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Quantitative Risk Assessment of Factors Affecting Construction Projects

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ABSTRACT

Unexpected increase in cost and delays in construction projects are caused by owner, contractor, environments...etc. in which several types of risk factors may occur concurrently. The effect of cost overrun and schedule overrun do not only influence the construction industry but the overall economy as well. Even though construction project increasing in cost and schedule have received extensive attention of researchers, risk response was not treated well in the literature. In order to meet the deadline of a project and due to the complex nature of construction projects, cost and scheduling should be flexible enough to accommodate changes without negatively affecting the overall project cost and duration. As such, the objectives of the presented research in this paper are to identify, study, and assess the effect of the factors that affect cost and time contingency. Data are collected from sixteen construction companies in Egypt.

Keywords: cost overrun, schedule overrun, likelihood, probability, scale

1. INTRODUCTION

Cost saving and time performance are usually essential to all parties who are involved in a construction project, i.e. owner, contractor, subcontractor, etc. The main causes of disputes in construction projects involve delay and failure to complete the work in the specified cost and time frame. The delivery time of a project is a key factor to the owner in terms of cost as much as it is for the contractor.

There are many sources of uncertainty in construction projects, which include the performance of construction parties, resources availability, environmental conditions, involvement of other parties, contractual relations, etc. As a result of these sources, construction projects may face problems that cause delay(s) in the project completion time [1].

The key success indicators of construction management system(s) include completing the project with cost and time, within the planned budget and duration, and within the required quality, safety, and environmental limits. These goals are interrelated where each of them is affecting and affected by the others. An accurate cost estimating and scheduling should be sought in order to meet the overall budget and time deadline of a project.

Time contingency is used to guarantee the completion time of either an activity or a project [2]. Due to the unique nature of construction projects, cost overrun and schedule overrun uncertainty are essential for true budget and scheduling, which should be flexible enough to accommodate changes without negatively affecting the overall cost and duration. It is also essential to allocate a contingency value to both cost and time [3]. Yet, there are situations where there could be delays in activities, whether they are within the critical path or not, which result in a delay in the overall project duration. These delays will consequently have a negative impact on the quality, budget, and might be safety of a project. Therefore, estimating cost and time contingencies are seen as a prime factor in achieving a successful construction project. Although several industrial sectors developed and used software for estimating time and cost contingencies in order to minimize delays and avoid being over budget, yet limited efforts are reported in the literature in the area of predicting time, i.e. schedule, contingency in construction projects. The overall objectives of the presented research in this paper are: 1. To identify and study the factors that affect cost overrun and schedule overrun; 2. To develop a probability distribution charts for likelihood, cost impact and schedule impact; and3. To quantify the risk assessment impact on cost and schedule.

