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PARTNER PERFORMANCE EVALUATION PROBLEM FOR CONSTRUCTION PROJECTS

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ABSTRACT

A team of contractors with varied specializations collaborate in construction projects. Each member's performance determines the success of these projects. These collaborations' competitiveness can be jeopardized if indications of how partners perform are not determinable. This is attributable to stepwise nature of human evaluations. Few research works have investigated techniques for evaluating contractors' performance. This study defined partners performance evaluation problem (PaPEP) in the construction sector as a multi attribute represented in a hierarchical structure. Analytical Hierarchy Process (AHP) a Multi-Criteria Decision Making (MCDM) algorithm was designed and used by different project consultants to evaluate the performance of partners to implement a mechanical engineering works for a building. Six case study groups were used to verify the results. PaPEP is a MCDM problem, solvable using AHP. Using AHP, it has been shown how evaluation preference and consensus can be attained if a group decision-evaluation process is used in the PaPEP. It can be stated that AHP can be incorporated in the design and development of new techniques for the PaPEP for construction projects. AHP algorithm can be used when evaluators' judgements is precise.

Keywords: Multi Criteria Decision Making (MCDM), Analytical Hierarchy Process (AHP), Partners Performance Evaluation Problem (PaPEP), Performance Prediction

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INTRODUCTION

Kenya has a well-developed building and construction industry with quality engineering, building and architectural design services readily available. The construction industry is a key sector in Kenya economy and has consistently posted the second highest growth (Kenya Economic survey, 2013). The industry also offers direct employment to a significant proportion of the labour force spread throughout the country (Kenya National Bureau of Statistics [KNBS] Report, 2016).

Construction industry contributes more than 10% to the country's economy (Kenya Economic Survey, 2016). The sector has a challenge of poor performance. Some projects upon completion do not last long (Mambo, 2010; Charagu, 2013). This is partly due to non deterministic nature of partners' performance. The project initiator cannot predict the performance of partners and therefore unable to put in place contingency measures to avert any crisis. Contractor attributes to be considered for performance evaluation cannot be approximated. Partner performance evaluation is a multi-criteria decision making problem with multiple performance criteria and sub-criteria. The problem needs a multi-criteria performance evaluation technique solution.

PREVIOUS WORKS

In the construction industry, time overruns and cost overruns are major performance evaluation issues (Kaming et al., 1997; Choudhury & Phatak, 2004; Olawale & Sun, 2010). For a successful construction project, time and cost efficiency of partners is important. If partners accomplish their tasks in good time and at reasonable costs, then the overall project will be considered efficacious. There are many causes of time and cost overruns of construction projects. Majority of the available literature on this subject examines the time and cost overruns of projects, without indicating how partners' activities influence these time and cost overruns.

Time overruns and causes

Time overruns is defined as the extension of time beyond planned completion dates traceable to the contractors (Kaming et al., 1997). Chan (2001) and Choudhury & Phatak (2004) defined time overruns as the difference between the actual completion time and the estimated completion time. Delays in projects are those that cause the project completion date to be delayed (Al-

Gahtani & Mohan, 2007). Factors related to time overruns vary with types of project, location, size and scope of project. Kaming et al. (1997) identified 5 causes of time overruns through a questionnaire survey in Indonesian high rise construction projects. These were: design changes, poor labour productivity, lack of adequate planning, shortage of materials and inaccuracy of material estimates. Kaming et al. (1997) do not explicitly state, if contract modification, lack of personnel experience and sometimes quality requirements, lead to more time spent in executing the project. Chan and Kumaraswamy (1997) reported five principle causes of time overruns, perceived among contractors, clients and consultants in Hong Kong construction projects. They included: poor site management and supervision, unforeseen ground conditions, delay in decision making, client initiated variations and design changes.

Frimpong et al. (2003) carried out a questionnaire survey in Ghana groundwater construction projects and ranked 26 factors responsible for project delays and cost overruns. The factors included, among others, planning and scheduling deficiencies, delays in work approval, inspection and testing of work, frequent breakdowns of construction plant and equipment, escalation of material prices, slow decision-making and difficulties in obtaining construction materials at official current prices. Kendall's coefficient of concordance (Cheng et al., 2010) was used to test the degree of agreement between owners, contractors and consultants and concluded that there was insignificant degree of disagreement. The five most important factors as agreed by owners, contractors and consultants as main causes of time and cost overruns were: monthly payment difficulties from agencies, poor contractor management, material procurement, poor technical performances and escalation of material prices.

Aibinu and Jagboro (2002) examined the effects of delay on the delivery of construction projects in Nigeria. Acceleration of site activities coupled with improved owner's project management procedures and inclusion of an appropriate contingency allowance in the pre-contract estimates were recommended as a means of minimizing the adverse effects of construction delays. These recommendations do not envisage scenarios where contractors, owners or consultants would require modifying the project requirements due to new development or unforeseen requirements, which might not have been factored in pre-contract estimates.

In addition, personnel experience which is critical in any construction project is not factored. Odeh and Battaineh (2002) studied the causes of construction delay at traditional contracts in Jordan. The study illustrated that labour productivity was the most important delay factor according to contractors. Inadequate contractor's experience, however, was the most important delay factor to consultants. Koushki et al. (2005) also identified estimates of time overruns and their causes. The three main causes of time overruns are changing orders, owner's financial constraints and owner's ignorance in construction issues. Both studies exclude the quality requirement of the project as a factor which may delay the project completion time.

Doloi et al. (2012) identified the key factors impacting delay in the Indian construction industry. They established the critical attributes for developing prediction models for the impact of these factors on delay. Regression modelling and factor analysis were used to examine the significance of the delay factors. The most critical factors of construction delay were identified as lack of commitment, inefficient site management, poor coordination in site, improper planning, lack of clarity in scope of project, lack of communication from factor analysis. The regression model indicated slow decision making from owners, poor labour productivity and architects' reluctance to change and / or rework mistakes in construction were the reasons that affected the overall delay of the project. These factors were also evidenced by Mambo (2010) in addition to accessibility to the project's site especially when the site is located in towns.

Shanmugapriya and Subramanian (2013) investigated the significant factors influencing time overruns in Indian construction projects. They observed 76 factors of time overruns and grouped them in to 12 major groups. Hierarchical assessment of factors was carried out to determine ranking of the factors based on the significance. This was based on Relative Importance Index (RII), calculated for each group of respondents i.e. contractors, consultants and owners and overall respondents. Their survey showed that the top 5 most significant factors of time overruns ranked by overall respondents were, change in material market rate (attributable to various reasons such as change in materials price in the market or unavailability of materials in the market), contract modification (the modification of the contract would lead to the project delay due to the addition of new work and replacement to the project requirements), higher level of quality requirement (to produce a higher quality product, requires more than the estimated time), project location (difficult to transport materials and equipment to a site) and placing overall responsibility on inexperienced personnel (takes more time on a project compared to the experienced ones).

