DECISION SUPPORTING SYSTEM FOR RISK ASSESSMENT IN CONSTRUCTION PROJECTS: AHP-SIMULATION BASED TECHNIQUE

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ABSTRACT

Unpredicted risk factors may occur through project execution, which lead to increase in the overall budget and duration. These risk factors may be due to site conditions, resources, project parties…etc. Some researchers developed their researches concerning the time contingency or cost contingency or both of them. This paper presents a model for assessing cost and time contingencies. The model presented here depends on Analytical Hierarchy Process (AHP). In the new formulation both cost and schedule overruns, and risk response will be taken into consideration simultaneously to decrease cost and time contingency. Results showed that cost and schedule overruns can be defined as normal probability distribution with a mean value of 34.5% and 37.9%, respectively. On the other hand, if risk response taken into consideration these values are reduced to 15.4% and 9.1%, respectively.

A Sensitivity analysis was carried out to investigate the impact of changing input: attributes and sub-criterions on the model output values (% change in schedule and cost overruns).The main contributions were: the two attributes, management strategy and unexpected surface conditions have 16.51%, and 13.83% impact on cost overrun and schedule overrun for best case scenario when risk response considered. On the other hand, for sub-criterions: owner, and site location these values are 9.86% and -9.47% on cost overrun for best case scenario and on schedule overrun for worst case scenario when risk response considered.

Validation of the developed model using three case study projects revealed that the model assess cost and schedule overruns with an accuracy of 91%. This value demonstrates that the obtained results are fairly good and acceptable.

Keywords: cost overrun, schedule overrun, probability, AHP, analytic hierarchy process, score, weight.

INTRODUCTION

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.

Due to the unique nature of construction projects, cost overrun and schedule overrun 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 (Touran, 2003). 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. The overall objective of the presented research in this paper is to develop a model that predicts cost overrun and schedule overrun percentage for construction projects in Egypt.

BACKGROUND

Time-delays and cost overruns are among the most common phenomena in the construction industry (Koushki, et al. 2005).There is no standard definition of contingency in which it could imply different meanings to estimators, contractors, and owners' organizations (Moselhi, 1997). Contingency is probably the most misunderstood, misinterpreted, and misapplied word in project execution (Patrascu, 1988). It is an amount of money or time (or other resources) added to the base estimated amount to achieve a specific confidence level or allow for changes where experience shows obligation (AACE, 2000). It can also be defined as the budget that is set aside to cope with uncertainties during construction (Touran, 2003) or the amount of money/time needed above the estimate to reduce the risk of overruns of project objectives to an acceptable level within the organization (PMI, 2013).

Smith and Bohn (1999) estimated the contingency as 5-10% of the contract value. On the other hand, Touran (2003) estimated two values of cost contingency: (1) 15% for underground construction activities and tunneling and (2) 7.5% for the rest of the project. Park and Pena-Mora (2004) estimated time contingency as 20% of the project duration.

Time contingency has been used to assure the completion time of a project and provide a degree of confidence that the planned duration can be successfully accomplished (Park and Pena-Mora, 2004; Mullholland and Christian, 1999; Barraza, 2011; COBRA, 2006). Kanoglu, (2003) stated that overruns of project time was common in construction projects. Illsley (2006) stated that, in the industrial sector, there were several project scheduling software such as Primavera, Microsoft Project, Risk Expert, etc. These software provided quantitative and qualitative analyses of project information, which were used to give a clearer picture of the true cost and time scale of any project considering risk, penalties, and complex scheduling variables.

MODEL CRITERIA, SUB-CRITERION AND ATTRIBUTES

Table 1 describes the proposed criteria, sub-criterions and attributes/risk factors in addition to the overall objective which is quantification of cost and schedule overruns.

RESEARCH METHODOLOGY

Figure.1 shows the detailed steps utilized to perform the various activities of the present research. Factors that affect cost and schedule overruns are identified and discussed using literature review and experts opinion. This process was discussed in details in El-Nawawy et. al (2015). A standard methodology is adopted in the current research in developing the proposed model as presented in table 1. The model used the collected data through questionnaires conducted by El-Nawawy et. al (2015) to develop the probability distribution using crystal ball software, concerning the attributes likelihood, cost impact and schedule impact.

The output charts developed by crystal ball software are imported by Microsoft excel 2010 spread-sheets to build the matrices. Each matrix describes the relation weights with respect to each sub-criterion, in order to be utilized by Analytic Hierarchy Process (AHP). The same procedure was applied to the relations between sub-criterion themselves, to develop the overall criteria matrices which will be transferred also to the AHP.

To increase model accuracy the AHP analysis will be applied for demonstrating the attributes cost impact weights, three loops will be run. The first one will utilize the mean values collected from the questionnaires; the second loop will utilize the minimum values while the final loop will utilize the maximum values. Therefore the optimistic and the pessimistic percentages can be achieved to determine the cost impact range.

Similarly, the schedule impact was developed using the same procedure to achieve the optimistic and the pessimistic percentages through three loops. After building the model, based upon the previous procedure, sensitivity analysis is then conducted to determine the factors that mostly affecting cost and schedule overruns. Finally, the developed model is validated to test its robustness in assessing cost and schedule contingencies.

MODEL DEVELOPMENT

The collected was gathered in Excel spreadsheets to build the hierarchy analytical process (AHP) methodology. The purpose is to evaluate attributes ranking and develop the relation matrices. These matrices will evaluate the relation between attributes in the same sub-criterion in addition to the evaluation between the sub-criterions themselves. For increasing the matrices consistencies, Expert choice 2000 software was utilized to best fit the matrices and reaches the optimum inconsistency ratio (CR) which should be close to zero (Saaty, 1982). The best fitting matrices will be transferred to MS. Excel to complete the AHP procedure and evaluate the weight of each attribute. The same procedure will be applied to determine the weight of each sub-criterion which will be identified as Score.

The weight of each attribute is multiplied into its sub-criterion score to converting its percentage from local weight to global weight. Equation no.1 will be used for multiplying the attribute global weight by its probability; this process will be iterated for all remaining attributes. The summation of the results will define the cost overrun index. On the other hand, the same methodology will be applied to schedule impacts to quantify the schedule overrun index.

With respect to enhancing the model efficiency, risk response will be taken into consideration to optimize the results.

$$C = \sum_{i}^{n} W_i \, x \, S_i \, x \, P_i \qquad (1)$$

Where C = cost overrun index or schedule overrun index for the project; n = number of attributes; W_i= weight of attribute i; S_i= score of sub-criterion itself i; and P_i=probability of occurrence of attribute i.

Pair-Wise Comparison Matrices Structure

The AHP technique is utilized as a platform to assess weights (W_i) of the intended attributes, then, assess scores (S_i) of the intended sub-criterions using the output values of the collected data and probability of occurrence (P_i). The previous procedure is iterated twelve times, considering three concerning minimum, maximum and mean values for each of cost overrun and schedule overrun *without* risk response. Also, concerning minimum, maximum and mean values for each of cost overrun and schedule overrun *with* risk response will be considered. These values will be used for determine the optimistic and pessimistic anticipated overruns.

Sub-criterion scores are determined using the pair-wise comparison matrix within the main criteria. These scores should sum to 1.0. Similarly, the local weights of attributes within each sub-criterion are determined using the pair-wise comparison matrix among these sub-criterions. They also should relatively sum to 1.0 among the specific sub-criterion. Then, the relative weight of each attribute is determined by multiplying the score of sub-criteria by the local weight of this attribute. The global weight (i.e. relative weight) should also sum to 1.0 for the entire list of factors (71 attributes). After determining the weights, the collected pair-wise comparison matrices are tested for consistency in order to ensure the robustness of the calculated relative weights scores of factors.