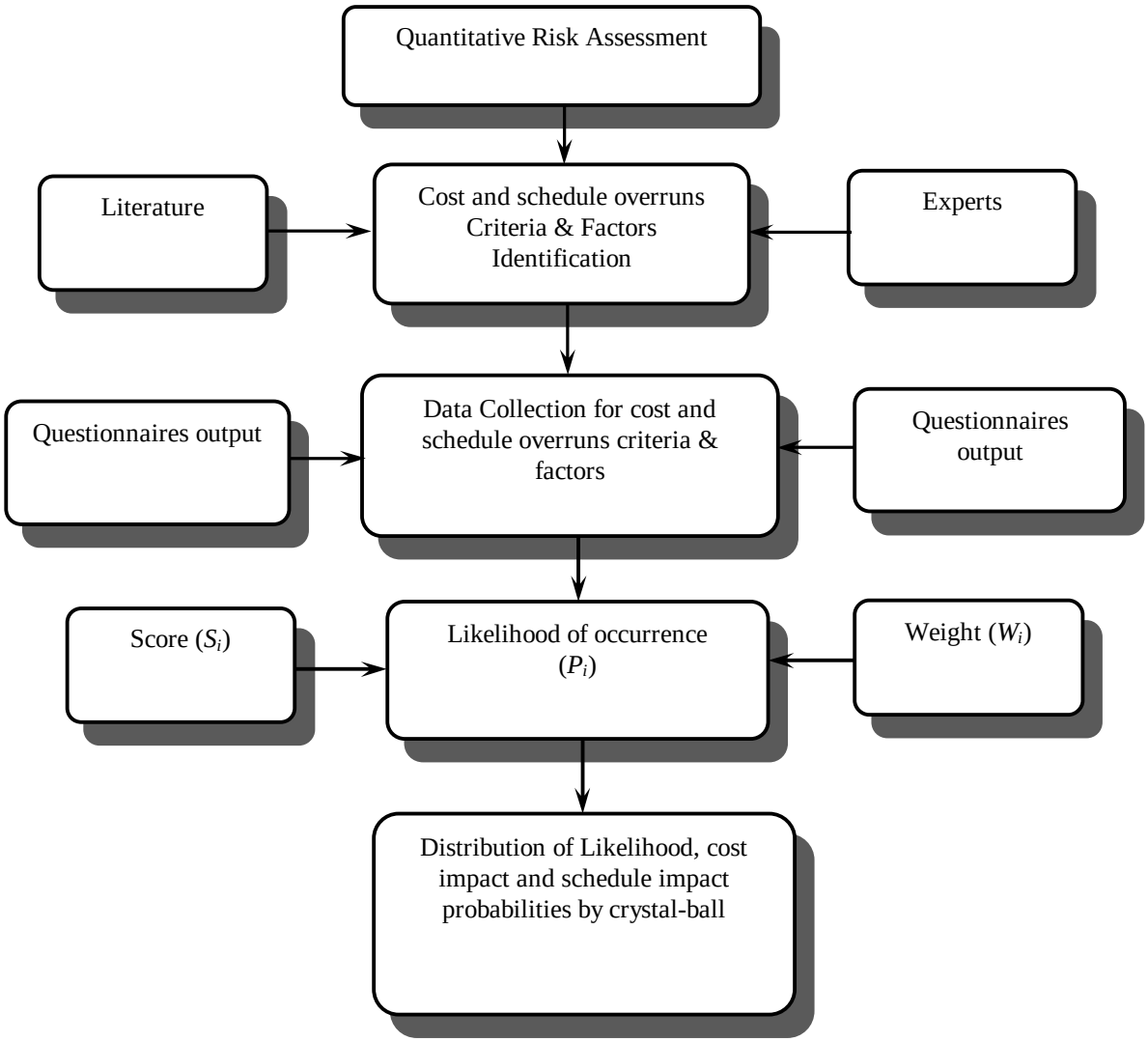

Figure -1: Research methodology

2. BACKGROUND

Delays have an adverse impact on project success interms of time, cost, quality and safety [1].Time-delays and cost overruns areamong the most common phenomena in the constructionindustry [4]. Therefore, plannersand schedulers have used time contingency toguarantee the completion time of either an activity ora project [2]. The easiest andsafest way to build a time contingency is to extend theproject end date to a point where there is a comfortableamount of positive float, which may not be costeffective or acceptable to the client. However, it mightnot also be acceptable to proceed in a project with azero float plan [5].

There is no standard definition of contingency inwhich it could imply different meanings to estimators,contractors, and owners' organizations[6]. Contingencyis probably the most misunderstood,misinterpreted, and misapplied word in projectexecution[7]. It is an amount of moneyor time (or other resources) added to the base estimatedamount to achieve a specific confidence levelor allow for changes where experience shows obligation[8]. It can also be defined as the budgetthat is set aside to cope with uncertainties during construction[3] or the amount of money/timeneeded above the estimate to reduce the risk of overrunsof project objectives to an acceptable level withinthe organization [9]. [10] Identified two major categories of contingency for constructionprojects:

- **Design Contingency**: it addresses the changes during the design process for factors, such as incomplete scope definition and inaccuracy of estimating methods as well as data [11].
- **Construction Contingency**: it addresses the changes during a construction process. Under a traditional procurement arrangement, the contract typicallycontains a variation clause(s) to allow for changes and provide a mechanism for determining and valuing variations.

There are many definitions for contingency in theliterature; most of them focused on cost contingency.Contingency has different meanings to different people.Despite its importance, estimating time contingencywas not thoroughly addressed in the literature.Prior to reviewing the estimating methods for projectcontingency, there are different attributes that affectcontingency.[12]Identified 55 factorsaffecting the performance of project schedule. They observed seven factors that have the most significantimpact on schedule outcome and divide them into twomain categories.

The first category included factorsthat encompassed the capability to improve performancelevel, such as owner's competence as well ascommitment and conflict among project members. Thesecond included factors that tended to retain the scheduleat its existing level, such as coordination amongproject members, lack of knowledge and skills for theproject managers, hostile socioeconomic environment, and uncertainty in selecting project members/team. In addition, [3] indicated that the effect ofchange orders increased the original cost and schedulesince they modified the original contract.[13]presented a methodology that incorporatednetwork analysis and duration uncertainty inproject time analysis. They studied the effect of variousfactors on time contingency using a linear equation.