Considering time overruns, this study observes that that most important factors applicable in Kenya are contract modification, required quality, personnel experience and site location. Contract modification entails everything to do with changes occasioned by either, project owners, contractors or consultants. Required quality is about the decisions by project owners demanding that project is executed with highest standards possible, which requires that more time is used to achieve the same. For personnel, the more experienced the contractors, consultants and other officers, the less time it takes to complete a project and vice versa. Finally, the location of the project determines the accessibility of personnel and materials to the site, affecting the project completion time. Among these factors, the ones that affect partners' performance are contract modification, required quality of the product and personnel experience. Site location is often beyond partners' control.

Cost overruns and causes

Cost overrun is defined as excess of actual cost over budget. Cost overrun is also referred to as cost escalation, cost increase, or budget overrun. Choudhry & Phatak (2004) defined the cost overrun as the difference between the original cost estimate and actual construction cost on completion of a construction project. In a study of infrastructure projects in Nigeria (Omoregie & Radford, 2006), it was found that the major factors of cost overruns were fluctuations in prices, financing and payments made for completed works, inefficient contract management, delays in schedule, changes in site condition, inaccurate estimates, shortages of materials, delay in imported materials, additional works, changes in design, subcontractors and nominated suppliers, adverse weather conditions, non-adherence to contract conditions, mistakes and disagreements in contract condition and fraudulent practices. Similarly, in Vietnam, Le-Hoai et al. (2008) found that the top 5 significant factors causing cost overruns in large construction projects were inadequate site management and supervision, lack of project management support, owner’s financial difficulties, contractors' financial difficulties and changes in design.

A study on UK's construction industry, Olawale and Sun (2010) identified 21 major factors causing cost overruns as changes in design, risk and uncertainty associated with projects, inaccurate evaluation of projects time and cost, non-performance of subcontractors, complexity of works, conflict between project parties, disagreements in contract documentation, contract and specification interpretation disagreement, inflation of prices, financing and payment, lack of proper training and experience of project manager, low skilled manpower, unpredictable weather condition, dependency on imported materials, lack of appropriate software, unstable interest rate, fluctuation of currency/exchange rate, weak regulation and control, projects fraud and corruption and unstable government policies.

Shanmugapriya & Subramanian (2013) investigated the significant factors influencing cost overruns in Indian construction projects. They observed 54 factors of cost overruns and grouped them in to 8 major groups. Hierarchical assessment of factors was carried out to determine ranking of the factors based on level of significance. It was assessed based on Relative Importance Index (RII) value, calculated for each group of respondents i.e. contractors, consultants and owners and also the overall respondents. The survey showed that the top 5 most significant factors of cost overruns ranked by overall respondents are high transportation cost (attributed to the long distance of the site from the market and high rent of the vehicles), change in material specification (change in the contract causes change in material specification which affects material costs) and escalation of material price, frequent breakdown of construction plants and equipment, rework (rework of sections of the project increases the cost).

The following factors can be enumerated as the main ones causing cost overruns: repeat job, personnel charges rate change, market rate change, material price change, equipment breakdown and change in transport cost. Among these factors, repeat job and change in charge rate are within partners' control while the rest are beyond partners' control but affects the overall project performance. Factors within partners' control should be managed well to attain cost effectiveness.

A Multi Criteria Hierarchical Evaluation Technique

Many research studies have analyzed and solved multi-criteria decision making problems using multi-level analysis of alternatives. Analytical Hierarchy Process (AHP) (Saaty, 1980) is a

MCDM algorithm that uses pairwise comparisons of alternatives to derive weights of importance from a multi-level hierarchical structure of objectives, criteria, sub-criteria and alternatives depending on the problem. In cases where the comparisons are not perfectly consistent, AHP provides an uncomplicated method for improving the consistency of the comparisons, by using the Eigenvalue method and consistency checking method (Saaty, 1980).

The hierarchical structure fits well with the structure of partner performance evaluation problem. Cheng et al. (1999) identified the shortcomings of AHP as follows: (i) It is used in nearly crisp (exact) decision applications, (ii) Does not take into account any uncertainty associated when mapping human judgement to a number scale, (iii) The subjective assessment of decision makers, and change of scale have great influence on the AHP outcome. Furthermore, Wang et al. (2008) found out that the increase in the number of characteristics geometrically increases the number of pairwise comparisons by $O(n^2/_2)$ which can lead to inconsistency or failure of the algorithm. Furthermore, AHP cannot solve non-linear models (Cheng et al., 1999).

Another weakness of AHP identified by Mikhailov (2003) is that it cannot be used when judgements are considered to be uncertain. In practice, human evaluation can sometimes be vague. The factors that contribute to ambiguity/fuzzy/uncertainty of judgements are: (i) lack of sufficient information about the problem domain, (ii) incomplete information, (iii) lack of methods for data validation, (iv) changing nature of the problem, (v) lack of appropriate scale. Zadeh (1963), Mikhailov (2003) and Covella and Olsina (2006) suggested the use of fuzzy logic to deal with subjectivity of the evaluators. Mikhailov (2003) argues that the best way to solve uncertain judgement is to express it in terms of fuzzy sets or fuzzy numbers (Mikhailov, 2003). In an attempt to address the shortcomings of AHP, Mikhailov (2003) introduced fuzzy logic in AHP. Fuzzy logic (Zadeh, 1963) deals with a continuum of variables and best addresses uncertainty and vagueness in input variables, in order to make rational decisions under such conditions. Fuzzy logic is derived from fuzzy set theory that has proven advantages within fuzzy, imprecise and uncertain decision situations and is an abstraction of human reasoning in its use of approximate information and uncertainty to generate decisions (Zadeh, 1965). It implements grouping of data with boundaries that are not sharply defined. Fuzzy logic is considered the best method compared to deterministic approaches, algorithmic approaches, probabilistic approaches and machine learning (Ahmad et al., 2004) for problems that users are not certain of the value of parameters to use.

Partners' performance evaluation outcome can be approximated and therefore can be considered certain. AHP analyses how the alternative solutions satisfy the sub-objectives and how sub-objectives influence objectives of the problem. This is done by computing local weights for alternatives in all levels of the hierarchy.