The AHP model has been widely used and applied in different engineering and management fields of theory and practice (Saaty, 1982; Al-Barqawi, 2006; Saaty,1991). It has been applied in multi-criteria decision making, planning and resource allocation, conflict resolution, and prediction problems (Saaty,1982; Saaty, 1991).Therefore, the AHP is used in the present research to assess the weights of various factors that affect cost and schedule overruns through pair-wise comparison matrices. These matrices have several important characteristics as shown in Tables 2, 4, and 5, while Table 3 shows the scale of preference between two elements.

The maximum eigen value (λ_{max}) for each matrix (see Eq. 2) is used as a reference index to calculate the consistency ratio (*CR*) of the required vector (Saaty,1982). The purpose is to validate whether the pair-wise comparison matrix provides a completely consistent evaluation. The eigenvector is a direct representation of the relative weights among the attributes in each considered matrix (Marzouk and Moselhi, 2003). The consistency ratio can be calculated using Eq.(s) 3 and 4 as follows:

$$\lambda_{max} = \sum \text{of eigenvectors per each matrix/size of matrix (n)} \qquad (2)$$

$$CR = CI / RI \qquad (3)$$

Where RI is known as random consistency index obtained from a large number of simulation runs and varies upon the order of the matrix. Table 6 shows values of RI for matrices of order1 to 10 (Saaty, 1982). CI is the consistency index for a matrix of order n and can be calculated as in Eq.4:

$$CI = (\lambda_{max} - n) / (n-1) \qquad (4)$$

The acceptable CR range depends on the size of the matrix (see table 7). If the value of CR is within the acceptable range, then this implies that the evaluation within the matrix is acceptable; otherwise, inconsistency of judgment had taken place.

Best Fitting of Matrices Consistency

As previous, the obtained consistency may be out of range given by Table 7, which means that matrix consistency is rejected. Applying the AHP process and reaching the optimum consistency which should be close to zero or within ranges given in table.7 is a mandatory requirement. Expert choice 2000 software is used; As an example, Fig.3a shows that the consistency range is 0.12 more than the acceptable range. Therefore, the matrix consistency is refused and should be best fitted. On the other hand, Fig. 3b demonstrates that the consistency range is 0.00, which means that the matrix consistency is optimum and best fitted. It must be noted that Expert choice 2000 software is very useful to apply AHP methodology taking into consideration the process will be iterated several times as mentioned before.

Re-export of Data and Risk Response

After best fitting of all sub-criterions and criteria matrices and reaching the optimum consistency, all matrices will be re-exported to MS. Excel to complete the assessment. It's important to note that this process will be repeated twelve times to enhance the results. The local weight of each attribute (Wi) and the score of each sub-criteria (Si) will be calculated and checked to insure the summation of each group equal to one. The data collected by the previous steps without risk response will be referred as proposed cost overrun and proposed schedule overrun which will be high and more than 30% (see Table 8 and 9). To increase the accuracy and modify the output to be more logic and close to the actual projects feedback, risk response will be utilized. Also, the collected output will be identified as planned mean cost overrun and planned mean schedule overrun which is around 16% and 9% respectively (see Table 8 and 9).

The risk response will be divided into four actions, (1) "avoid" means that the attribute impact is taken into consideration in the direct cost and the project schedule and doesn't need to consider as a risk factor, (2) "accept" means that the attribute cost impact or schedule impact will be taken as same as its initial value, (3) "mitigate" means that the attribute impact will be reduced to specific values may be to the minimum or another percentage, it depends on how to mitigate the assigned factor, (4) "transfer" means that the responsibility of such factor will be transferred from one party to another. This is as per using of insurance company, back to back subcontract agreement, transfer of some responsibilities to the client himself. Here; the factor impact can't be taken as zero value but may be has some effect due to supervision or its effect on the relations and internally cooperation in the project.

MODEL IMPLEMENTATION

The above explained steps are utilized for implementing the developed model and performing the intended analysis. Table 8 shows a brief for the collected data using mean values for probability of occurrence, score of sub-criterion and weight of attributes. This table is repeated six times, three for cost overrun and three for schedule overrun. The first stage concerning mean values, while the second and third stages concerning minimum and maximum values, respectively.

Integrated AHP-Based Method Analysis and Application of Risk Response

For risk response, if the attribute impact will be avoided, the proposed value will be taken equal to zero, if the action will be accepted, the proposed value will be taken as same as its original value, if the action is mitigated, the proposed value will be reduced to its half value, if it's transferred, 12% only of its initial value will be taken. These values will be used to calculate the optimistic and the pessimistic overruns to help the top management to decide the right decision for cost and time contingency percentages.

The user may be optimistic based on presence of opportunities, the importance of tender acquisition and the level of competition. On the other hand, the user may be pessimistic based on high level of qualifications (know how), or short listed of special contractors, or some troubles may occur during execution of project.

Sensitivity Analysis

Sensitivity analysis is carried out to investigate the impact of changing input attributes/risk factors on the model output values (percentage of change in schedule and cost overruns).The analysis is performed in two-steps procedure: firstly, changing one attribute at a time, and secondly, changing a set of attributes that belong to a single sub-criterion. The estimated percentage of change in cost and schedule overruns is calculated as per Eq. 5.

$$\%\ Change = [Oi - O_r / O_i] \qquad (5)$$

Where Oi is the cost or schedule overrun for a certain scenario and Or is the schedule or cost overrun for the reference scenario.

The first step is conducted by setting the value of the attribute (under consideration) at its boundary limits (i.e. worst and best scenarios) while considering the remaining attributes at their threshold values. Mean values can be considered as threshold values. On the other hand, worst case scenario can be considered as maximum values, in addition best case scenario can be considered as minimum values. The proposed values (without risk response) of cost overrun and schedule overrun will be calculated. Also, the planned values (risk response is considered) will be calculated. The percentage change in cost or schedule overrun in worst-case scenario (proposed and planned) and best-case scenario (proposed and planned) taking into consideration a single attribute at a time. Eight charts need to be illustrated, four concerning cost overrun and four concerning schedule overrun, but due to limited space; one example will be presented, Fig.11 illustrates the percentage of change in cost overrun versus attributes based on worst case scenario and Planned state. Table 10 presents the highest and least impact of attributes variation on cost and schedule overrun.

The second step of the sensitivity analysis is conducted by setting the values of a set of attributes (that belong to a single sub-criterion) at their boundary limits (i.e. worst and best case scenarios) while considering the remaining attributes at their threshold values. The purpose of this step is to observe the impact of a single sub-criterion change at a time. The percentage change in cost or schedule overrun in worst and best case scenarios (considering a single sub-criterion at a time). As previously eight charts need to be illustrated , four concerning cost overrun and four concerning schedule overrun, but due to limited space two examples will be presented. Fig. 9 illustrates the percentage of change in schedule overrun versus sub-criterion based on best case scenario and planned state. On the other hand, Fig. 10 illustrates the percentage of change in cost overrun versus sub-criterion based on worst case scenario and proposed state. Table 11 presents the highest and least impact of sub-criterion variation on cost and schedule overrun.

MODEL VALIDATION

In order to validate the precision of predicted cost contingency and time contingency index using the developed model, data are collected from experts and projects database regarding planned and actual cost. Also, planned finish dates and delays in their previous construction projects. Table 12 shows the data collected for three huge construction projects in details in order to compare with the developed model. Table 13 shows the results. The results revealed that the percentage of overrun error between actual data and model output is ± 9% approximately for cost and schedule.

