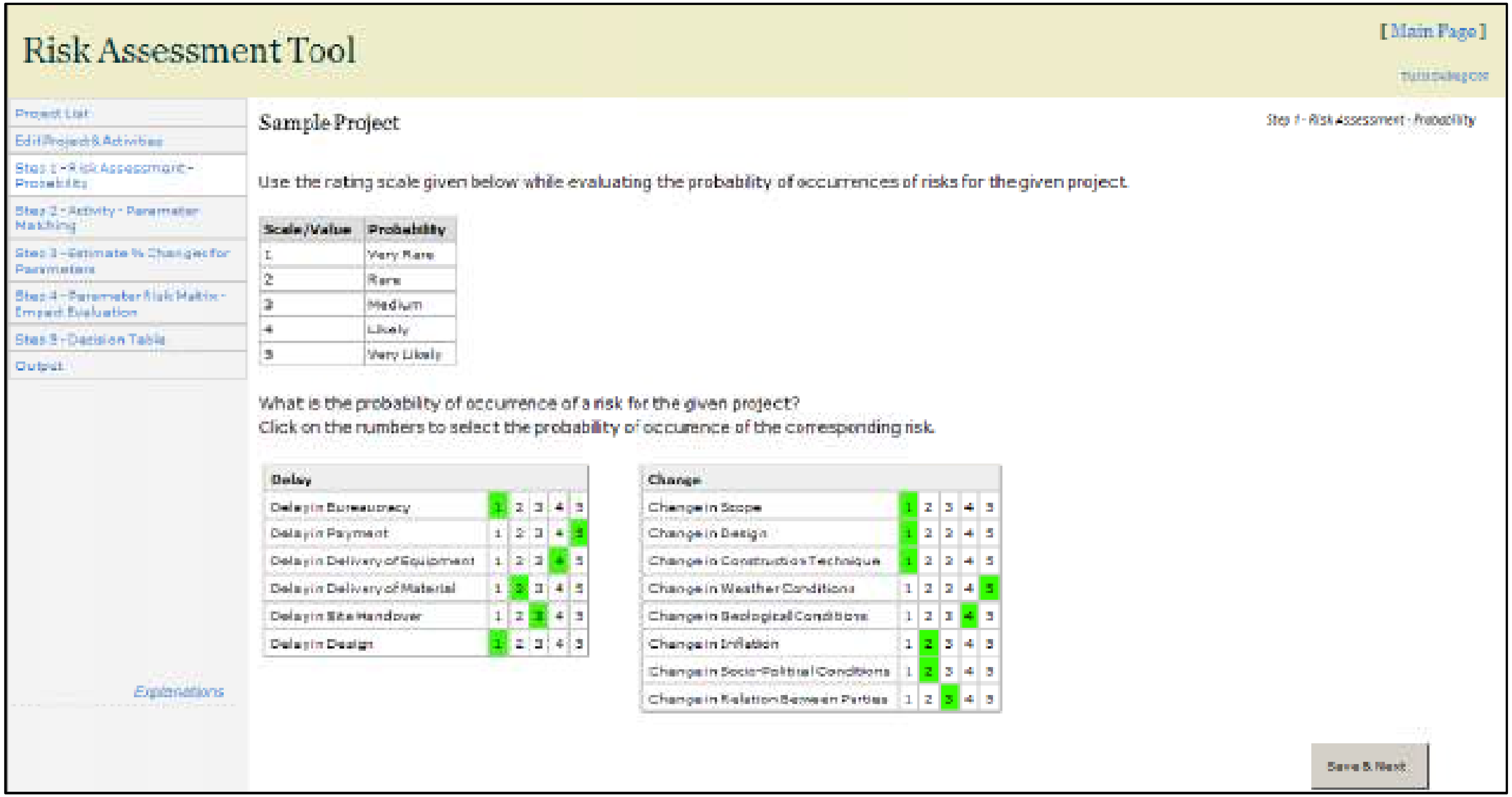

Figure A.2 Risk Assessment – Probability Page

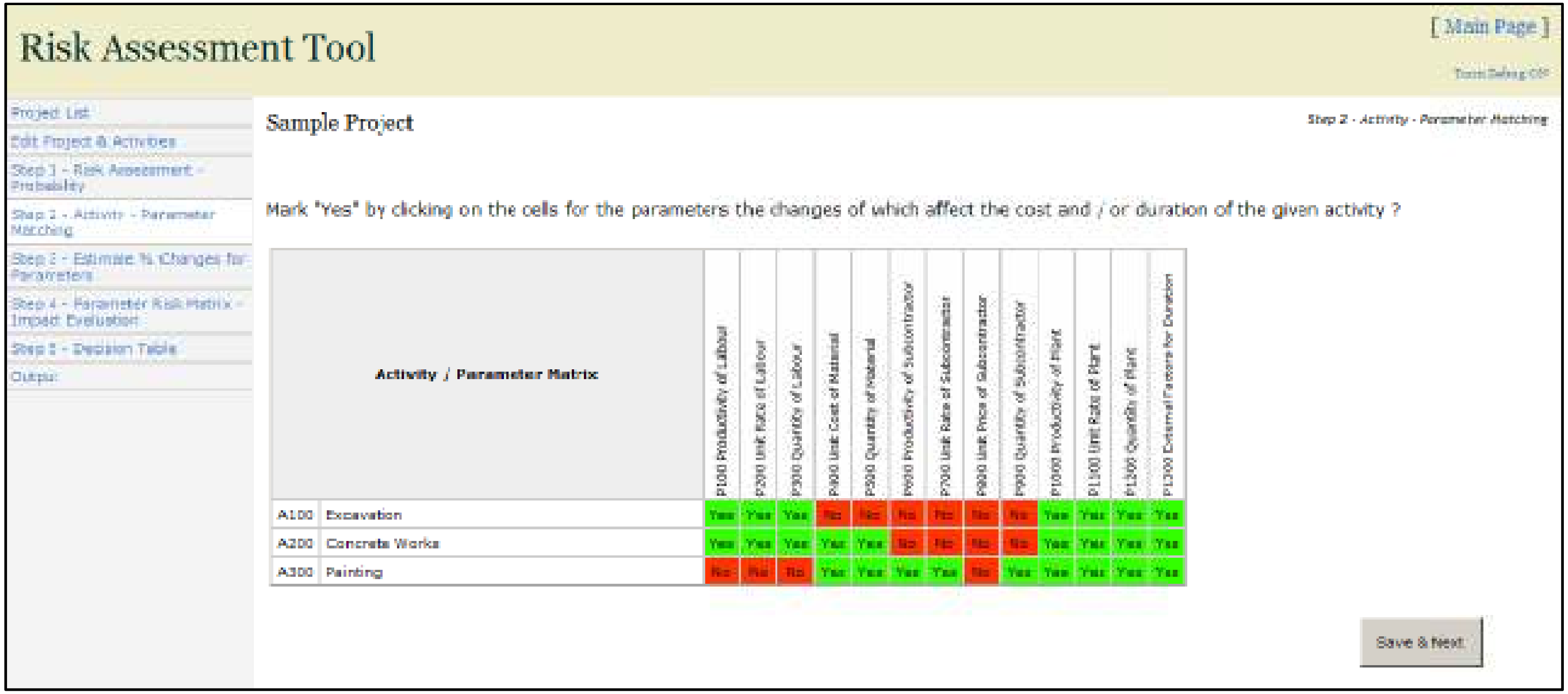

Figure A.3 Activity Parameter Matching Page of Sample Project

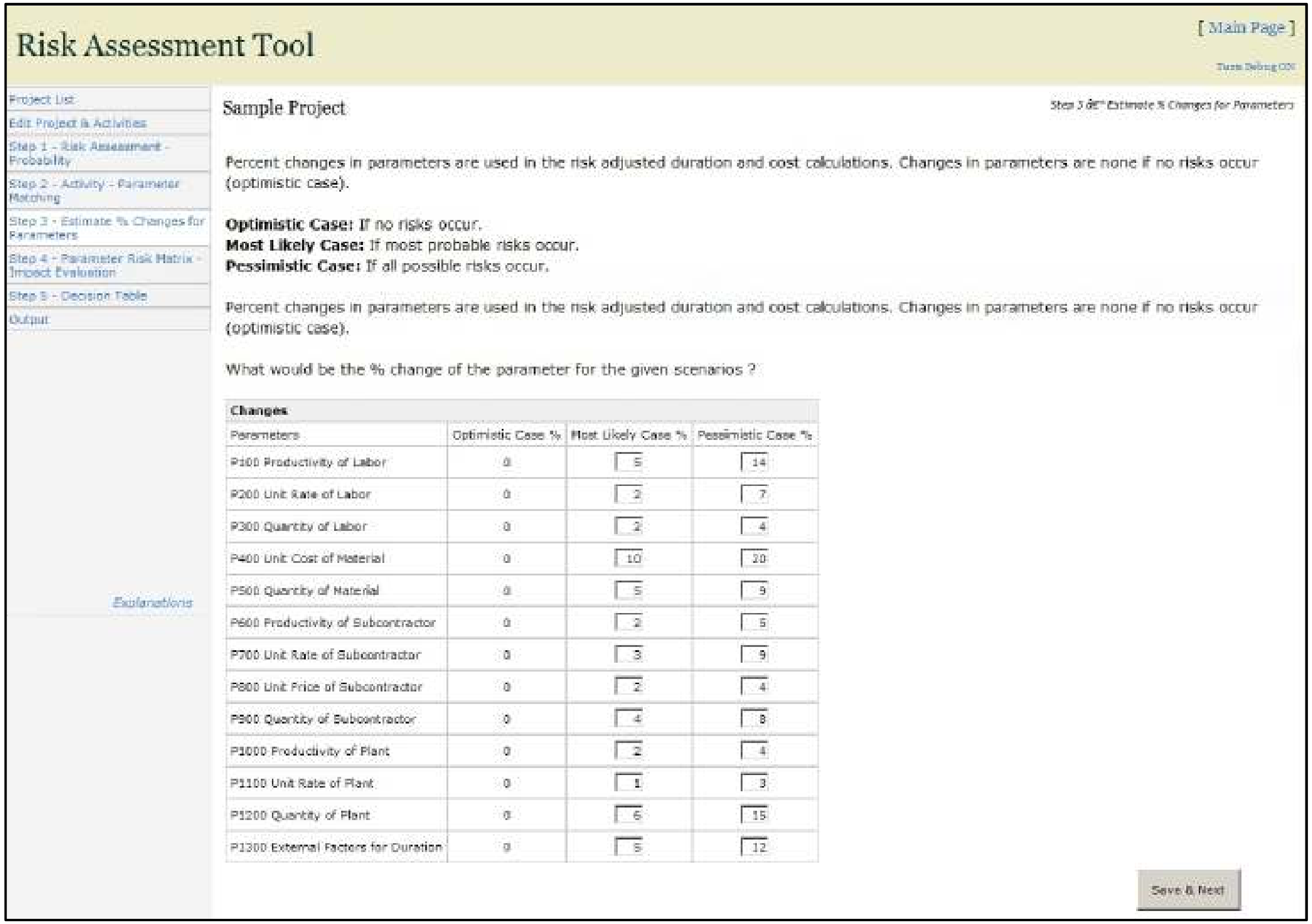

Figure A.4 % Changes for Parameters Page of Sample Project

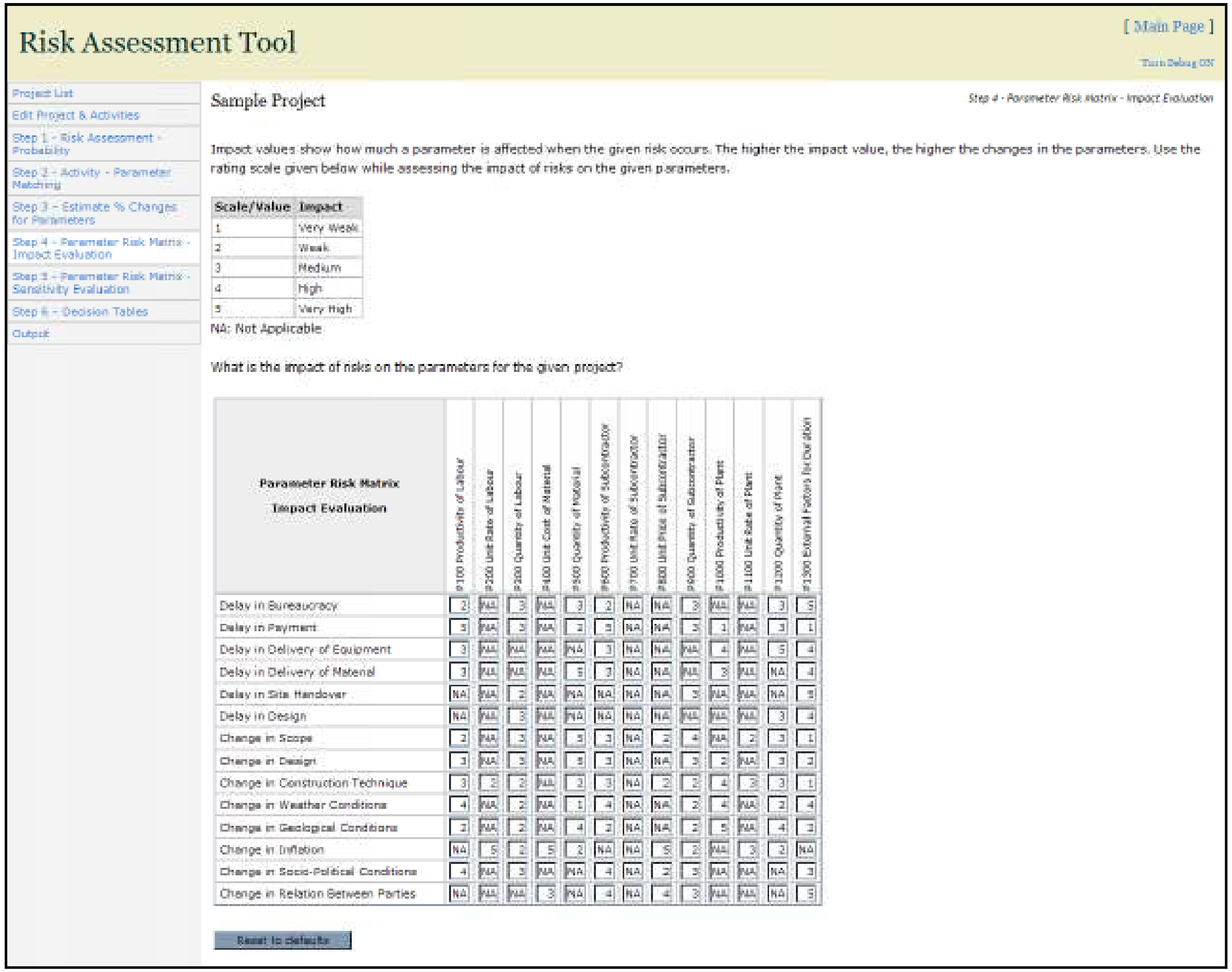

Figure A.5 Parameter – Risk Impact Evaluation Page of Sample Project

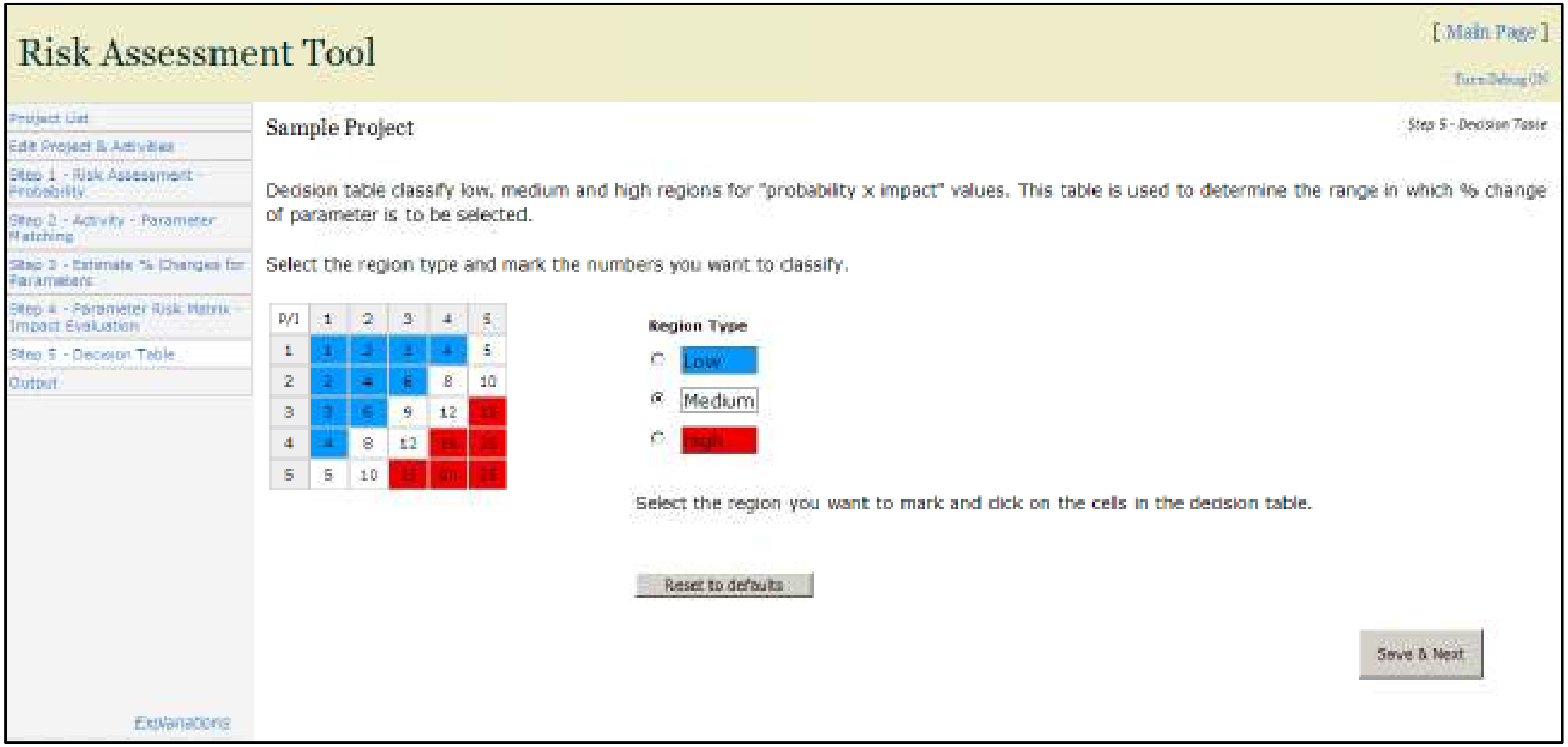

Figure A.6 Decision Table Page of Sample Project

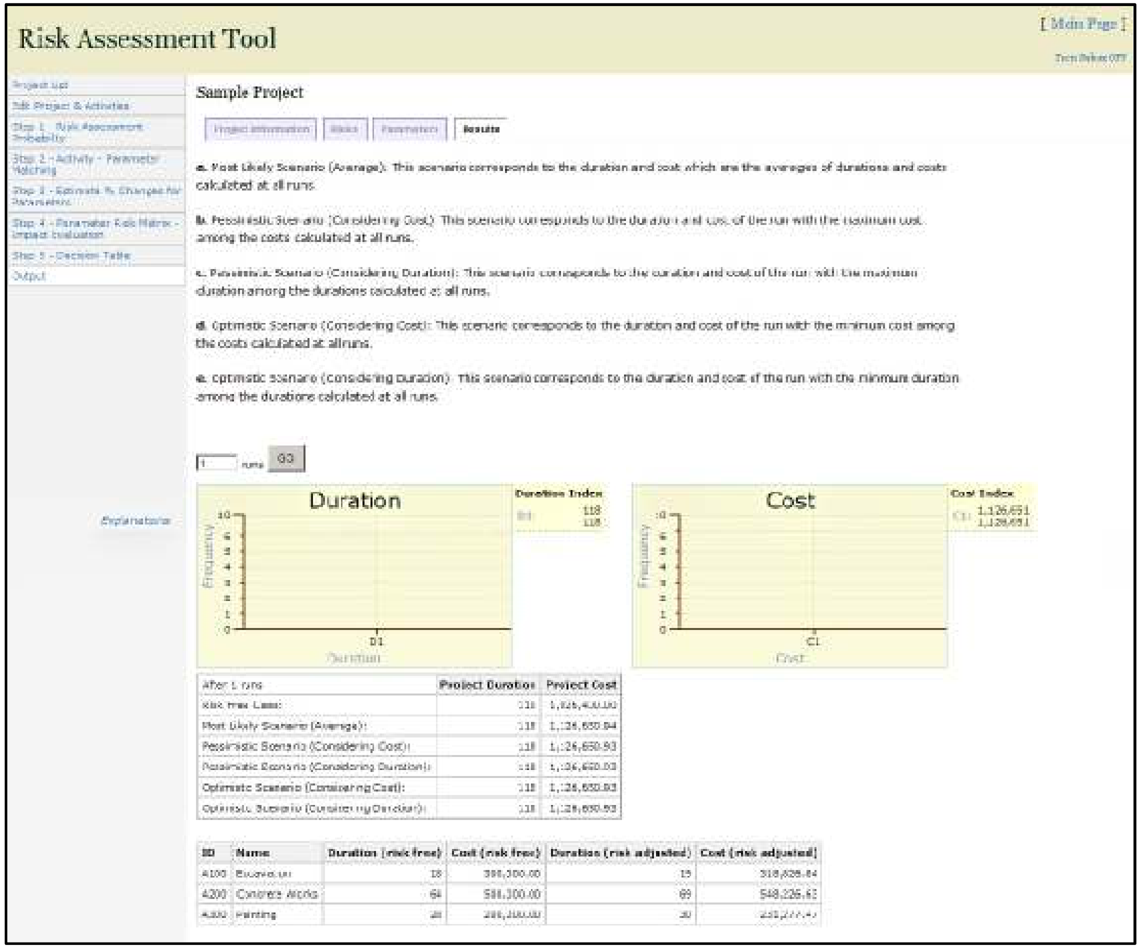

Figure A.7 Output Page of Sample Project

APPENDIX B