There are many factors that impact time contingency in which it is not only important to identify these factorsbut assess their impact on the project duration aswell. Mostengineers, planners, and agencies relied on their experienceto estimate cost and time contingencies [3]; [13]; [14];[15]. The contractor's contingencywas represented as a fixed percentage of the contractvalue [16] or as a percentageof total project cost or duration [3]. The completion date of a project wasoften missed due to uncertain events in which their impactwas difficult to predict because of the uniquenessof construction projects.

Schedule contingency analysis is the process of identifyingand evaluating contingency factors, present oranticipated, and determining both the probability andimpact of identified contingency factors [17]. It is a preliminary step in establishing aschedule and time control strategy, which is intendedto increase theprobability of desired outcome while minimizing risk factors [12].

3. FACTORS AFFECTING COST OVERRUN AND SCHEDULE OVERRUN

Based on literature and the opinion of practitioners/Expert through about forty questionnaires,several imperative factors that affect cost and time contingency are identified and studied.They are dividedinto four major criteria: A) Site conditions, B) Resources, C) Project parties, D) Project features related factors. Table 1shows the detail of these main criteria and theirfactors. Site conditions include environmental, Sub-surface andSite location. Resources include Labor, Equipment and Material.On the other hand, project parties cover Owner, Engineering & Design, Contractor and Project management.In addition Project features cover Financial, Political and schedule sub-criterion.

The detail attributes/risk factors related for each sub-criterion are shown in Table 1.It is quite clear thatthe identified criteria and factors effectively contributeto the uncertainty in construction project cost and scheduling,which in turns, impact the assessment of cost and schedule overruns.In the present research, these factors are considered in predicting project budget and time contingencies.

4. RESEARCH METHODOLOGIES

Figure 1 shows the detailed steps utilized to performthe various activities of the present research. Factorsthat affect cost and schedule overruns are identified and discussedusing literature review and experts opinion. Aquestionnaire survey is conducted to collect the impactof each factor. The researchmethodology is performed using probability distribution developed bycrystal ball software. The collected data through questionnaires will be used to illustrate the min., mean, maximum and standard division values.

The output charts developed by crystal ball software will be divided into three stages, the first one illustrates the probability distribution per each attribute likelihood "P_i", the second stage will concern the cost impact probability distribution either for attributes which will be defined as "weight W_i", or concerning the sub-criterion itself, which will be defined as "Score S_i", furthermore the thirdstage will reflect the schedule impact probability distribution either for attributes/risk factor or for the sub-criterions themselves as described previously.These data will be used by AHP based simulation modeling which will be described in detail in another paper.

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5. DEVELOPMENT OF DATA AND CHARTS

5.1 Introduction

Cost and schedule overruns analysis are defined in this research as the process of Identifying and evaluating contingency factors, present or anticipated, and determining the cost and schedule overruns indexes. In order to assess these indexes, some steps are utilized to perform the intended analysis. These steps are discussed further in the following sections.

The questionnaires have been developed to evaluate the probability of attributes in addition to attributes cost impact and schedule impact, these questionnaires cover a lot of attributes/risk factors from literature to allocate various categories as per environmental and financial effects which had included by 66 factors and increased up to 71 factors by practitioners advice, for example these added factors as per Equipment malfunctions, Ad-hoc consultants, availability of variations, Owner financial capacity and tax rate.

The data have been mentioned in Excel spreadsheets to determine the min., max., mean values in addition to standard deviation, the evaluated weights have been transformed into percentages using (PMBOK® Guide) chapter-11 scales. The probability distribution of likelihood, cost impact and schedule impact have been developed using Oracle crystal ball Release 11.1.2.3 software, these charts will be used in the graphical mode, on the other hand the user can use the numerical mode simply. The spreadsheets will be used to present the heat maps and tornado charts as discussed later.

Table -1 Factors affecting cost and schedule overruns

Criteria	Sub-criterion	Attributes/risk factor	Risk Probability					Cost Risk Impact					Schedule Risk Impact				
			Very Low	Low	Moderate	High	Very High	Very Low	Low	Moderate	High	Very High	Very Low	Low	Moderate	High	Very High
			1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Site conditions	Environmental	Earthquake															
		Precipitation /flood															
		Unpredicted Weather conditions															
		Pollution															
	Sub-surface	Unexpected Surface conditions															
		Archeological survey done															
		Geo-technical investigation															
	Site location	Construction area (rural/urban)															
		Access conditions															
		On-site congestion															
		Delay in permits and licenses															
		Security requirements															
		Safety regulation															
		Differing site conditions															
Resources	Labor	Labor skills level															
		Labor availability															
		Drop in Labor productivity															
		Labor accidents															
		Human resource planning															
		Working hours restrictions															
	Equipment	Equipment quality															
		Equipment breakdown															
		Equipment maintenance															
		Equipment malfunctions															
	Material	Material delivery															
		Material storage															
		Material theft & damage															
		Material procurement															
		Non-conforming material															
		Material monopoly															
		Nominated vendors															