CONCLUSIONS

Estimating cost and scheduling contingencies are major factors in achieving a successful and realistic budget and schedule for construction projects. In the current research, factors that affect budget and time contingency obtained from surveys in previous research are used. The obtained data are processed to assess factors' weights, using the Analytic Hierarchy Processes (AHP). Then a model is developed to predict cost and schedule overruns. Results show that cost and schedule overruns can be defined as normal probability distribution with a mean value of 34.5% and 37.9%respectively. On the other hand, if risk response taken into consideration these values will be reduced to 15.4% and 9.1% respectively.

A Sensitivity analysis was carried out to investigate the impact of changing input: attributes/risk factors on the model output values (% change in schedule and cost overruns). Also, the impact of changing each sub-criterion was performed. This analysis was carried out for worst and best case scenarios. Each scenario was performed when risk response is considered and without risk response. The results revealed that the highest effect for attribute: management strategy (16.51%) on cost overrun for best case scenario when risk response considered. Also, unexpected surface conditions (13.83%) on schedule overrun for best case scenario when risk response considered. On the other hand, the highest effect for sub-criterion: owner (9.86%) on cost overrun for best case scenario when risk response considered. Also, site location (-9.47%) on schedule overrun for worst case scenario when risk response is considered. The developed model was validated using three case study projects, which show robust results in assessing cost and schedule overruns with average value of 91%. This value demonstrates that the obtained results are fairly good and acceptable.

REFERENCES

AACE (2000). "AACE international's risk management dictionary." Cost Engineering, 42(4), 28–31.

Al-Barqawi, H. A. (2006). *Condition Rating Models for Underground Infrastructure: Sustainable Water Mains*. Msc Thesis, Concordia University, Montreal, Quebec, Canada, Montreal, Quebec, Canada.

Barraza, G. (2011). "Probabilistic estimation and allocation of project time contingency." Journal of Construction Engineering and Management, 137(4), 259–265.

COBRA (2006). "The construction and building research. "Conference of the Royal Institution of Chartered Surveyors, London, United Kingdom.

El-Nawawy, O.A.M., Abdel-Alim, A.M.,and Bassiony, M.S. (2015) " Quantitative Risk Assessment of Factors Affecting Construction Projects" International Journal of Computer Science, Volume 3, Issue 3, March.

Illsley, R. (2006). Business Intelligence Pert master. Risk Expert, v7.8, Butler Group Subscription Services, New Jersey, United States.

Kanoglu, A. (2003). "An integrated system for duration estimation in design/build projects and organizations."Journal of Engineering, Construction and Architecture Management, 10(4), 272–282.

Koushki, P., Al-Rashid, K., and Kartam, N. (2005). “Delays and cost increases in the construction of private residential projects in Kuwait.” Construction Management and Economics, 23(3), 285–294.

Marzouk, M., and Moselhi, O. (2003). "A Decision Support Tool for Construction Bidding", Construction Innovation, Vol. 3, No. 2, pp. 111-124.

Moselhi, O. (1997). “Risk assessment and contingency estimating.” Transactions of the American Association of Cost Engineers.

Mulholland, B. and Christian, J. (1999). “Risk assessment in construction schedules.” Journal of Construction Engineering and Management, 125(1), 8–15.

Park, M. and Peña-Mora, F. (2004). “Reliability buffering for construction projects.” Journal of Construction Engineering and Management, 130(5), 626–637.

Patrascu, A. (1988). Construction Cost Engineering Handbook. Marcel Dekker, New York, United States.

PMI (2013). A Gide to the Project Management of Knowledge (PMBOK Guide) - Fifth Edition. Project Management Institute, Pennsylvania, United States.

Saaty, T. (1982). Decision Making for Leaders: The Analytic Hierarchy Process for Decision in a Complex World. Lifetime Learning Publications, Belmont, California, United States.

Saaty, T. (1991). Decision Making with Dependence and Feedback: The Analytic Network Process. RWS Publications, Pittsburgh, Pennsylvania, United States.

Smith, G. and Bohn, C. (1999). “Small to medium contractor contingency and assumption of risk.” Journal of Construction Engineering and Management, 125(2), 101–108.

Touran, A. (2003). “Calculation of contingency in construction projects.” IEEE Transactions on Engineering Management, 50(2), 135–140.

Table 1: Proposed Analytical Hierarchy Process (AHP) – Model

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

Table 2: Typical pair-wise comparison matrix for different attributes

Attribute	a_1	a_2	a_3	a_4
a_1	1	a_{12}	a_{13}	a_{14}
a_2	a_{21}	1	a_{23}	a_{24}
a_3	a_{31}	a_{32}	1	a_{34}
a_4	a_{41}	a_{42}	a_{43}	1
Column summation	T_1	T_2	T_3	T_4

Table 3: Scale of preference between two elements (Saaty,1982)

Rank	Definition	Explanation
1	Equally preferred	Two activities contribute equally to the objectives
3	Moderately preferred	Experience and judgment slightly favor one activity over another
5	Strongly preferred	Experience and judgment strongly or essentially favor one activity over another
7	Very strongly preferred	An activity is strongly favored over another and its dominance is demonstrated in practice
9	Extremely preferred	The evidence favoring one activity over another is of the highest degree possible of affirmation
2,4,6,8	Intermediate values	Used to represent compromise between the preferences listed above
Reciprocals	Reciprocals for inverse comparisons	

Table 4: Relative matrix

Attribute	a_1	a_2	a_3	a_4	Row total	Row average
a_1	$1/T_1$	a_{12}/T_2	a_{13}/T_3	a_{14}/T_4	S_1	avg_1
a_2	a_{21}/T_1	$1/T_2$	a_{23}/T_3	a_{24}/T_4	S_2	avg_2
a_3	a_{31}/T_1	a_{32}/T_2	$1/T_3$	a_{34}/T_4	S_3	avg_3
a_4	a_{41}/T_1	a_{42}/T_2	a_{43}/T_3	$1/T_4$	S_4	avg_4

Table 5: Corresponding matrix

Attribute	a_1	a_2	a_3	a_4	Row total	eigenvector
a_1	$1x\ avg_1$	a_{12} x avg_2	a_{13} x avg_3	a_{14} x avg_4	SS_1	SS_1/avg_1
a_2	a_{21} x avg_1	1 x avg_2	a_{23} x avg_3	a_{24} x avg_4	SS_2	SS_2/avg_2
a_3	a_{31} x avg_1	a_{32} x avg_2	1 x avg_3	a_{34} x avg_4	SS_3	SS_3/avg_3
a_4	a_{41} x avg_1	a_{42} x avg_2	a_{43} x avg_3	1 x avg_4	SS_4	SS_4/avg_4

Table 6: Average RI based on matrix size Adopted from (Saaty,1982)

Size of matrix (n)	Random consistency index (RI)
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Table7: Acceptable ranges for CR (Saaty,1982)

Size of matrix (n)	Consistency ratio
3	0.05
4	0.08
≥ 5	0.10

Table 8: Probability of occurrence, local weight of attributes cost impact and score of sub-criterions cost impact using mean values