Table B.1 Charrette Test Form – User 1

Step – 1: Use traditional methods described above for the calculation of project duration and cost, activities' risk adjusted durations and costs.	
What is the risk free cost and risk free duration calculated using the traditional method?	RF Cost: $702,519.00 RF Duration: 41days
What is the risk adjusted cost and risk adjusted duration using the traditional method?	RA Cost: $810,551.85 RA Duration: 56 days
How much time did you spend for the calculation of project duration and cost, activities' risk adjusted durations and costs?	45 minutes
Step – 2: Use the developed tool for the calculation of project duration and cost, activities' risk adjusted durations and costs.	
What is the risk free cost and risk free duration calculated using the traditional method?	RF Cost: $706,419.00 RF Duration: 54 days
What is the risk adjusted cost and risk adjusted duration using the traditional method?	RA Cost: $968,298.51 RA Duration: 89 days
How much time did you spend for the calculation of project duration and cost, activities' risk adjusted durations and costs?	30 minutes
Which method gives more reliable results?	Traditional Method for Both

Table B.2 Charrette Test Form – User 2

Step – 1: Use traditional methods described above for the calculation of project duration and cost, activities' risk adjusted durations and costs.	
What is the risk free cost and risk free duration calculated using the traditional method?	RF Cost: $702,519.00 RF Duration: 41
What is the risk adjusted cost and risk adjusted duration using the traditional method?	RA Cost: $769,.205.00 RA Duration: 70
How much time did you spend for the calculation of project duration and cost, activities' risk adjusted durations and costs?	50 minutes
Step – 2: Use the developed tool for the calculation of project duration and cost, activities' risk adjusted durations and costs.	
What is the risk free cost and risk free duration calculated using the traditional method?	RF Cost: $706,419.00 RF Duration: 54
What is the risk adjusted cost and risk adjusted duration using the traditional method?	RA Cost: $890,274.24 RA Duration: 89
How much time did you spend for the calculation of project duration and cost, activities' risk adjusted durations and costs?	45 minutes
Which method gives more reliable results?	Traditional Method for RF Case Developed Tool for RA Case