METHODOLOGY

The research methodology was hybrid, employing a combination of theoretical and empirical work. Literature review provided the theoretical part while the industrial case scenarios provided the empirical part. This combination seemed suitable as the theoretical approach helped consider a holistic view of construction projects and the empirical approach ensured that the ideas that were developed based on the theoretical approach were applicable in the construction industry.

Using mixed research methods brings out both qualitative and quantitative aspects of the topic under study. In this study, qualitative evaluation methods were used during data collection because of their usefulness in providing detailed information and rich description of phenomena in a short time.

Using a combined research approach, the disadvantages of each of the methods used can be minimized and their advantages maximized. Dubé and Paré (2003) argue that a "multi-method approach to research involves several data collection techniques, such as interviews and documentation, organized to provide multiple but dissimilar data sets regarding the same phenomena". Further, mixed methods are used when researchers want to avoid "being carried away by vivid, but false, impressions in qualitative data, and it can bolster findings when it corroborates those findings from qualitative evidence".

Partners' performance evaluation was done after the partners had been selected. Once the team was formed, performance evaluation was conducted on the partners. A suitable team of partners was selected using AHP but any other appropriate technique could be used. In order to evaluate performance of partners, the following steps were applied. (1) Identification of the performance evaluation criteria, (2) Selection of the performance evaluation method, (3) Performance prediction and (4) Performance monitoring (Petersen & Matskin, 2003; Tolle, 2004). First, the criteria for evaluating partners' performance were determined. They represented the desired level of performance of the collaboration. The second step required the selection of the performance evaluation method to be used for evaluating performance of partner companies. Third, the partners performance was predicted and the final step was partners' performance monitoring. It was determined that partners' performance monitoring was a continuous process.

Partner Performance Evaluation Criteria

Focus group interview was conducted with 80 evaluators to establish the performance evaluation criteria used for evaluating partners implementing construction projects tasks. Additionally, a questionnaire (in the appendix) was given to the evaluators to indicate their preference of one company over another by examining their profiles. The questionnaire was used to indicate level of importance of each criteria (time and cost) against each other in the performance evaluation process.

The identified criteria were corroborated with the criteria from existing literature. Performance evaluation criteria from evaluators were categorized. Specific categories identified were: Contract modification (CM), quality requirement (RQ), site location accessibility (SL), personnel experience (PE), change in material market rate (MR), material price change (PC), equipment breakdown (EB), rework/repeat job (RJ), change in transport cost (TC) and change in personnel charge rate (PR). These categories were further classified into two general categories, time and cost. Time as a general category comprised CM, RQ, SL and PE. These factors could affect the expected project completion time while factors like MR, PC, PC, RJ, TC and PR could affect the project cost.

Selection of Performance Evaluation Method

Second, partners' performance evaluation technique was identified. AHP method was used because performance evaluation problem could be hierarchically structured and performance evaluation values could be approximated with a degree of certainty. Figure 1 shows the hierarchy used for this process. Time and cost were identified as evaluation criteria. This hierarchical representation allows determination of the influence of lower levels elements of the hierarchy on the higher level elements. For example, how a change in material cost affect the overall project cost and how contract modification influence the time the project takes to complete.

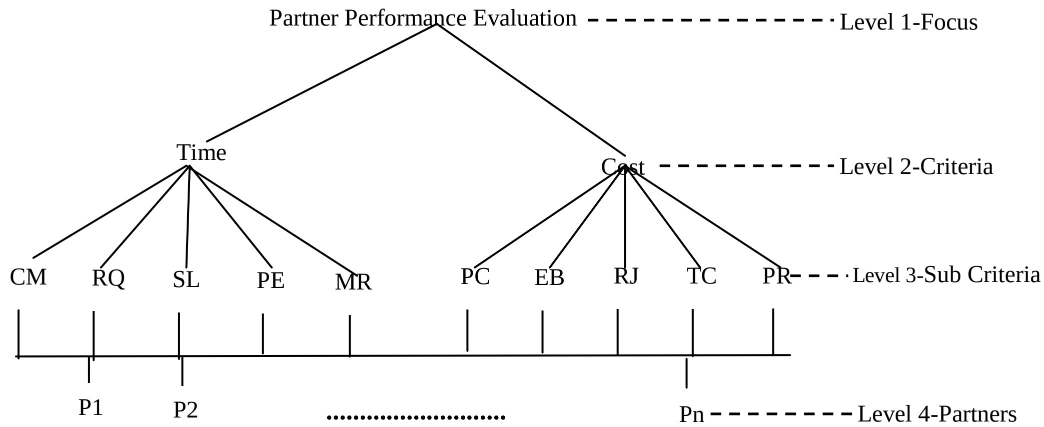

Figure 1: Hierarchy of the partner performance evaluation problem

The Analytical Hierarchy Process

AHP method uses pairwise comparisons of values assigned by evaluators to alternatives (criteria, sub criteria and partners) in a multi-level hierarchical structure to derive their relative weights (Saaty, 1980). The hierarchical structure fits well with the hierarchical structure of performance evaluation problem. According to Saaty (1980), AHP algorithm has the following steps: (1) Define the problem and state its goal/objectives; (2) Decompose the complex problem into a hierarchical structure of alternatives; (3) Employ pairwise comparisons and form pair-wise comparison matrices; (4) Use the Eigenvalue method to estimate the relative weights; (5) Check the consistency of decision judgements; (6) Aggregate the relative weights to obtain the overall rating for alternatives. Figure 2 summarizes the steps of AHP.

According to Vila & Beccue (1995) and in the context of this study, the first step for AHP is to decompose a problem into a number of hierarchical levels. At the highest level, the objectives are placed, then performance evaluation criteria and sub criteria are at the next two levels and partners are at the lowest level of the hierarchy. Each of the alternatives is normally associated with a weight that indicates its significance in relation to other alternatives.

