Identifying needs and potential for decision support in construction procurement

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ABSTRACT | Procurement options in construction have proliferated amidst innovative approaches to financing projects, segregating functions, choosing participants and managing processes. Recent studies confirm that the selection of 'appropriate' procurement options is a necessary (although insufficient) condition for improving project performance levels. One such study compared procurement *vs.* non-procurement related variables in influencing project performance. Data from a sample of building projects in Hong Kong was used to develop time and cost over-run models, through multiple linear regression and artificial neural network techniques. These exercises indicated the significance of 'procurement variables' such as 'payment modality' (e.g.: fixed price lump sum) as well as 'non-procurement variables' such as client characteristics (that include secondary variables/ factors such as 'client type' and 'client experience') and project characteristics (including secondary variables such as 'building type' and 'project complexity'). A follow-up pilot study next evaluated (a) the relative impacts of various procurement and non-procurement variables on eleven identified project performance criteria; and (b) the feasibility of developing a decision support system for improved construction procurement that targets these eleven performance criteria, while 'modelling in' (and therefore incorporating) the influences of significant non-procurement variables. A viable model of a decision support system is thereby developed to help optimise project-specific procurement decisions by clients and their advisers.

KEYWORDS | construction, decision support, knowledge-based, performance, procurement

1 Background and Introduction

Recurrent cost and time over-runs, quality shortfalls, prolonged disputes or frequent accidents in the construction industry are often addressed by ad hoc and compartmentalised industry initiatives that focus on one or two aspects at a time, for example on quality assurance or on dispute resolution. Recommendations from such initiatives may therefore not reach the root causes of generic problems that generate such symptoms. Comprehensive industry reviews, as in the UK (Latham, 1994; Egan, 1998) have identified inappropriate procurement options as one of the major sources of such problems. 'Procurement' is taken in the broader context of the definition of the CIB (International Council for Research and Innovation in Building and Construction) Working Commission W92 on Procurement, as 'the framework within which construction is brought about, acquired or obtained'. This is taken from the viewpoint of a client who 'procures' various project management, design and construction

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services within an appropriate framework that must be established at the outset.

Emerging evidence on the criticality of appropriate procurement systems in influencing performance has inspired innovations in various procurement sub-systems, e.g. through: (a) functional regroupings, as in 'Construction Management', 'Design-Construct' or BOT (Build-Operate-Transfer – where the BOT consortium recovers their costs by charging user fees e.g. tolls, over an agreed operation period before transferring back the asset); (b) new Forms/ Conditions of Contract, as in the 'New Engineering Contract' of the UK Institution of Civil Engineers; (c) speedier dispute minimisation/ resolution modalities such as through partnering or mediation; and (d) fresh approaches to selecting contractors that do not rely on price alone. It is opportune to consolidate the scattered experiences gained from such innovations - in knowledge-bases that would be of benefit to construction clients and their advisers (consultants), who may not be familiar with the relative merits of all available options and their potential impact on performance levels in specific scenarios. For example, Rwelamila (2000), found that many construction consultants lack real expertise and appropriate training in this area, whereas most clients rely on them for advice on selecting procurement systems. He showed how incorrect decisions are thus often taken with unfortunate consequences. This exemplifies the needs addressed by the present paper.

On the other hand, questions have been raised by previous researchers on the relative influences of procurement *vs*. non-procurement related variables on project performance levels. For example, non-procurement variables such as project complexity and client experience levels may significantly impact on project performance. These prompted the formulation of a basic model for a study of the impact of both procurement and non-procurement variables on cost and time performance of Hong Kong building projects. Relevant results from this first study are summarised to show the importance of both sets of variables on time and cost performance. A more holistic conceptualisation of procurement systems is also proposed, so as to integrate more 'intelligent' work packaging at the project conceptualisation stage and 'smarter' selection of the various participatory teams (e.g. of client representatives, project managers, consultants, contractors and suppliers).