Sub-criterion score (S_i)	Attributes/risk factor	Attribute cost impact local weight (W_i)	Attribute Probability of occurrence (P_i)	Proposed mean cost overrun% S_i x W_i x P_i	Risk response	Planned mean cost overrun%
Environmental 9.6%	Earthquake	9.0%	16.7%	0.14%	avoid	0.00%
	Precipitation /flood	3.3%	29.4%	0.09%	avoid	0.00%
	Unpredicted Weather conditions	76.7%	46.4%	3.41%	mitigate	1.71%
	Pollution	10.9%	40.3%	0.42%	accept	0.42%
Sub-surface 6.8%	Unexpected Surface conditions	14.9%	48.2%	0.49%	accept	0.49%
	Archeological survey done	74.5%	27.6%	1.40%	mitigate	0.70%
	Geo-technical investigation	10.6%	40.9%	0.29%	mitigate	0.15%
Site location 2.4%	Construction area (rural/urban)	1.4%	57.3%	0.02%	mitigate	0.01%
	Access conditions	7.2%	40.3%	0.07%	mitigate	0.03%
	On-site congestion	7.2%	42.1%	0.07%	mitigate	0.04%
	Delay in permits and licenses	36.9%	33.0%	0.29%	accept	0.29%
	Security requirements	3.2%	34.8%	0.03%	accept	0.03%
	Safety regulation	28.8%	50.0%	0.35%	accept	0.35%
	Differing site conditions	15.2%	46.4%	0.17%	accept	0.17%
Labor 9.6%	Labor skills level	29.4%	34.8%	0.98%	accept	0.98%
	Labor availability	6.8%	33.0%	0.22%	accept	0.22%
	Drop in Labor productivity	8.9%	38.5%	0.33%	mitigate	0.16%
	Labor accidents	1.8%	34.8%	0.06%	transfer	0.01%
	Human resource planning	44.3%	34.8%	1.48%	avoid	0.00%
	Working hours restrictions	8.9%	52.4%	0.45%	avoid	0.00%
Equipment 21.9%	Equipment quality	10.0%	34.8%	0.76%	avoid	0.00%
	Equipment breakdown	50.2%	34.8%	3.83%	mitigate	1.01%
	Equipment maintenance	29.8%	18.5%	1.21%	mitigate	1.01%
	Equipment malfunctions	10.0%	34.8%	0.76%	transfer	0.00%
Material 4.5%	Material delivery	8.9%	33.0%	0.13%	transfer	0.02%
	Material storage	17.6%	29.4%	0.23%	accept	0.23%
	Material theft & damage	9.8%	29.4%	0.13%	transfer	0.02%
	Material procurement	2.5%	43.9%	0.05%	mitigate	0.02%
	Non-conforming material	9.8%	29.4%	0.13%	avoid	0.00%
	Material monopoly	49.0%	31.2%	0.69%	avoid	0.00%
	Nominated vendors	2.4%	43.9%	0.05%	avoid	0.00%
Owner 28.0%	Owner type	42.0%	33.0%	3.88%	avoid	0.00%
	management strategy	14.0%	25.8%	1.01%	accept	1.01%
	organization structure	14.0%	25.8%	1.01%	accept	1.01%
	Work/labour permits	28.0%	33.0%	2.59%	avoid	0.00%
	on-site access	2.0%	42.1%	0.24%	mitigate	0.12%
Engineering and Design 1.1%	Team experience	10.8%	40.3%	0.05%	avoid	0.00%
	Project goal	2.7%	36.7%	0.01%	mitigate	0.01%
	Complexity of design	15.1%	33.0%	0.05%	avoid	0.00%
	Ad-hoc consultants	60.5%	40.9%	0.27%	avoid	0.00%
	Design error	10.8%	25.8%	0.03%	transfer	0.00%

Table 8: Probability of occurrence, local weight of attributes cost impact and score of sub-criterions cost impact using mean values (Continued)

Sub-criterion Score (S_i)	Attributes/risk factor	Attribute cost impact local weight (W_i)	Attribute Probability of occurrence (P_i)	Proposed mean cost overrun% S_i x W_i x P_i	Risk response	Planned mean cost overrun%
Contractor	Contractor pre-qualified	5.2%	51.8%	0.04%	avoid	0.00%
1.6%	New technology	5.2%	59.7%	0.05%	avoid	0.00%
	Defective work	1.3%	34.8%	0.01%	accept	0.01%
	Rework	5.2%	25.8%	0.02%	accept	0.02%
	no of subcontractors	26.1%	45.2%	0.19%	accept	0.19%
	Contractor Reputation	23.9%	36.7%	0.14%	avoid	0.00%
	Nominated sub-contractors	6.8%	43.9%	0.05%	avoid	0.00%
	no. of current projects	26.1%	25.8%	0.11%	avoid	0.00%
Project	Management experience	2.3%	40.3%	0.02%	avoid	0.00%
management	Owner quality assurance	29.3%	46.4%	0.33%	accept	0.33%
2.4%	Scope definition	10.7%	46.4%	0.12%	avoid	0.00%
	quality control process	41.5%	46.4%	0.46%	accept	0.46%
	Type of contract	7.0%	38.5%	0.06%	accept	0.06%
	availability of variations	9.1%	44.5%	0.10%	avoid	0.00%
Financial	Type of Funds	0.7%	29.4%	0.01%	transfer	0.00%
4.6%	Fluctuation in prices	1.7%	48.2%	0.04%	accept	0.04%
	Invoices delay	18.7%	50.0%	0.43%	accept	0.43%
	Change in currency rate	3.3%	51.8%	0.08%	accept	0.08%
	Owner financial capacity	8.6%	36.7%	0.15%	accept	0.15%
	Progress payment	10.4%	36.7%	0.18%	accept	0.18%
	rate of interest	1.6%	48.2%	0.04%	accept	0.04%
	tax rate	3.3%	51.8%	0.08%	mitigate	0.04%
	foreign currency	46.3%	29.4%	0.63%	mitigate	0.31%
	project size	5.5%	48.2%	0.12%	mitigate	0.06%
Political	Bribery and Corruption	77.1%	63.3%	0.34%	accept	0.34%
0.7%	Wars and revolutions	9.2%	42.1%	0.03%	avoid	0.00%
	Military coup	4.6%	33.0%	0.01%	avoid	0.00%
	Changes in laws and regulations	9.2%	53.6%	0.03%	transfer	0.00%
Schedule	Fast track schedule	25.0%	51.8%	0.88%	avoid	0.00%
6.8%	Project duration	75.0%	36.7%	1.87%	accept	1.87%
100%	Summation			34.49%		15.40%

Table 9: Summary of results concerning EC2000 best fit calculations

Proposed mean cost overrun%	34.5%	Proposed mean schedule overrun%	37.9%
Planned mean cost overrun%	**15.4%**	**Planned mean schedule overrun%**	**9.1%**
Proposed min. cost overrun%	10.0%	Proposed min. schedule overrun%	10.0%
Planned min. cost overrun%	**4.2%**	**Planned min. schedule overrun%**	**3.2%**
Proposed max. cost overrun%	76.3%	Proposed max. schedule overrun%	40.3%
Planned max. cost overrun%	**37.3%**	**Planned max. schedule overrun%**	**8.9%**

Optimistic cost overrun %	9.8%	Optimistic schedule overrun %	6.2%
Pessimistic cost overrun %	26.3%	Pessimistic schedule overrun %	9.0%
Using PERT technique %	17.2%	Using PERT technique %	8.1%

Table 10: Highest and least impact of attributes variations on cost and schedule overruns