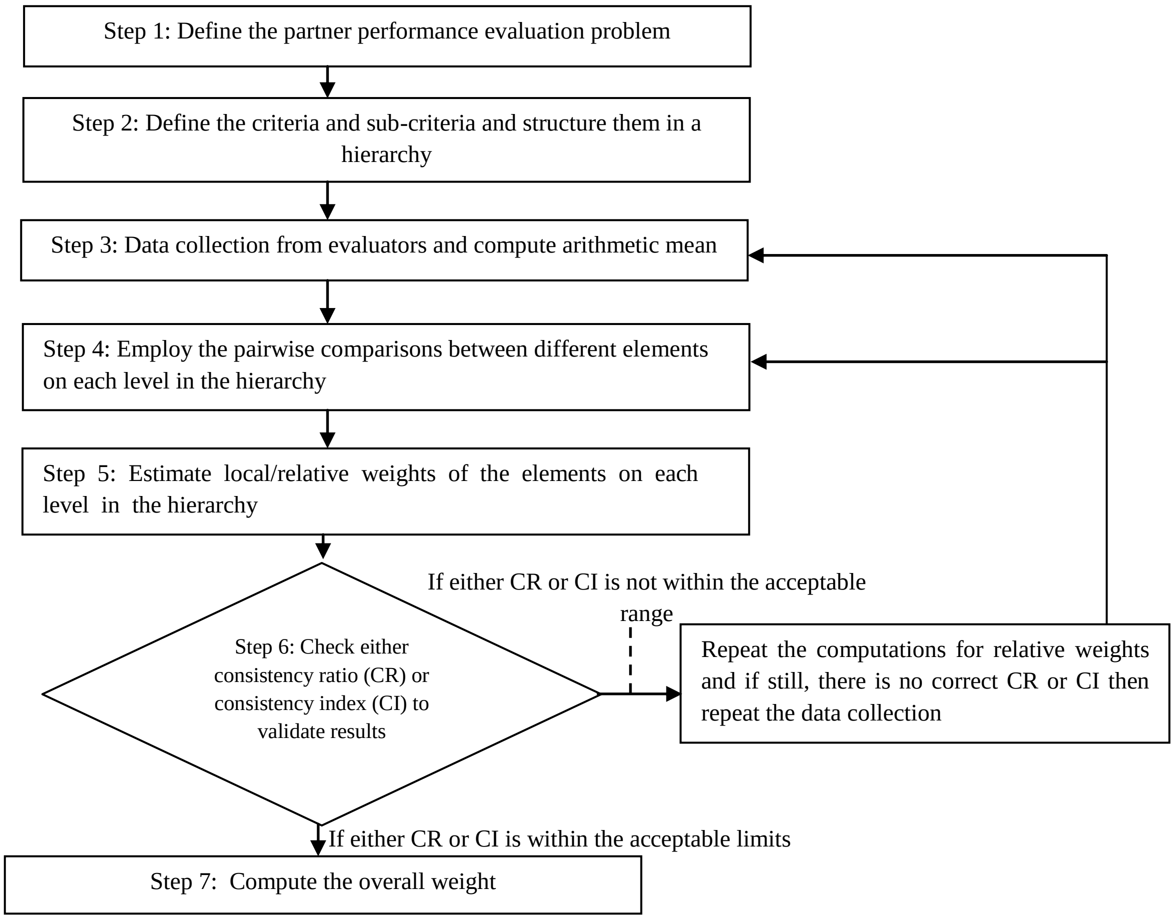

Figure 2: Steps of AHP

Evaluators give their opinions on the importance of alternatives. From these opinions local and global weights are derived.

Local weights are relative weights of each alternative. Computation of relative weights is performed through pairwise comparison of the alternatives, using the Saaty nine-point scale (Table 1). This results in so called, pairwise comparison matrices (PCM) of alternatives at the same level in the hierarchy.

Table1: Saaty scale (Saaty, 1980)

Definition	Level of importance
Equal importance	1
Moderate importance over one another	3
Essential or strong importance	5
Very strong or demonstrated importance	7
Absolute importance	9
Intermediate values between adjacent scales	2, 4, 6, 8

Saaty (1980) proposes that alternatives can be assigned a crisp (exact) value to show how important an alternative is viz a viz others. For example, if two alternatives have equal importance, each is assigned the numerical value 1 and if one alternative have moderate importance over the other, then it is assigned a numerical value 3. If one alternative is strongly or essentially important than another, it is assigned value 5, while value 7 is assigned to an alternative that has very strong or demonstrated importance over another. If an alternative is absolutely important than another, it is assigned numerical value 9. Saaty (1980) proposes the Eigenvalue method to compute pairwise comparison matrix and relative local weights.

Computation of local and global weights

To achieve this requirement, evaluators results using AHP is established. Aggregated/averaged (arithmetic mean) rating of time and cost by evaluators was 9 and 7 respectively. If another set of evaluators were invited, possibly another set of different values would be found. In Table 2 the values of the comparison matrix of time against itself is 9/9 which is 1, while time weighed against cost is 9/7=1.29. In the same manner the weight of cost against time is 7/9 = 0.78.

Table 2: PCM for performance Evaluation criteria

Performance criteria	Time	Cost	Priority Vector	Local Weight
Time	1	1.29	0.56	0.56
Cost	0.78	1	0.44	0.44
Sum	1.78	2.29	1.00	1.00

Table 2 is normalized and priority vector values of time and cost are 0.56 and 0.44 respectively. Normalization is achieved by dividing the PCM value by the sum of its column. For example, PCM for time against itself is 1 and the sum of its column is 1.78. Its normalized value (NV) is 1/1.78=0.56 while NV for cost/time is 0.78/1.78=0.44. NV for time/cost is 1.29/2.29=0.56 while NV for cost/cost is 1/2.29=0.44. Local weight (LW) of an alternative is computed by finding the arithmetic mean of NVs of the alternative in a row. For that matter, LW of time is (0.56+0.56)/2=0.56. Likewise LW of cost is 0.44. Time factor has the highest local weight attributable to the fact that, change in project completion time affects the cost of the project. It can be stated that varying completion time consequently affects the total cost of the project.

To determine if the data collected from evaluators were consistent, maximum approximate Eigen value, λ_{max}, is calculated by finding the sum of the products of priority vector values of criterion in Table 2 and respective totals of the column of PCM values for the respective criterion in the same table. In this case λ_{max}= 0.56 x 1.78 + 0.44 x 2.29 =2.0. Saaty (1980) suggests that Consistency Index (CI) of a matrix of order n is (λ_{max}-n)/(n-1) and values are consistent if CI $\leq$ 0.1. In this case, n=2 and CI=$^{(2-2)}/_{1}$ = 0. This process is repeated for other levels of the hierarchy.

The aggregated responses for the time criterion sub-criteria from evaluators were 9, 7, 3, 7, 5 for CM, RQ, SL, PE and MR respectively. Normalized Reciprocal PCM and priority vectors for time sub criteria is as in Table 3.