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Project parties	Owner	Owner type
		management strategy
		organization structure
		Work/labour permits
		on-site access
	Engineering and Design	Team experience
		Project goal
		Complexity of design
		Ad-hoc consultants
		Design error
	Contractor	Contractor pre-qualified
		New technology
		Defective work
		Rework
		no of subcontractors
		Contractor Reputation
		Nominated sub-contractors
		no. of current projects
	Project management	Management experience
		Owner quality assurance
		Scope definition
		quality control process
		Type of contract
		availability of variations
Project features	Financial	Type of Funds
		Fluctuation in prices
		Invoices delay
		Change in currency rate
		Owner financial capacity
		Progress payment
		rate of interest
		tax rate
		foreign currency
		project size
	Political	Bribery and Corruption
		Wars and revolutions
		Military coup
		Changes in laws and regulations
	Schedule	Fast track schedule
		Project duration

Table -2 Heat map concerning attributes *COST* impact

Probability	V,low	Low	Medium	High	V.high
V.high		Bribery and Corruption	New technology		Construction area (rural/urban)
High	Unpredicted Weather conditions Working hours restrictions no of subcontractors Safety regulation Invoices delay	Differing site conditions Change in currency rate tax rate project size Owner quality assurance Scope definition quality control process Fast track schedule	Unexpected Surface conditions Contractor pre-qualified Fluctuation in prices rate of interest		Changes in laws and regulations
Medium	Pollution Progress payment	Geo-technical investigation Drop in Labor productivity on-site access Contractor Reputation Access conditions On-site congestion Owner financial capacity Ad-hoc consultants Project duration	Material procurement Nominated vendors Nominated sub-contractors Type of contract availability of variations	Team experience Management experience	Project goal Wars and revolutions
Low	Archeological survey done Labor skills level Human resource planning Material monopoly Owner type Work/labour permits Equipment breakdown Equipment malfunctions Delay in permits and licenses foreign currency	Labor availability Material delivery Material storage Material theft & damage Non-conforming material Equipment quality	Precipitation /flood Labor accidents Complexity of design		Defective work Security requirements Type of Funds Military coup
V.low	management strategy organization structure Equipment maintenance no. of current projects	Earthquake	Rework Design error		

Attributes COST Impact

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5. 2. Collection and probability distribution

The questionnaires have been prepared in Arabic language and English language to be simply filled; the sheets have been distributed in three evaluated portions, the first one concerning the probability of occurring of attribute, the second portion assigned for attribute cost impact and the third portion assigned for attribute schedule impact. The evaluation category is spread to five levels, very low=1, low=2, moderate=3, high=4 and very high=5, table 1illustrates these details.

Table -3: Heat map concerning attributes *SCHEDULE* impact

Probability	V,low	Low	Medium	High	V.high
V.high	Bribery and Corruption			New technology	Construction area (rural/urban)
High	Unpredicted Weather conditions no of subcontractors Fluctuation in prices Invoices delay Change in currency rate rate of interest tax rate project size Changes in laws and regulations	Working hours restrictions Safety regulation Differing site conditions Owner quality assurance quality control process	Unexpected Surface conditions Contractor pre-qualified Scope definition Fast track schedule		
Medium	Nominated vendors Contractor Reputation Nominated sub-contractors Owner financial capacity Progress payment Type of contract availability of variations	Pollution Geo-technical investigation Drop in Labor productivity on-site access Access conditions On-site congestion Ad-hoc consultants Project duration	Material procurement	Team experience Management experience	Project goal Wars and revolutions
Low	Archeological survey done Human resource planning Material monopoly Owner type Work/labour permits Equipment breakdown Delay in permits and licenses Type of Funds foreign currency	Labor skills level Labor availability Material storage Equipment quality Equipment malfunctions	Precipitation /flood Labor accidents Material delivery Material theft & damage Non-conforming material Complexity of design		Defective work Security requirements Military coup
V.low	management strategy organization structure no. of current projects	Earthquake Equipment maintenance		Rework Design error	

Attributes SCHEDULE Impact

To change the previous ranks into numerical scales (PMBOK® Guide) – Fifth Edition chapter-11 will be utilized, MS. Excel 2010 has been used to develop spreadsheets to present the collection data and calculate the mean, minimum and maximum values in addition to the standard divisions, Oracle® Crystal Ball Release 11.1.2.3 software will be used for represent the probability distribution for all attributes as same as the probability distribution of sub-criterions themselves, referred to (PMBOK® Guide) – Fifth Edition chapter-11 some distributions are frequently used as per Beta, triangular and lognormal distribution.