			Highest Impact		Least Impact	
			Attribute	% Change	Attribute	% Change
Worst case scenario	Cost overrun	Proposed	Equipment breakdown	-2.17%	Unpredicted Weather conditions Type of Funds	0.00%
		Planned	Owner type	9.62%	Unexpected Surface conditions Type of Funds	0.00%
	Schedule overrun	Proposed	Pollution	-0.44%	Nominated vendors availability of variations	0.00%
		Planned	Delay in permits and licenses	-12.57%	Many factors as per Bribery and Corruption	0.00%
Best case scenario	Cost overrun	Proposed	Earthquake	-4.57%	Material monopoly	-0.001%
		Planned	management strategy	16.51%	Ad-hoc consultants	-0.006%
	Schedule overrun	Proposed	Earthquake	-2.13%	Access conditions	-0.009%
		Planned	Unexpected Surface conditions	13.83%	Many factors as per Wars and revolutions	0.00%

Table 11: Highest and least impact of sub-criterion variations on cost and schedule overruns

			Highest Impact		Least Impact	
			Sub-criterion	% Change	Sub-criterion	% Change
Worst case scenario	Cost overrun	Proposed	Equipment	1.20%	Environmental	-0.04%
		Planned	Owner	7.55%	Engineering and Design	0.29%
	Schedule overrun	Proposed	Financial	-0.70%	Project management	-0.02%
		Planned	Site location	-9.47%	Political	0.00%
Best case scenario	Cost overrun	Proposed	Environmental	-2.12%	Project management	0.02%
		Planned	Owner	9.86%	Political	0.004%
	Schedule overrun	Proposed	Environmental	-1.05%	Labor	0.04%
		Planned	Owner	5.25%	Political	0.00%

Table 12: Information concerning the three actual case study projects

Description	Project-1	Project-2	Project-3
Name	Tina-Abu sultan gas pipeline	Port Said East container Terminal Phase-2	Al-Arish – Taba Gas pipeline
Scope of work	of 32”/60 km steel PL	EPC of terminal and buildings	Construction only of 36”/254 km steel PL
Client	GASCO	Suez canal container terminal	East Gas Company
Type of project	Not FIDIC, Unit rates	FIDIC, Lump sum	Not FIDIC, Lump sum
Location	Ismailia	Port said	Sinai
Price in US$	9,728,685	164,869,316	45,269,440
Planned cost	7,958,064	147,887,777	35,672,319
Actual cost	8,772,651	156,834,988	38,533,239
Planned start date	26/9/2005	12/9/2009	31/3/2002
Actual start date	14/9/2005	23/9/2009	13/4/2002
Planned duration (months)	12	32.7 (140 weeks)	12
Actual duration (months)	13.2	34.9	12.8

Table 13: Summery of comparison results between actual projects and developed model outputs

Description	Project -1	Project -2	Project -3
Planned finish date	25/9/2006	29/5/2012	30/3/2003
Actual finish date	14/10/2006	4/8/2012	18/4/2003
Duration calendar days	365	980	365
Delay in days	31	67	19
% delay (Actual Time Contingency)	8.49%	6.84%	5.21%
Planned cost US$	7,958,064	147,887,777	35,672,319
Actual cost US$	8,772,651	156,834,988	38,533,239
Variance in cost US$	814,587	8,947,211	2,860,920
% cost variance(Actual Cost Contingency)	10.24%	6.05%	8.02%
%Predicted Time contingency by developed model	7.74%	6.33%	5.73%
% Predicted Cost Contingency by developed model	9.35%	6.62%	8.61%
% *schedule overrun* error between actual data and model output	8.83%	7.46%	-9.98%
% *cost overrun* error between actual data and model output	8.69%	-9.42%	-7.36%