Table 3: Normalized reciprocal PCM for Time Sub Criteria and Priority vector

Sub criteria	CM	RQ	SL	PE	MR	Priority Vector
CM	0.29	0.29	0.39	0.22	0.29	0.296
RQ	0.23	0.23	0.30	0.23	0.37	0.272
SL	0.10	0.14	0.13	0.10	0.07	0.108
PE	0.23	0.18	0.04	0.17	0.11	0.146
MR	0.16	0.16	0.13	0.28	0.16	0.178

λmax = 0.296 x 3.45 + 0.272 x 4.38 + 0.108 x 7.66 + 0.146 x 5.96 + 0.178 x 6.27 = 5.02606

CI = (5.02606-5) / (4) =0.006 and CR= CI/RI = 0.006/ 1.12 = 0.0054< 0.1 (i.e. consistent).

Similarly, the aggregated responses for the cost criterion sub-criteria were 9, 3, 7, 7, 5 for PC, EB, RJ, TC and PR respectively. Their normalized PCM and priority vectors are shown in Table 4.

Table 4: Normalized Reciprocal PCM and Priority Vector for Cost Sub Criteria

Sub criteria	PC	EB	RJ	TC	PR	Priority Vector
PC	0.30	0.49	0.19	0.22	0.29	0.299
EB	0.10	0.16	0.35	0.23	0.37	0.242
RJ	0.13	0.10	0.15	0.10	0.07	0.110
TC	0.30	0.13	0.05	0.17	0.11	0.152
PR	0.17	0.12	0.25	0.28	0.16	0.196

λmax = 0.298 x 3.32 + 0.242 x 6.09 + 0.110 x 6.62 + 0.152 x 5.96 + 0.196 x 6.27 = 5.32618

CI = (5.32618-5) / (4) =0.08 and CR= CI/RI = 0.006 / 1.12 = 0.073 < 0.1 (i.e. consistent).

Global weights are derived by merging/multiplying local weights of alternatives at lower levels in the hierarchy to local weights of alternatives in the parent levels in the hierarchy. Global weights for each sub criteria are shown Table 5.

Table 5: Relative Weights for the Partner Performance Evaluation Sub Criteria

Criteria	Local weight	Sub-criteria	Local weight	Global weight
		Contract Modification (CM)	0.296	0.166
		Level of Required Quality (RQ)	0.272	0.152
		Site Location Accessibility (SL)	0.108	0.060
Time	0.56	Personnel Experience (PE)	0.146	0.082
		Material Market Rate Change (MR)	0.178	0.100
		Market Price Change (PC)	0.299	0.132
		Equipment Breakdown (EB)	0.242	0.106
		Rework / Repeat Job (RJ)	0.110	0.048
Cost	0.44	Transport Cost Change (TC)	0.152	0.067
		Personnel Charge Rate Change (PR)	0.196	0.086

Global weight (GW) for CM is derived by multiplying local weight of Time criterion by local weight of CM that is 0.56 x 0.296 = 0.166; GW for EB is 0.44 x 0.242=0.106. Likewise GW for PC is 0.44 x 0.299=0.132.

Partners' performance prediction

This study suggests that computing "the product of global weights of partners' performance evaluation sub criteria (sub criteria that directly affects performance of partners i.e. CM, RQ, PE and RJ)" and "priority weights of selected partners" and finding their geometric mean can give a good indication of (approximately predict expected) partners' performance. Sub criteria like site location accessibility, market rate change, material price change, equipment breakdown and change in transport cost are beyond partners’ control but can affect the overall project performance.

This process helps predict expected approximate partners' performance. The study also suggests that expected partners’ performance can be computed based on each performance sub criterion. This is because different partners can perform differently on each performance sub criterion, resulting in different overall performance (i.e. when performances of partners on all performance sub criteria are combined).

For the partners’ performance sub criteria proposed (contract modification, required quality, personnel experience and repeat job with global weights of 0.166, 0.152, 0.082 and 0.048 respectively), they are relevant in the following ways: For contract modification, it is expected that a partner that does least modification performs better (lesser time and cost) than the one with most modifications. Likewise, best performing partner on required quality sub criteria, is the one which produces the highest quality product. In addition, partner with the highest personnel experience is expected to perform better (will take lesser time and cost) than others with lesser experience even as partners that do least repeat jobs would perform better (take lesser time and cost) than those that do most repeat jobs. CM sub criterion has the highest weight and therefore the most important sub criterion.

Given a pool of prospective partners who can implement a defined construction project task, like structural, electrical or interior design works, a hierarchical method like AHP (Saaty, 1980) or Fuzzy AHP (Mikhailov, 2003) can be used to evaluate and select the right partners for the task.

Suppose for a mechanical engineering works task in a building project, partners' evaluation and selection criteria were: business, technical and management. Business sub criteria were: financial security (FS), business strength (BS) and strategic position (SP); Technical sub criteria were: technical capability (TC), development speed (DS), cost of development (CD) and information technology (IT) and Management sub criteria were: collaboration record (CR), cultural compatibility (CC) and management ability (MA). For each sub criterion, 5 partners (partners 1 to 5 were evaluated) and one (1) was to be selected. Table 6 summarizes the results of this process.

Table 6: Results of Evaluators Data by AHP

Criteria	Local weight	Sub-criteria	Local weight	Global weight	P1	P2	P3	P4	P5
Business	0.391	FS	0.527	0.206	0.333	0.167	0.233	0.112	0.155
		SP	0.170	0.066	0.433	0.167	0.111	0.101	0.188
		BS	0.303	0.118	0.285	0.143	0.333	0.154	0.085
Technical	0.304	TC	0.379	0.115	0.188	0.250	0.167	0.274	0.121
		DS	0.214	0.065	0.129	0.375	0.115	0.122	0.259
		CD	0.286	0.087	0.250	0.150	0.368	0.211	0.021
		IT	0.121	0.037	0.133	0.267	0.267	0.194	0.139
Management	0.304	CR	0.496	0.151	0.367	0.333	0.211	0.022	0.067
		CC	0.188	0.057	0.200	0.100	0.066	0.289	0.345
		MA	0.316	0.096	0.100	0.400	0.315	0.179	0.006
				Priority Weight	0.264	0.233	0.229	0.150	0.122

Global weight (GW) for FS is 0.391 x 0.527 = 0.206, GW for TC is 0.304 x 0.379=0.115. Likewise GW for CC is 0.304 x 0.188=0.057. Finally priority weights (PWs) for partners are derived by finding the sum of products of global weights of each sub criterion and the local weight of the partner in the sub criterion. For instance PW for partner 1 is 0.206 x 0.333 + 0.066 x 0.433 + 0.118 x 0.285 +0.155 x 0.188 + 0.065 x 0.129 + 0.087 x 0.250 + 0.037 x 0.133 + 0.151 x 0.367 + 0.057 x 0.200 + 0.096 x 0.100 = 0.264. PWs for partners 2 to 5 are derived in the same way.