Table B.3 Charrette Test Form – User 3

Step – 1: Use traditional methods described above for the calculation of project duration and cost, activities' risk adjusted durations and costs.	
What is the risk free cost and risk free duration calculated using the traditional method?	RF Cost: $702,519.00 RF Duration: 41days
What is the risk adjusted cost and risk adjusted duration using the traditional method?	RA Cost: $810,551.85 RA Duration: 56 days
How much time did you spend for the calculation of project duration and cost, activities' risk adjusted durations and costs?	40 minutes
Step – 2: Use the developed tool for the calculation of project duration and cost, activities' risk adjusted durations and costs.	
What is the risk free cost and risk free duration calculated using the traditional method?	RF Cost: $706,419.00 RF Duration: 54
What is the risk adjusted cost and risk adjusted duration using the traditional method?	RA Cost: $974,521.03 RA Duration: 89
How much time did you spend for the calculation of project duration and cost, activities' risk adjusted durations and costs?	35 minutes
Which method gives more reliable results?	Traditional Method for Both

Table B.4 Charrette Test Form – User 4

Step – 1: Use traditional methods described above for the calculation of project duration and cost, activities' risk adjusted durations and costs.	
What is the risk free cost and risk free duration calculated using the traditional method?	RF Cost: $ 702,519.00 RF Duration: 41
What is the risk adjusted cost and risk adjusted duration using the traditional method?	RA Cost: $1,156,698.00 RA Duration: 62
How much time did you spend for the calculation of project duration and cost, activities' risk adjusted durations and costs?	90 minutes
Step – 2: Use the developed tool for the calculation of project duration and cost, activities' risk adjusted durations and costs.	
What is the risk free cost and risk free duration calculated using the traditional method?	RF Cost: $702,519.00 RF Duration: 41
What is the risk adjusted cost and risk adjusted duration using the traditional method?	RA Cost: $ 944,111 RA Duration: 68
How much time did you spend for the calculation of project duration and cost, activities' risk adjusted durations and costs?	40 minutes
Which method gives more reliable results?	Traditional Method for RF Case Developed Tool for RA Case

Table B.5 Charrette Test Form – User 5

Step – 1: Use traditional methods described above for the calculation of project duration and cost, activities' risk adjusted durations and costs.	
What is the risk free cost and risk free duration calculated using the traditional method?	RF Cost: $702,519.00 RF Duration: 41
What is the risk adjusted cost and risk adjusted duration using the traditional method?	RA Cost: $ 878,973.75 RA Duration: 54
How much time did you spend for the calculation of project duration and cost, activities' risk adjusted durations and costs?	40 minutes
Step – 2: Use the developed tool for the calculation of project duration and cost, activities' risk adjusted durations and costs.	
What is the risk free cost and risk free duration calculated using the traditional method?	RF Cost: $ 702,519.00 RF Duration: 41 days
What is the risk adjusted cost and risk adjusted duration using the traditional method?	RA Cost: $1.009.085,09 RA Duration: 67 days
How much time did you spend for the calculation of project duration and cost, activities' risk adjusted durations and costs?	35 minutes
Which method gives more reliable results?	Traditional Method for RF Case Developed Tool for RA Case

Table B.5 Charrette Test Form – User 6

Step – 1: Use traditional methods described above for the calculation of project duration and cost, activities' risk adjusted durations and costs.	
What is the risk free cost and risk free duration calculated using the traditional method?	RF Cost: $702,519.00 RF Duration: 41
What is the risk adjusted cost and risk adjusted duration using the traditional method?	RA Cost: $ 951,295.00 RA Duration: 65
How much time did you spend for the calculation of project duration and cost, activities' risk adjusted durations and costs?	45 minutes
Step – 2: Use the developed tool for the calculation of project duration and cost, activities' risk adjusted durations and costs.	
What is the risk free cost and risk free duration calculated using the traditional method?	RF Cost: $ 702,519.00 RF Duration: 41 days
What is the risk adjusted cost and risk adjusted duration using the traditional method?	RA Cost: $935.793,79 RA Duration: 69 days
How much time did you spend for the calculation of project duration and cost, activities' risk adjusted durations and costs?	40 minutes
Which method gives more reliable results?	Traditional Method for RF Case Developed Tool for RA Case

Table B.6 Evaluation Form – User 1

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The instructions were helpful.			X		
Mathematical Calculations were clearly defined.		X			
I did not face with any difficulties while using the software?				X	
The software is easy to use.			X		

Recommendations and Comments:

CPM calculation for risk free case is not correct.

Pessimistic and Optimistic results are too close to each other.

Table B.7 Evaluation Form – User 2

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The instructions were helpful.			X		
Mathematical Calculations were clearly defined.				X	
I did not face with any difficulties while using the software?				X	
The software is easy to use.				X	

Recommendations and Comments:

I think terminology is a bit confusing. For example, I couldn't understand the difference between unit rate, unit cost and quantity of subcontractor. Therefore, I find it difficult to give rates for these items.