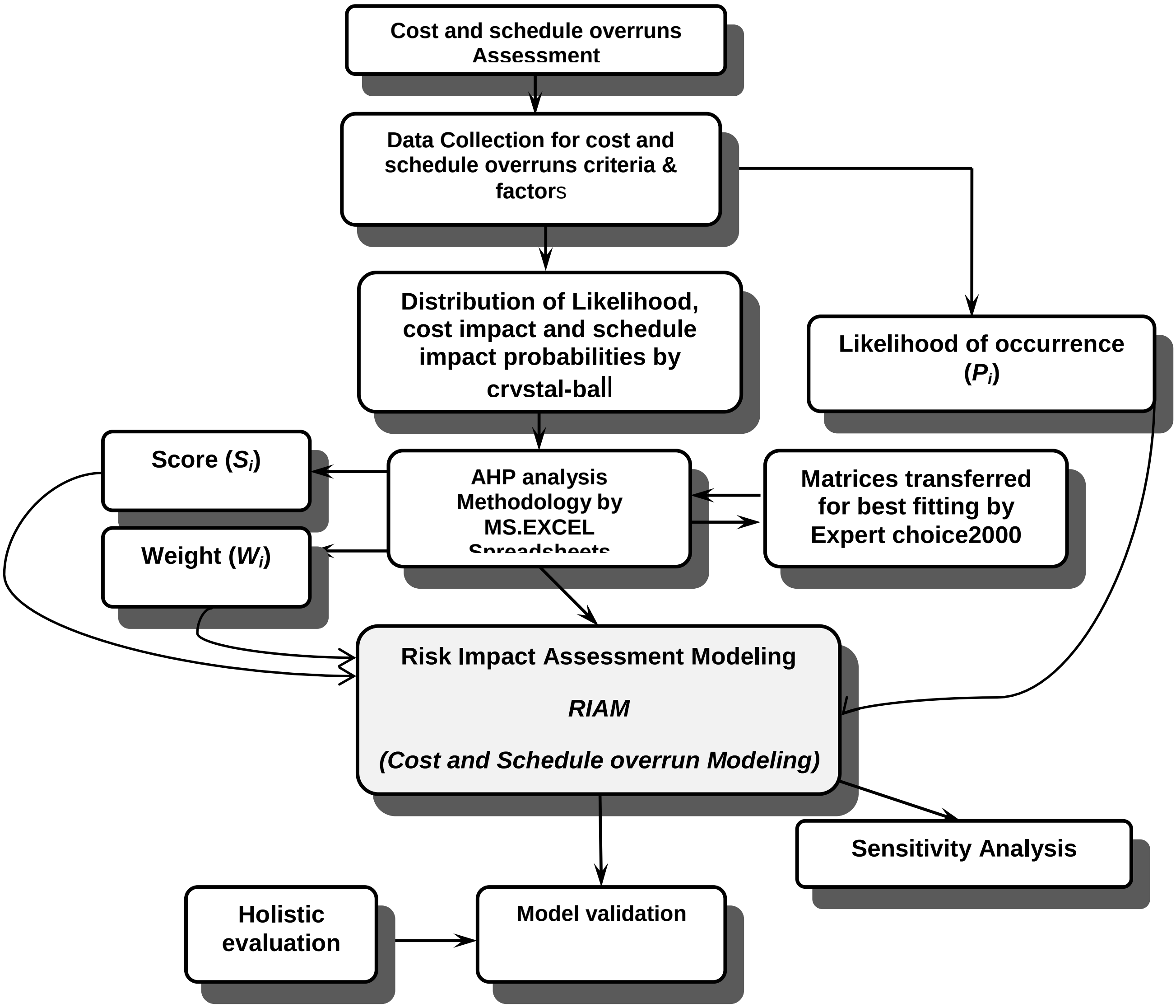


Figure 1: Research Methodology

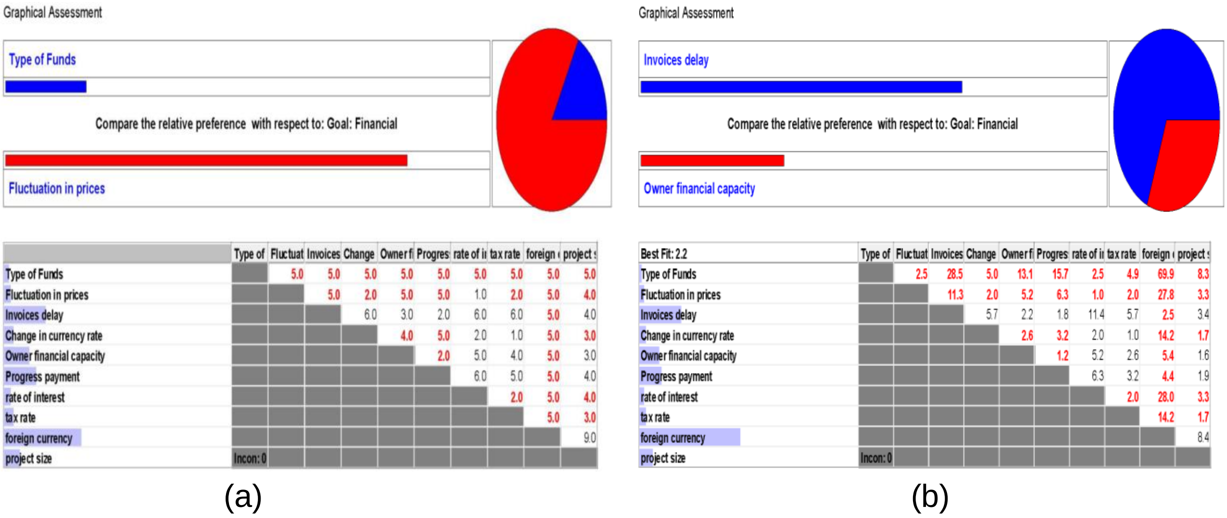
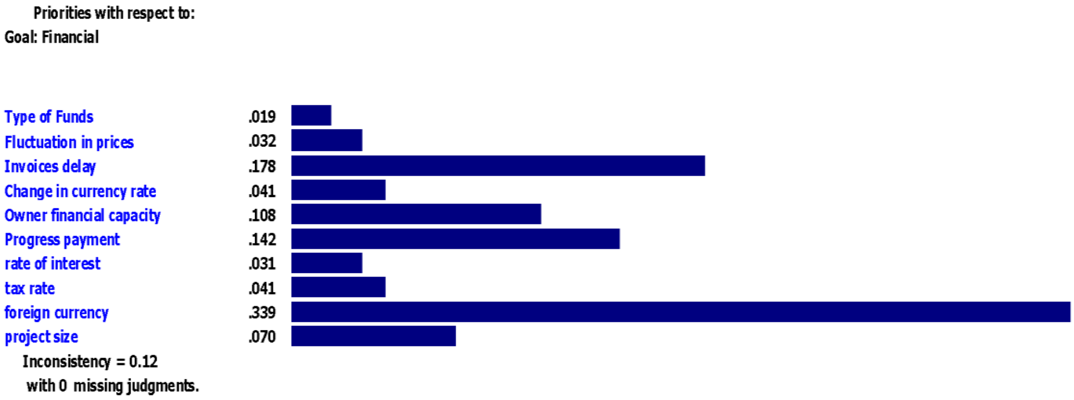
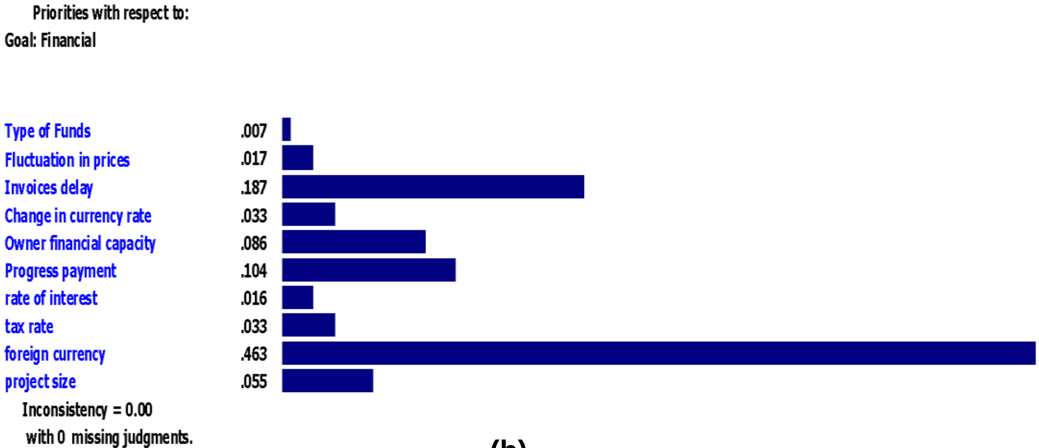


Figure 2: Example of cost overrun by AHP application for FINANCIAL sub-criterion matrix
a) **without best fit** **b) after best fitting**

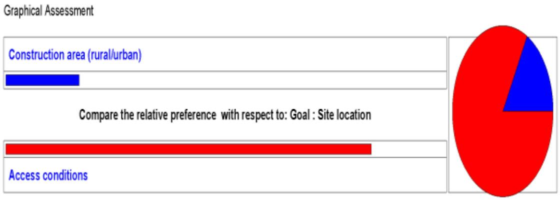


(a)



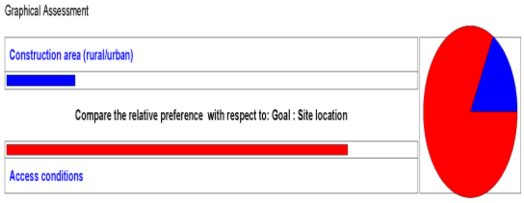
(b)

Figure 3: Calculation of row average and consistency range CR for FINANCIAL sub-criterion
a) without best fit **b) after best fitting**



	Constru	Access	On-site	Delay in	Security	Safety r	Differing
Construction area (rural/urban)		5.0	5.0	5.0	2.0	5.0	5.0
Access conditions			2.0	5.0	8.0	4.0	3.0
On-site congestion				5.0	8.0	4.0	3.0
Delay in permits and liecenses					11.0	5.0	6.0
Security requirments						5.0	5.0
Safety regulation							2.0
Differing site conditions	Incon: 0						

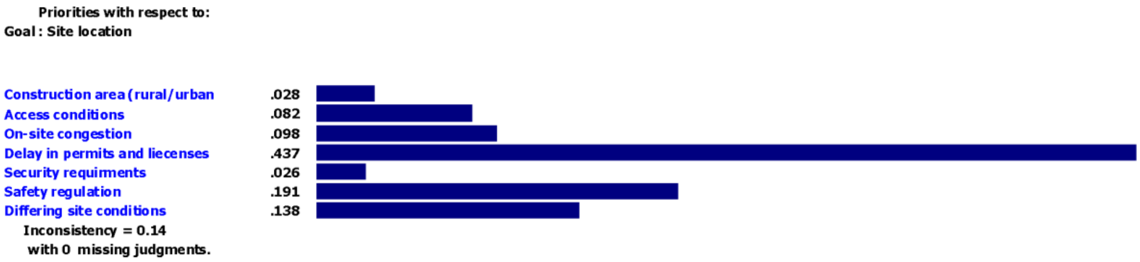
(a)