The following section describes the expected outcomes of partners' performance on CM sub criterion. In Table 7, the value in the last column of row 1 is attained as $(0.264 \times 0.166)^{1/2}$ = 0.209. Other values in the last column are achieved in the same way.

Table 7: Relative Weights for CM Evaluation Sub-criterion

Partner	Priority Weight	CM Criterion Global Weight	Geometric Mean
Partner 1	0.264		0.209
Partner 2	0.233		0.197
Partner 3	0.229	0.166	0.195
Partner 4	0.150		0.158
Partner 5	0.122		0.142

This process is repeated to all the performance evaluation sub-criteria and geometric mean weights are computed for all partners. To verify the outcome, the process was replicated with data from six case studies. The relative performance of each partner in the six cases is predicted. For case 1, partners' performance for contract modification is computed. The results are shown in chart 1.

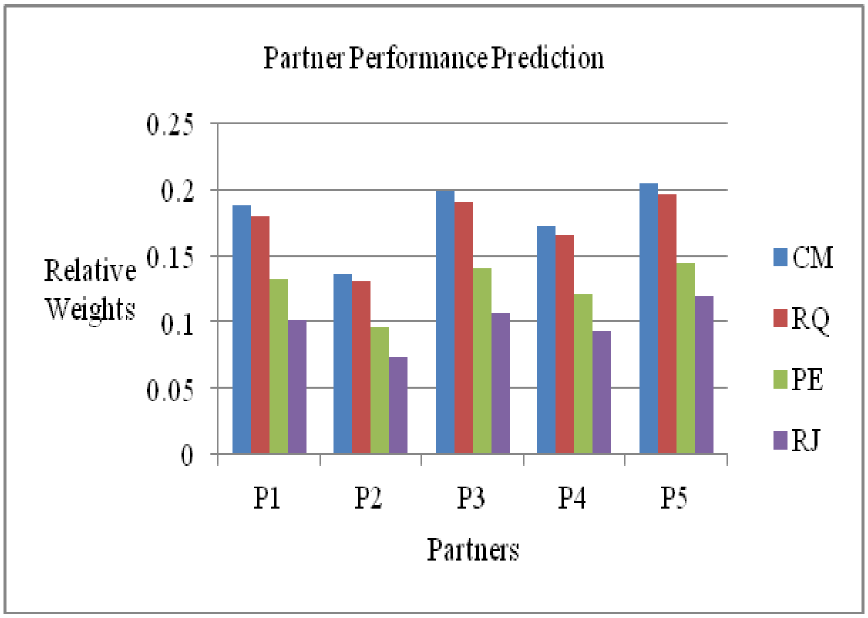

Chart 1: Partner Performance Prediction for case 1

As shown in the chart 1, Partners P3 and P5 would perform better than P1, P2 and P4 on sub-criterion contract modification. They would make the least modification with P5 being the best. Partners P1, P3 and P5 would perform better than P2 and P4 on required quality. Their work would be of the highest quality. P5 and P3 would outweigh others in repeat job. They would have the least repetitions of work. All partners would perform comparatively equal in personnel experience. This prediction process was repeated to all the cases. Different partners would perform differently per sub-criterion. There would be no one dominant partner in all the cases. It can be stated that each partner's relative weight of importance in each sub-criteria varies.

Partners' performance for different scenarios using AHP technique when relative weights for partners' evaluation and selection criteria were fixed and interchanged were simulated. The first scenario was when the relative weights for business, technical and management criteria were 0.41, 0.36 and 0.23 respectively, the relative weights of partners for the performance evaluation sub criterion, CM is as shown in Table 8. In Table 8, business, technical and management criteria are assigned weights of 0.41, 0.36 and 0.23 respectively for the three algorithms. The second scenario was when the relative weights for business, technical and management criteria were

0.23, 0.41 and 0.36 respectively. The third scenario was when the relative weights for business, technical and management criteria were 0.36, 0.23 and 0.41 respectively.

Table 8: AHP Partner Performance on Contract Modification

Algorithm	P1	P2	P3	P4	P5
Business Criterion Emphasized	0.209	0.194	0.195	0.160	0.143
Technical Criterion Emphasized	0.201	0.204	0.194	0.163	0.141
Management Criterion Emphasized	0.211	0.201	0.195	0.154	0.141

When business criterion is emphasized, P1 would perform better than others. P2 and P3 have almost similar performance predictions, followed by P4 and P5. When technical criterion is emphasized, P1 would perform better than others. P2 and P3 have almost similar performance predictions, followed by P4 and P5. When management criterion is emphasized, P1 would perform better than others. P2 and P3 have almost similar performance predictions, followed by P4 and P5.

Partners' Performance Monitoring

The final step in partners' performance evaluation is monitoring of their activities. Each partner is charged with implementation of a task. The project initiator (coordinator) monitors the progress of each partner and the overall project. A prototype was developed using Java Agent Development Environment (JADE) to assist project coordinators monitor progress. In the prototype each partner is an agent. Inter-agent communication for partners' progress monitoring is comparable to the basic request-reply server based communications where the coordinator takes the role of a server and the partners take the roles of clients.

This server-client setup has reversed roles, where the server makes updates' requests from clients and the clients reply with update values. However, the clients can also send update values to the server without the server making the requests. The coordinator agent sends an agent communication language message (ACL-Message) to all the agents requesting their work progress. Each agent reply back with the progress values.

The JADE run-time automatically posts messages into a receiver's private message queue as soon as they arrive. An agent can pick up messages from its message queue using receive method. This method returns the first message in the message queue (removing it from the queue), or null if the message queue is empty. In order to monitor the progress of each task, the coordinator agent receives progress messages from partner agents as shown in Figure 3.