Also, deciding the most likely and pessimistic changes in Step 3 is not easy. I find it difficult to relate the risk items with these changes.

Table B.8 Evaluation Form – User 3

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The instructions were helpful.		X			
Mathematical Calculations were clearly defined.		X			
I did not face with any difficulties while using the software?		X			
The software is easy to use.		X			

Recommendations and Comments:

The risk free calculations are not correct.

The difference between the risk adjusted results for pessimistic and optimistic scenarios should be higher.

Table B.9 Evaluation Form – User 4

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The instructions were helpful.			X		
Mathematical Calculations were clearly defined.		X			
I did not face with any difficulties while using the software?			X		
The software is easy to use.				X	

Recommendations and Comments:

It may be better for each step to include some brief description about each step' s mathematical calculations, aim and terms, then it can be more user friendly for experts in the sector. Tool uses more detailed estimation as considers activity level assessments and performing activity level assessment is very time consuming process and requires considering lots of information at the same time, however this tool is considering all aspects and make sure that nothing is forgotten. So the tool is more reliable than subjective methods performed by experts. But the only fact that makes reduce its reliability is its hidden processes.

Table B.10 Evaluation Form – User 5

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The instructions were helpful.				X	
Mathematical Calculations were clearly defined.			X		
I did not face with any difficulties while using the software?				X	
The software is easy to use.					X

Recommendations and Comments:

The tool includes several scenarios and task based adjustments which seems more appropriate. On Risk impact matrix:

Impact of risks on parameter should be easier to understand.

Top Row text can be aligned horizontally. It is hard to read.

Parameters can be grouped (such as Labour, Subcontractor, plant) and this fill out process can be divided done according to these groups at different sub-steps. It shall be easier for the user.

Table B.11 Evaluation Form – User 6

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The instructions were helpful.				X	
Mathematical Calculations were clearly defined.			X		
I did not face with any difficulties while using the software?					X
The software is easy to use.					X
Recommendations and Comments: It is an effective tool which can be used as an activity based risk assessment tool in a short time. Since scenarios are created with the developed tool, the results are more reliable.					

APPENDIX C

Table C.1 Activities of the Hypothetical Project

Activity ID	Activity Name	Predecessor Activity	Relation Type	Duration (days)	Total Cost ($)
A100	Block A1 - Excavation	-		2	$980,00
A200	Block A1 - Lean Concrete	A100	FS	1	$140,80
A300	Block A1 - Foundation Works	A200	FS	4	$14.185,00
A400	Block A1 - Backfill	A300	FS+3	5	$300,00
A500	Block A1 - Floor 1 Section 1 Tunnel	A400	FS	1	$13.265,00
A600	Block A1 - Floor 1 Section 2 Tunnel	A500	FS	1	$13.265,00
A700	Block A1 - Floor 2 Section 1 Tunnel	A600	FS	1	$13.265,00
A800	Block A1 - Floor 2 Section 2 Tunnel	A700	FS	1	$13.265,00
A900	Block A1 - Floor 3 Section 1 Tunnel	A800	FS	1	$13.265,00
A1000	Block A1 - Floor 3 Section 2 Tunnel	A900	FS	1	$13.265,00
A1100	Block A2 - Excavation	A100	FS	2	$980,00
A1200	Block A2 - Lean Concrete	A1100	FS	1	$140,80
A1300	Block A2 - Foundation Works	A1200	FS	4	$14.185,00
A1400	Block A2 - Backfill	A1300	FS+3	5	$300,00
A1500	Block A2 - Floor 1 Section 1 Tunnel	A1400	FS	1	$13.265,00
A1600	Block A2 - Floor 1 Section 2 Tunnel	A1500	FS	1	$13.265,00

Table C.1 Continued

Activity ID	Activity Name	Predecessor Activity	Relation Type	Duration (days)	Total Cost ($)
A1700	Block A2 - Floor 2 Section 1 Tunnel	A1600	FS	1	$13.265,00
A1800	Block A2 - Floor 2 Section 2 Tunnel	A1700	FS	1	$13.265,00
A1900	Block A2 - Floor 3 Section 1 Tunnel	A1800	FS	1	$13.265,00
A2000	Block A2 - Floor 3 Section 2 Tunnel	A1900	FS	1	$13.265,00
A2100	Block B1 - Excavation	A1100	FS	2	$980,00
A2200	Block B1 - Lean Concrete	A2100	FS	1	$140,80
A2300	Block B1 - Foundation Works	A2200	FS	4	$14.185,00
A2400	Block B1 - Backfill	A2300	FS+3	5	$300,00
A2500	Block B1 - Floor 1 Section 1 Tunnel	A2400, A1000	FS, FS	1	$13.265,00
A2600	Block B1 - Floor 1 Section 2 Tunnel	A2500	FS	1	$13.265,00
A2700	Block B1 - Floor 2 Section 1 Tunnel	A2600	FS	1	$13.265,00
A2800	Block B1 - Floor 2 Section 2 Tunnel	A2700	FS	1	$13.265,00
A2900	Block B1 - Floor 3 Section 1 Tunnel	A2800	FS	1	$13.265,00
A3000	Block B1 - Floor 3 Section 2 Tunnel	A2900	FS	1	$13.265,00
A3100	Block B1 - Floor 4 Section 1 Tunnel	A3000	FS	1	$13.265,00
A3200	Block B1 - Floor 4 Section 2 Tunnel	A3100	FS	1	$13.265,00
A3300	Block B2 - Excavation	A2100	FS	2	$980,00
A3400	Block B2 - Lean Concrete	A3300	FS	1	$140,80
A3500	Block B2 - Foundation Works	A3400	FS	4	$14.185,00
A3600	Block B2 - Backfill	A3500	FS+3	5	$300,00