	Constru	Access	On-site	Delay in	Security	Safety r	Differing
Construction area (rural/urban)		5.0	5.0	25.6	2.2	20.0	10.6
Access conditions			1.0	5.1	2.3	4.0	2.1
On-site congestion				5.1	2.3	4.0	2.1
Delay in permits and liecenses					11.7	1.3	2.4
Security requirments						9.1	4.8
Safety regulation							1.9
Differing site conditions	Incon: 0						

(b)

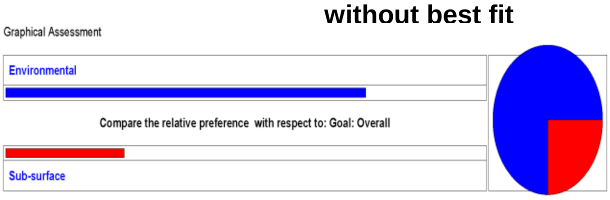
Figure 4: Example of cost overrun by AHP application for Site location Sub-criterion matrix; a)without best fit b) after best fitting



(a)

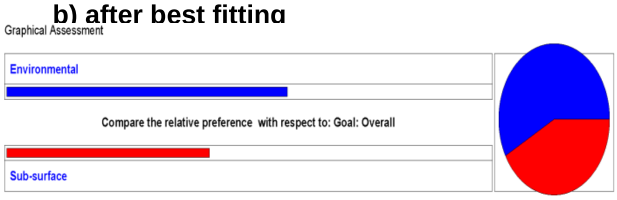
(b)

Figure 5: Calculation of row average and consistency range CR for SITE LOCATION Sub-criterion without best fit b) after best fitting



	Environ	Sub-sur	Labor	Material	Owner	Equipm	Contrac	Site loca	Financia	Enginee	Political	Project	Schedul
Environmental		3.0	2.0	4.0	5.0	3.0	5.0	4.0	3.0	6.0	9.0	4.0	3.0
Sub-surface			3.0	3.0	5.0	4.0	4.0	3.0	2.0	5.0	8.0	3.0	2.0
Labor				4.0	5.0	3.0	5.0	4.0	3.0	6.0	9.0	4.0	3.0
Material					5.0	5.0	3.0	2.0	2.0	4.0	7.0	2.0	2.0
Owner						3.0	8.0	7.0	7.0	10.0	11.0	8.0	6.0
Equipment							7.0	6.0	5.0	8.0	10.0	6.0	5.0
Contractor								2.0	3.0	3.0	5.0	2.0	4.0
Site location									2.0	4.0	6.0	2.0	3.0
Financial										5.0	7.0	2.0	2.0
Engineering and Design											4.0	4.0	5.0
Political												5.0	5.0
Project management													3.0
Schedule	Incon: 0												

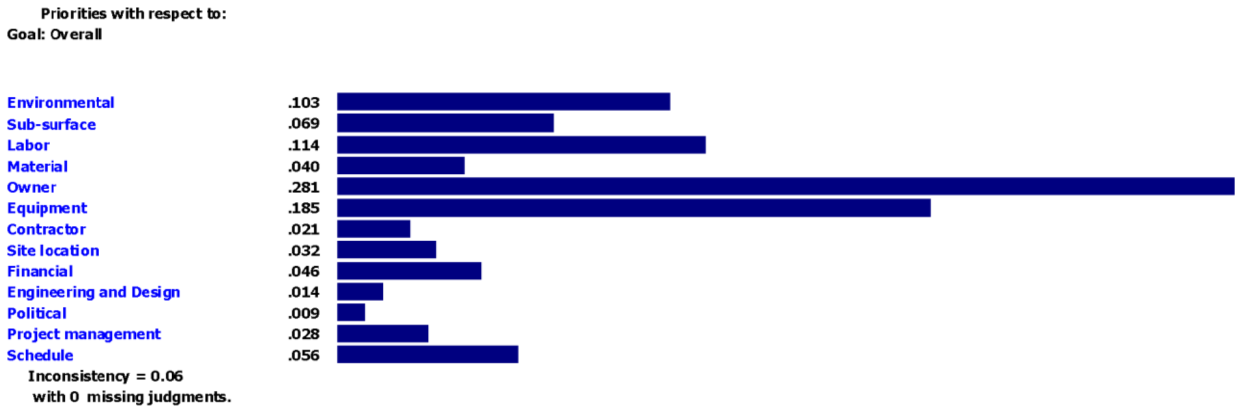
(a)



	Environ	Sub-sur	Labor	Material	Owner	Equipm	Contrac	Site loca	Financia	Enginee	Political	Project	Schedul
Environmental		1.4	1.0	2.1	2.9	2.3	5.9	4.0	2.1	8.4	14.5	4.0	1.4
Sub-surface			1.4	1.5	4.1	3.2	4.2	2.9	1.5	6.0	10.4	2.9	1.0
Labor				2.1	2.9	2.3	5.9	4.0	2.1	8.4	14.6	4.0	1.4
Material					6.2	4.8	2.8	1.9	1.0	4.0	6.9	1.9	1.5
Owner						1.3	17.2	11.7	6.1	24.6	42.5	11.7	4.1
Equipment							13.5	9.2	4.8	19.3	33.3	9.1	3.2
Contractor								1.5	2.8	1.4	2.5	1.5	4.2
Site location									1.9	2.1	3.6	1.0	2.9
Financial										4.0	7.0	1.9	1.5
Engineering and Design											1.7	2.1	6.0
Political												3.6	10.4
Project management													2.9
Schedule	Incon: 0												

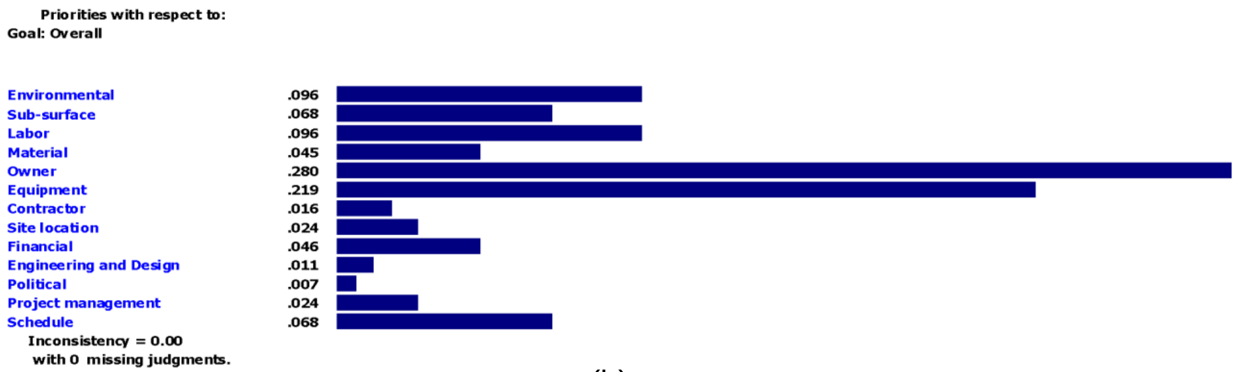
(b)

Figure 6: Example of cost overrun by AHP application for OVERALL criteria matrix a) without best fit b) after best fitting



(a)

Model Name: Overall



(b)