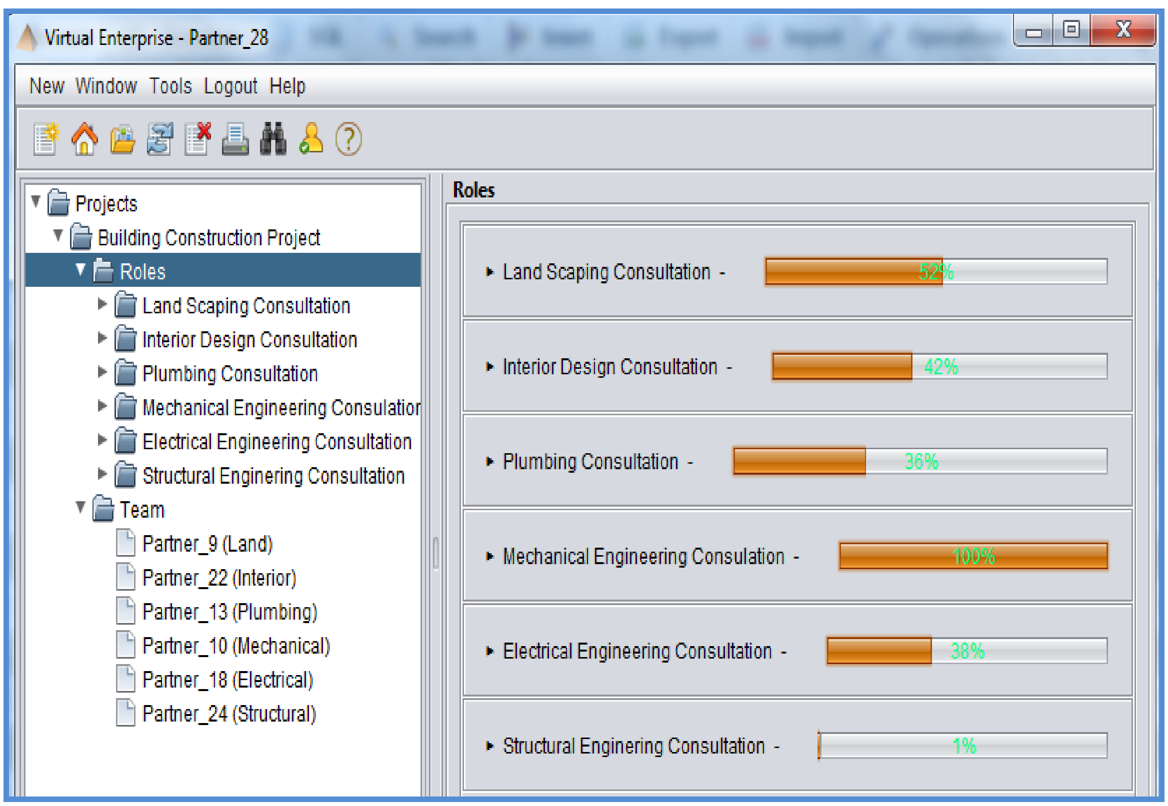

Figure 3: Task Progress Monitoring

Different task are completed at different times depending on the partners' performance. The coordinator agent is also able to monitor the overall project progress as shown in Figure 4. Each agent's progress can be monitored by the coordinator agent. Combining each agent's progress results in overall project progress which can be monitored by the coordinator agent in real time. The individual agent's progress enables the project owner to make relevant interventions if delays are exhibited.

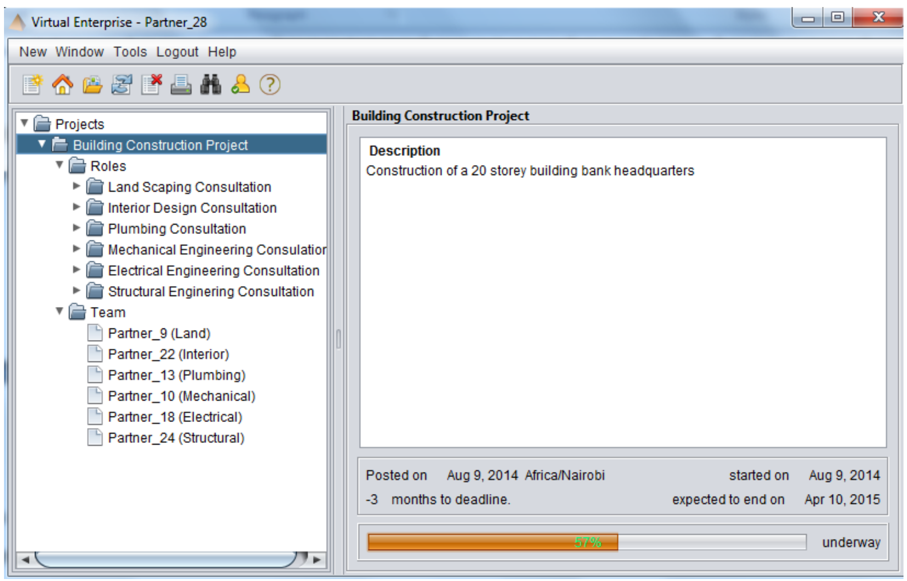

Figure 4: Overall project progress monitoring

As shown in Figure 5 each partner agents updates its progress status which is sent to the coordinator agent. Figure 5 shows the progress of agent implementing structural engineering works to be at 40%, that is four (4) out of ten (10) sub processes have been accomplished.

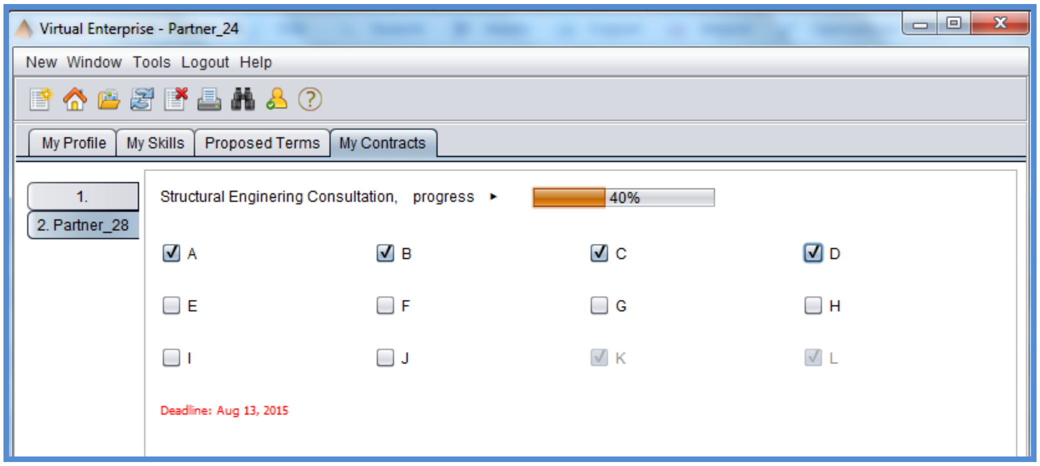

Figure 5: Partner updates structural engineering works progress

Figure 6 shows the progress of agent implementing electrical engineering works to be at 50%, that is five (5) out of ten (10) sub processes have been accomplished.