Table C.1 Continued

Activity ID	Activity Name	Predecessor Activity	Relation Type	Duration (days)	Total Cost ($)
A3700	Block B2 - Floor 1 Section 1 Tunnel	A3600, A6700	FS, FS	1	$13.265,00
A3800	Block B2 - Floor 1 Section 2 Tunnel	A3700	FS	1	$13.265,00
A3900	Block B2 - Floor 2 Section 1 Tunnel	A3800	FS	1	$13.265,00
A4000	Block B2 - Floor 2 Section 2 Tunnel	A3900	FS	1	$13.265,00
A4100	Block B2 - Floor 3 Section 1 Tunnel	A4000	FS	1	$13.265,00
A4200	Block B2 - Floor 3 Section 2 Tunnel	A4100	FS	1	$13.265,00
A4300	Block B2 - Floor 4 Section 1 Tunnel	A4200	FS	1	$13.265,00
A4400	Block B2 - Floor 4 Section 2 Tunnel	A4300	FS	1	$13.265,00
A4500	Clock C1 - Excavation	A3300	FS	2	$980,00
A4600	Clock C1 - Lean Concrete	A4500	FS	1	$140,80
A4700	Clock C1 - Foundation Works	A4600	FS	4	$14.185,00
A4800	Clock C1 - Backfill	A4700	FS+3	5	$300,00
A4900	Clock C1 - Floor 1 Section 1 Tunnel	A4800, A2000	FS, FS	1	$13.265,00
A5000	Clock C1 - Floor 1 Section 2 Tunnel	A4900	FS	1	$13.265,00
A5100	Clock C1 - Floor 2 Section 1 Tunnel	A5000	FS	1	$13.265,00
A5200	Clock C1 - Floor 2 Section 2 Tunnel	A5100	FS	1	$13.265,00
A5300	Clock C1 - Floor 3 Section 1 Tunnel	A5200	FS	1	$13.265,00
A5400	Clock C1 - Floor 3 Section 2 Tunnel	A5300	FS	1	$13.265,00
A5500	Clock C1 - Floor 4 Section 1 Tunnel	A5400	FS	1	$13.265,00
A5600	Clock C1 - Floor 4 Section 2 Tunnel	A5500	FS	1	$13.265,00

Table C.1 Continued

Activity ID	Activity Name	Predecessor Activity	Relation Type	Duration (days)	Total Cost ($)
A5700	Clock C1 - Floor 5 Section 1 Tunnel	A5600	FS	1	$13.265,00
A5800	Clock C1 - Floor 5 Section 2 Tunnel	A5700	FS	1	$13.265,00
A5900	Clock C1 - Floor 6 Section 1 Tunnel	A5800	FS	1	$13.265,00
A6000	Clock C1 - Floor 6 Section 2 Tunnel	A5900	FS	1	$13.265,00
A6100	Clock C1 - Floor 7 Section 1 Tunnel	A6000	FS	1	$13.265,00
A6200	Clock C1 - Floor 7 Section 2 Tunnel	A6100	FS	1	$13.265,00
A6300	Clock C1 - Floor 8 Section 1 Tunnel	A6200	FS	1	$13.265,00
A6400	Clock C1 - Floor 8 Section 2 Tunnel	A6300	FS	1	$13.265,00
A6500	Clock C1 - Floor 9 Section 1 Tunnel	A6400	FS	1	$13.265,00
A6600	Clock C1 - Floor 9 Section 2 Tunnel	A6500	FS	1	$13.265,00
A6700	Movement of Crane - 1	A3200	FS	2	$2.000,00

Table C.2 Cost Distribution of the Activities

Activity Name	Subcont. Cost ($)	Plant Cost ($)	Labour Cost ($)	Material Cost ($)
Excavation	$980,00	$0,00	$0,00	$0,00
Lean Concrete	$0,00	$30,00	$30,00	$80,80
Foundation Works	$0,00	$3.800,00	$960,00	$9.425,00
Backfill	$0,00	$200,00	$100,00	$0,00
Floor X Section X Tunnel	$0,00	$2.400,00	$480,00	$10.385,00