Figure 7: Calculation of row average and consistency range CR using Expert choice 2000 for Overall criteria

a) without best fit b) after best fitting

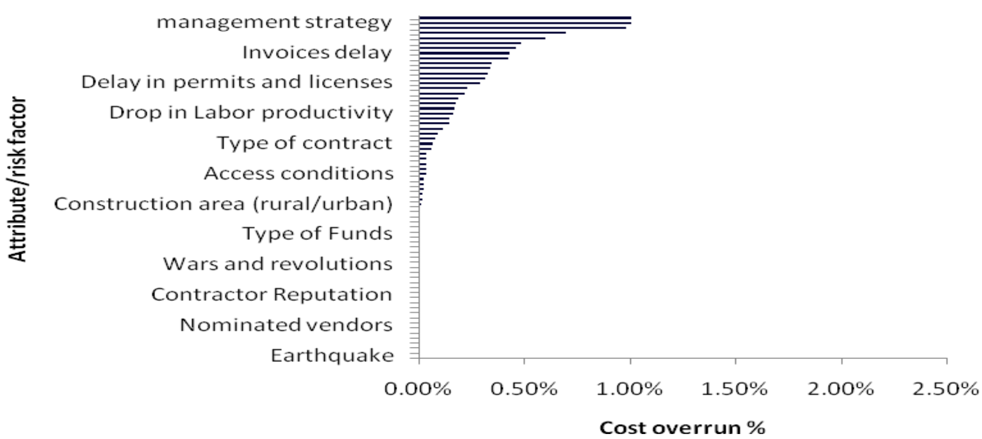


Fig.8: Planned Cost overrun Tornado Chart (with risk response)

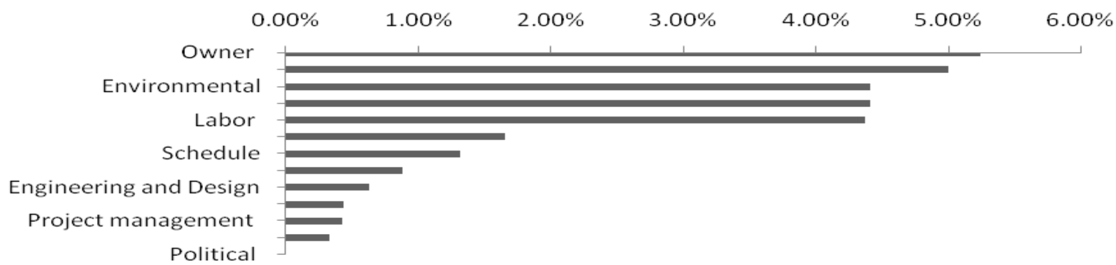


Figure 9: Percentage of change in schedule overrun versus sub-criterion (Planned state/best case scenario)

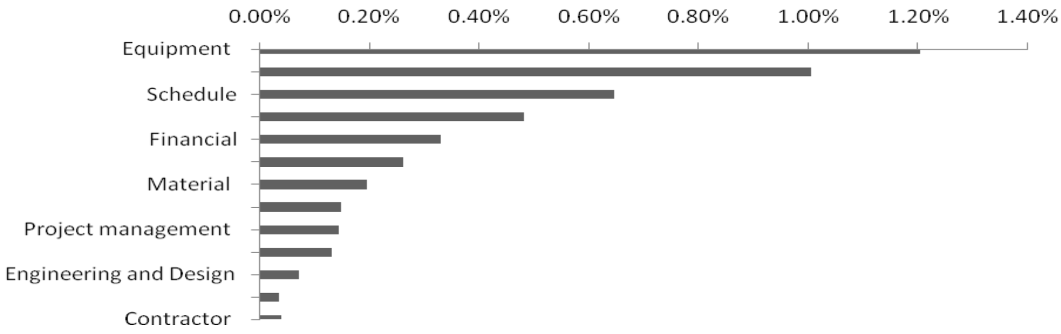


Figure 10: Percentage of change in cost overrun versus sub-criterion (Proposed state/worst case scenario)

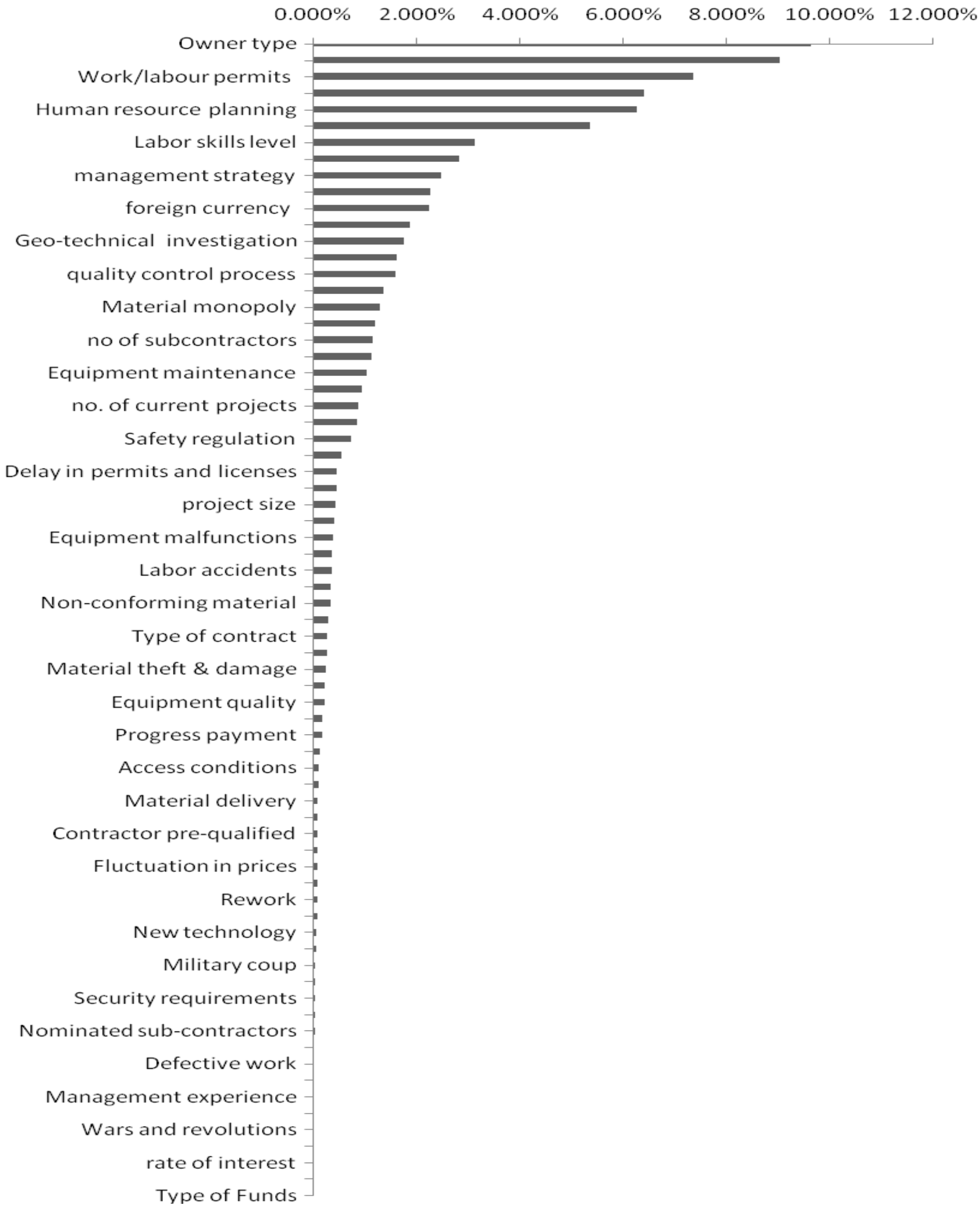


Figure 11: Percentage of change in cost overrun versus attributes (Planned state/worst case scenario)