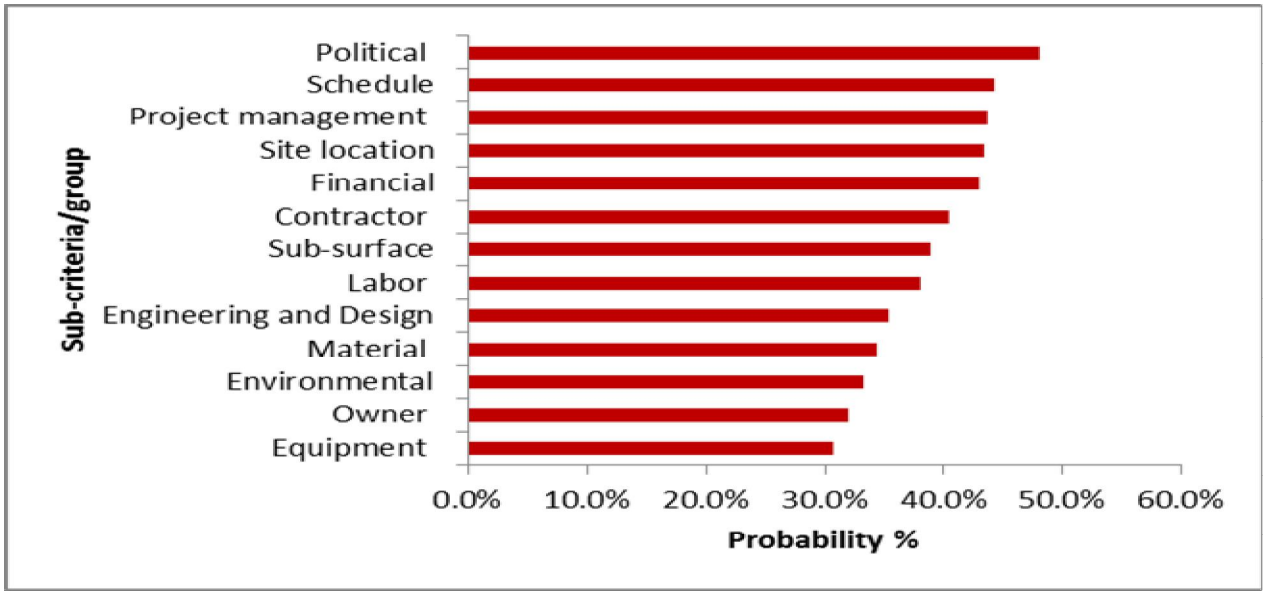

Figure -2: Attributes Probability Tornado Chart (for Sub-criterion)