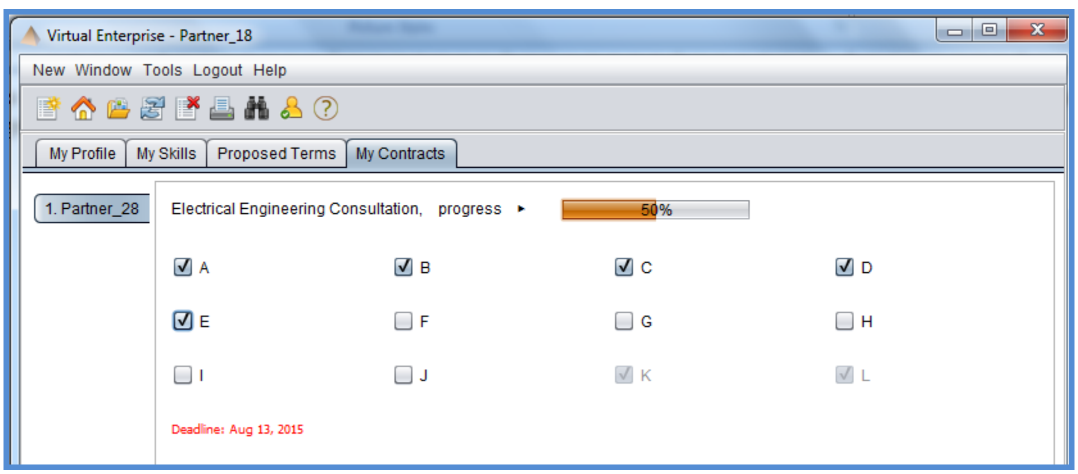

Figure 6: Partner updates electrical engineering works progress

The progress of other agents can be shown indicating how many sub processes have been accomplished at a given point in time of project implementation.

RESULTS AND DISCUSSIONS

PaPEP can be structured hierarchically and solved using multi criteria performance evaluation technique. Performance evaluation factors that are directly linked to partners include: contract modification, required quality of the product and personnel experience, repeat job and change in charge rate. In order to evaluate performance of partners, the following steps are applicable. (1) Identification of the evaluation criteria, (2) Selection of the performance evaluation method, (3) Performance prediction and (4) Performance monitoring (Petersen & Matskin, 2003; Tolle, 2004). First, the criteria for evaluating partners' performance are determined. They represent the desired level of performance of the collaboration. The second step requires the selection of the decision-making method to be used for evaluating performance of partner companies. Third, the partner's performance is predicted and finally, monitoring of performance is done.

Performance evaluation criteria for evaluating construction project partners evaluators include: Contract modification (CM), quality requirement (RQ), site location accessibility (SL), personnel experience(PE), change in material market rate (MR), material price change(PC), equipment breakdown (EB), rework/repeat job (RJ), change in transport cost (TC) and change in personnel charge rate (PR). These categories were further classified into two general categories, time and cost. Time as a general category comprised CM, RQ, SL and PE. These factors could affect the expected project completion time while factors like MR, PC, PC, RJ, TC and PR could affect the project cost.

Partners' performance for different scenarios using AHP technique when relative weights for partners' evaluation and selection criteria were fixed and interchanged were simulated. The first scenario was when the relative weights for business, technical and management criteria were 0.41, 0.36 and 0.23 respectively. The second scenario was when the relative weights for business, technical and management criteria were 0.23, 0.41 and 0.36 respectively. The third scenario was when the relative weights for business, technical and management criteria were 0.36, 0.23 and 0.41 respectively.

Using AHP, it has been shown how evaluation preference and consensus can be attained if a group decision-evaluation process is used in the PaPEP. It can be stated that AHP can be incorporated in the design and development of new techniques for the PaPEP for construction projects.

In order to monitor the progress of each task, the coordinator agent receives progress messages from partner agents. Different task are completed at different times depending on the partners' performance. The coordinator agent is also able to monitor the overall project progress. Each agent's progress can be monitored by the coordinator agent. Combining each agent's progress results in overall project progress, which can be monitored by the coordinator agent in real time. The individual agent's progress enables the project owner to make relevant interventions if delays are exhibited.

FURTHER WORK

An avenue for future study is to consider how the results of this study could be used for partner performance evaluation problems in general. This research could be carried out to determine the applicability of this technique to other industries and other research fields.

More case studies could be considered using the technique to determine its weaknesses and recommendations for its improvement. In this regard, views of all professionals in the construction industry could be considered to develop the technique. This would increase acceptability of the technique in the industry.

The limitations of AHP could probably be addressed in future research. Further studies may be required to confirm whether the developed technique from this study could be generalized.

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APPENDIX: QUESTIONNAIRE

Partner Performance Evaluation

Indicate your choice with a tick (√) on the label provided.

1. Indicate how important is each of the following criterion in measuring partner performance in the project. Use the symbols "A to E" with A being "Extremely important" and E being "Not at all important". Choose the symbol which best indicates your choice.

Criterion		Extremely important	Very important	Important	Weakly important	Not at all important
Time		A	B	C	D	E
Cost		A	B	C	D	E

2. Indicate how important each of the following sub-criterion in affecting expected project delivery time is. Use the symbols "A to E" with A being "Extremely important" and E being "Not at all important". Choose the symbol which best indicates your choice.

Sub criterion		Extremely important	Very important	Important	Weakly important	Not at all important
Contract modification (few or many) (CM)		A	B	C	D	E
Level of quality requirement (High, Medium, Low) (RQ)		A	B	C	D	E
Site location (Easy to access or not easy to access all the time) (SL)		A	B	C	D	E
Experience of personnel (PE)		A	B	C	D	E
Material market rate (Increase or decrease) (MR)		A	B	C	D	E

3. Indicate how important each of the following sub-criterion in affecting expected project cost is. Use the symbols "A to E" with A being "Extremely important" and E being "Not at all important". Choose the symbol which best indicates your choice.

Sub criterion		Extremely important	Very important	Important	Weakly important	Not at all important
Material price escalation (PC)		A	B	C	D	E
Breakdown of equipment (EB)		A	B	C	D	E
Rework of sections (RJ)		A	B	C	D	E
Transport cost variation (TC)		A	B	C	D	E
Change in personnel charge rate (PR)		A	B	C	D	E