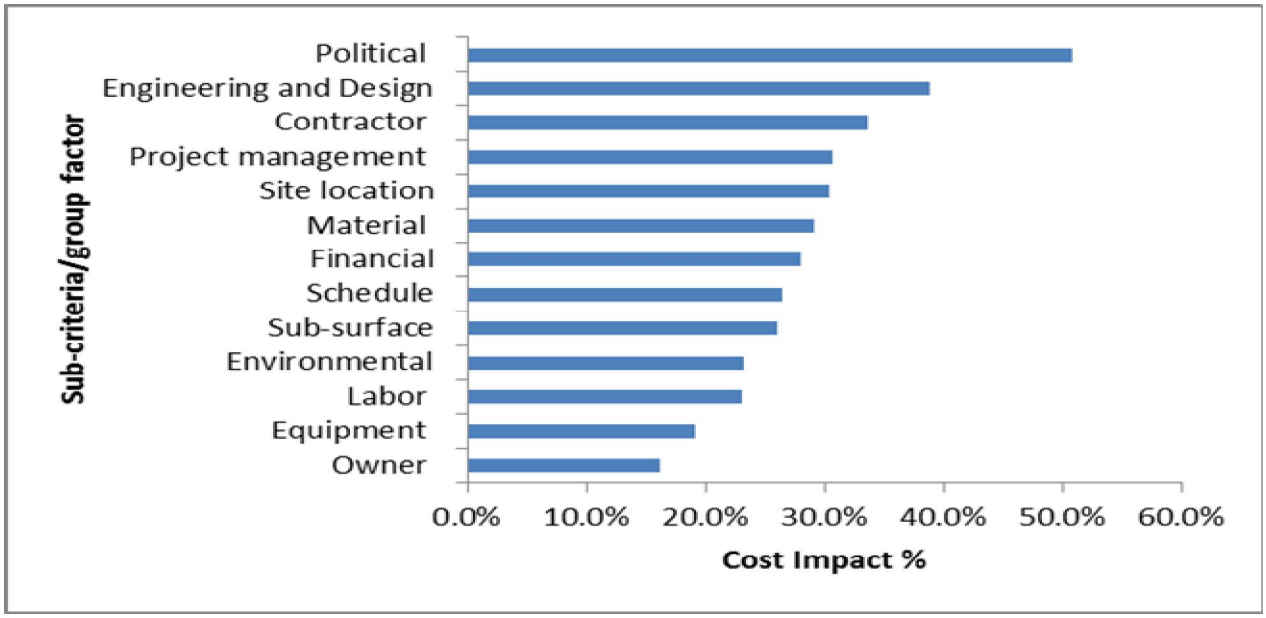

Figure -3: Tornado Chart for Sub-criterion Cost Impact

The probability distribution will be iterated three times for likelihood of occurring, cost impact and schedule impact, these charts will be used in graphical mode if the user need to insert the percentages according to their probability, on the other hand numerical mode can be used for choosing minimum or maximum or mean values directly. Some figures concerning tornado charts and probability distribution will be illustrated below as examples, due to limit space all charts and figures can't be illustrated.

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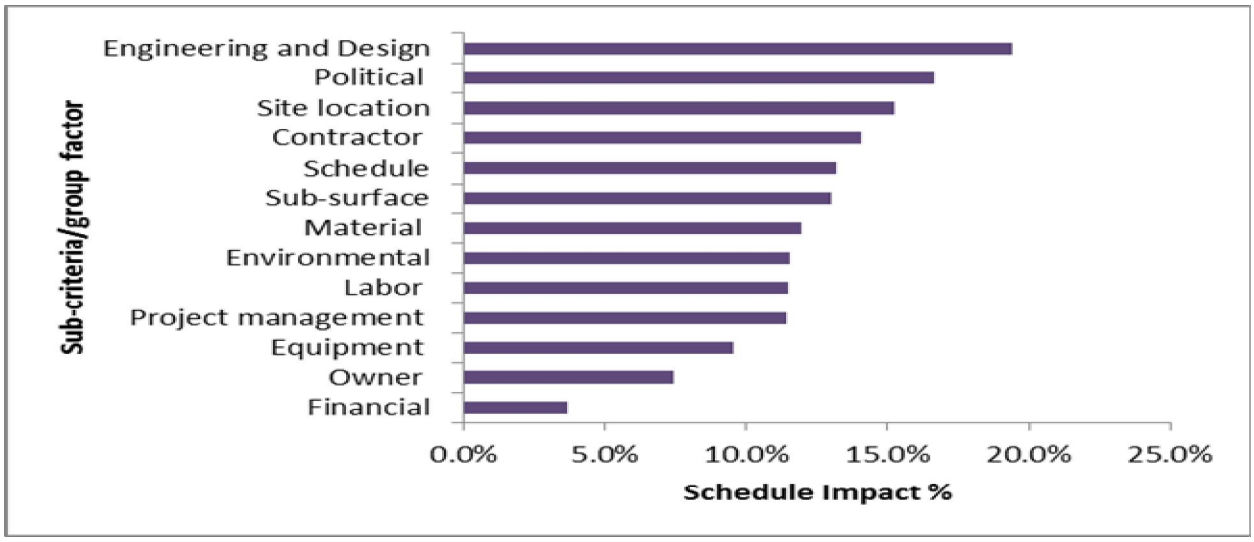

Figure -4: Tornado Chart for Sub-criterion Schedule Impact

6. DATA COLLECTION

Data are collected through one mean questionnaire and structured interviews to collect information on casestudy projects. A survey is conducted in the form of aquestionnaire to collect projectsrisk factors and its probability in addition to its cost and schedule overruns from the construction firms in Egypt. The questionnaire is designed usingthe significant factors identified by literature andexperts as shown in Table 1. The questionnaire includes three parts. Part one includes the respondentpersonal general information, i.e. years of experience, total value of completed works, type of company partnership,type of the projects, project duration. Otherwise parttwo,includes the identified attributes probability of occurrence, cost impact and schedule overrun.Part three includes any additional attributes have been added by practitioner.In orderto facilitate the answers of reviewers, a scale from1-5 is used, using a scale range as mentioned in article 5.1 above.

Physical and telephone interviews are conductedwith senior managers of sixteen companies,which are located in Egypt, or located outside Egypt but have some projects here. The surveyed companies have experience historyranges from 15 to 60 years in the construction industry.

They work in variety of projects, such as pipelines, tanks, refineries, infrastructure, silos …etc. The variety of companies' type is taken into consideration as per national/international huge companies, construction firms, consultants and insurance group. 38 feedbacks have been received, 5 have been rejected due to shortage data, the type of contact engineers are 3 consultants, 4 project managers, 6 construction managers, 4 planners, 7 cost estimators, 1 contract administrator, 1 insurance engineer and 7 site engineers. The budget values of projects that runby the interviewed managers range from $25 to $500Million US dollars and the durations range from6 months to 3 years. Three case study projects areselected to test the robustness of developed model.

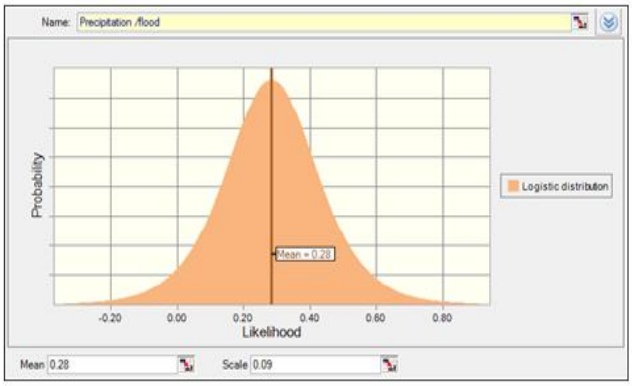

Figure-5: Likelihood probability distribution for *PRECIPITATION/FLOOD* Attribute

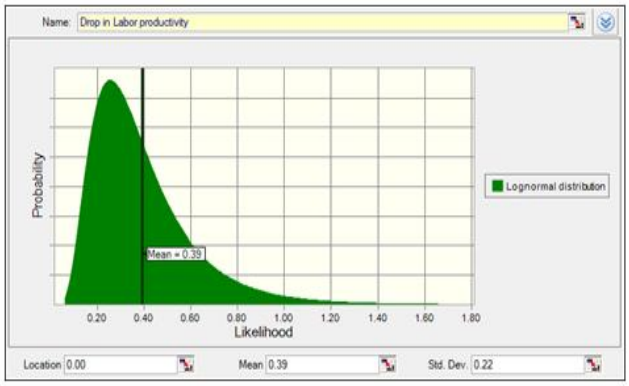

Figure-6: Likelihood probability distribution for *DROP IN LABOR PRODUCTIVITY* Attribute

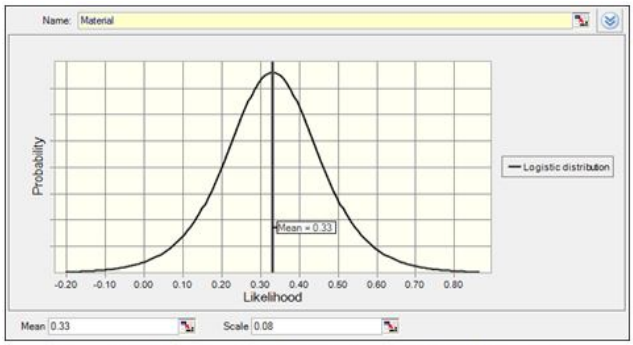

Figure-7: Likelihood probability distribution for *MATRIAL* Sub-criterion

Figure-8: Cost impact probability distribution for *ORGANIZATION STRUCTURE* attribute

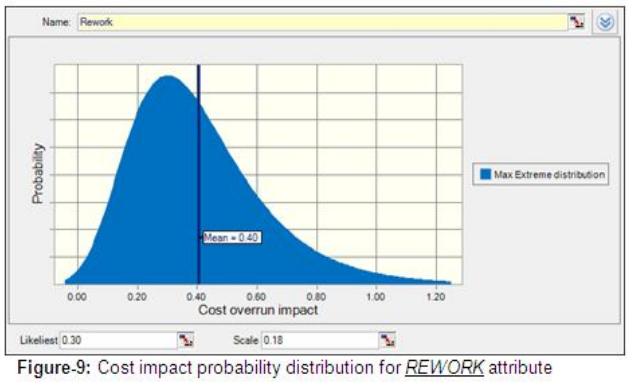

Figure-9: Cost impact probability distribution for *REWORK* attribute

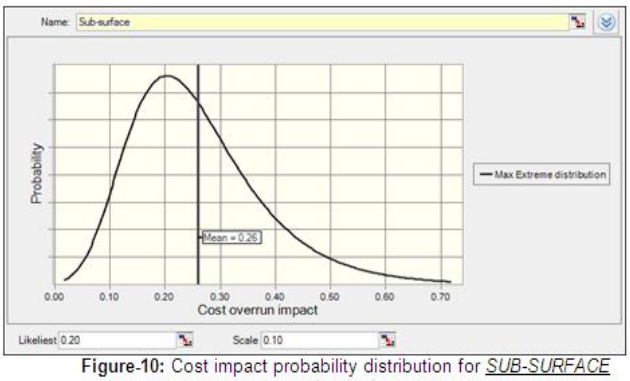

Figure-10: Cost impact probability distribution for *SUB-SURFACE* sub-criterion

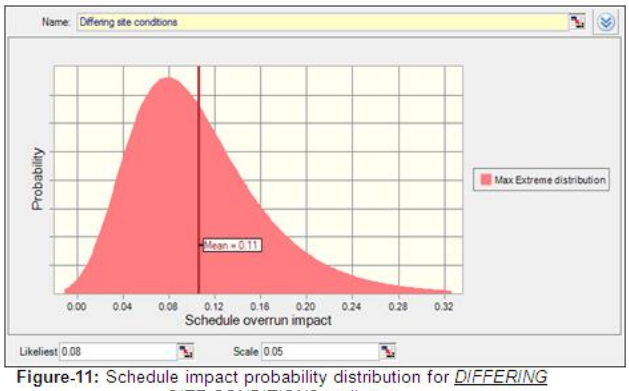

Figure-11: Schedule impact probability distribution for *DIFFERING SITE CONDITIONS* attributes

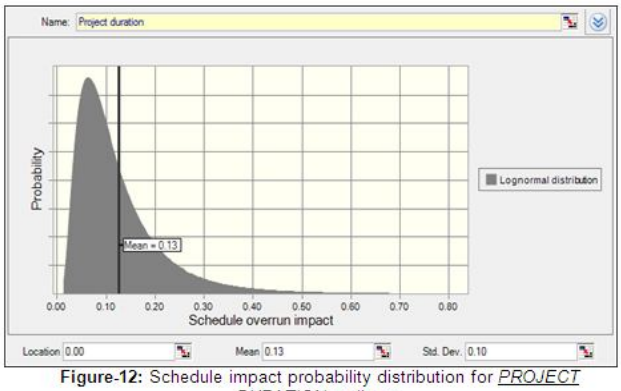

Figure-12: Schedule impact probability distribution for *PROJECT DURATION* attributes

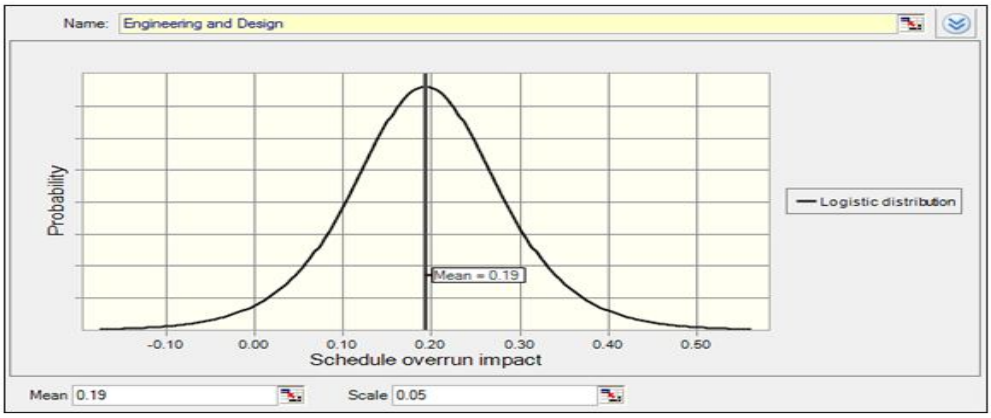

Figure-13: Schedule impact probability distribution for *ENGINEERING & DESIGN* sub-criterion

7. CONCLUSIONS

Estimating cost and scheduling contingenciesaremajorfactors in achieving a successful and realistic budget and schedulefor construction projects. In the present research, asurvey is sent to many construction companies to identify, qualify study, assess, and quantify the factors that affect budget and time contingency.

From table 2 and table 3 as presented above, there are some attributes located in the red zone which reflect the great probability and impact effect of such factors, if the cost estimator take the impact of that attributes as same as their values, the budget and schedule will increase accordingly, and the tenderer maybe unsuccessful. Therefore risk response and risk plan shall be studied and controlled to transfer or mitigate the impact of said factors to another party such as insurance company, sub-contractor or the client himself, which enhance the cost and schedule contingency demand. On the other hand the attributes located in the green zone have little probability and impact, these factors may be neglected or avoid.

From figures 2, 3 and 4 political sub-criterion can be considered as the most probable and impacted factor, on the other hand owner sub-criterion can be considered the lowest probable and impacted factor

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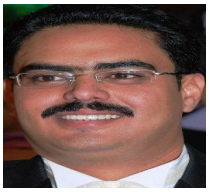

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