Observations derived from the subsequent (follow-up) pilot study are the main and final focus of this paper. These observations confirmed the need for considering other performance criteria (other than cost and time performance alone) when choosing an appropriate procurement system. The effects of 'procurement' and 'non-procurement' variables on the performance criteria such as 'higher quality', 'dispute minimisation' and 'lower life cycle costs' were thus investigated in this pilot study. A methodology for developing relevant knowledge-bases was also successfully tested. This strengthens the case made in this paper for developing a knowledge-based decision support system for facilitating (a) performance-oriented procurement choices and (b) compatible operational sub-systems. Relevant observations from two other recent studies in Hong Kong also contribute to the conclusions in this paper.

2 Relevant Insights from Previous Research by Others

The impacts of various non-procurement related variables on project performance levels has been previously studied, by for example Rwelamila and Hall (1994); Naoum and Mustapha (1995); and Walker (1997). Each of them focused on specific aspects such as human factors; clients' and designers' characteristics and team communications - in studies based in South Africa, U.K. and Australia respectively. Meanwhile, the continued criticality of procurement-related variables has also been confirmed in the Egan Report on the U.K. construction industry (Egan, 1998). In the specific domain of claims and disputes: Rhys Jones (1994) in the U.K. and Bristow and Vasilopoulous (1995) in

Canada, found that these were often triggered by adversarial culture, unrealistic tendering and ambiguous contract documents, that were in turn traced to inappropriate procurement systems.

Walker (1997) compared the relative impacts of traditional *vs.* non-traditional procurement systems on 'construction time performance' (CTP) using 102 variables in analysing 64 projects in Australia. He identified the importance of (1) sound working relationships between the client's representative team and the construction management team; and (2) sound planning and risk management; while also concluding that (3) procurement method is a significant factor affecting CTP. For example, the early involvement of the construction team in design development was recommended - through different non-traditional procurement methods, such as 'construction management' and 'design-construct'. In the USA, Miller et al. (2000) substantiated the need to formulate a model that supports 'multiple project delivery methods' infrastructure procurement. This paper addresses such needs.

3 Relevant Findings from Recent Research in Hong Kong

The following sub-sections contain relevant extracts from findings in three parallel recently completed research projects in Hong Kong. While the initial methodologies and interim findings of these research projects were mapped by Kumaraswamy et al. (1997), further developments led to refined methods, additional surveys and detailed conclusions.

3.1 Comparing Procurement and Non-procurement related Impacts on Time and Cost Performance Levels in Hong Kong Building Projects

This study was launched to assess the relative significance of different procurement *vs.* non-procurement related variables in influencing performance outcomes, given the diversity of previously reported findings, as sampled in the foregoing section. Findings from the first phase of this study, that were based on the analysis of 46 questionnaires and detailed data from 32 building projects in Hong Kong, suggested the importance of non-procurement related variables in this domain (Dissanayaka and Kumaraswamy, 1999a). Specifically, the time over-run and cost over-run models developed by multiple linear regression analysis indicated the relative significance of the following non-procurement variables (in addition to the programmed duration and original cost estimate): project complexity, client type, client/ client representative characteristics and contractor characteristics.

However, it may be argued that the last factor could in turn be related to selection methods and procurement strategies. A second phase of this study was launched, based on the observations from the first phase. More detailed project data was collected from 30 projects. Figure 1 represents the postulated structure of a construction procurement system with five sub-systems (work packaging, functional grouping, payment modalities, contract conditions and selection methodologies). Various possible options within each sub-system are indicated in Figure 1. The continued proliferation of such options underlines the usefulness of a decision support system for facilitating appropriate choices in selecting options within each sub-system with a view to assembling them into a synergistic project-specific procurement framework. Both multiple linear regression and artificial neural networks techniques were applied to discern any significant influences of the postulated procurement and non-procurement variables. Details of the methods and findings (including significance values and model equations) of the above study are necessarily reported separately (Dissanayaka and Kumaraswamy, 1999a; and 1999b) because of paper length limitations and the specific focus on the subsequent pilot study in this paper. However, it is relevant to note, subject to the limitations of the small sample size, and the residual influences of interacting variables, that:

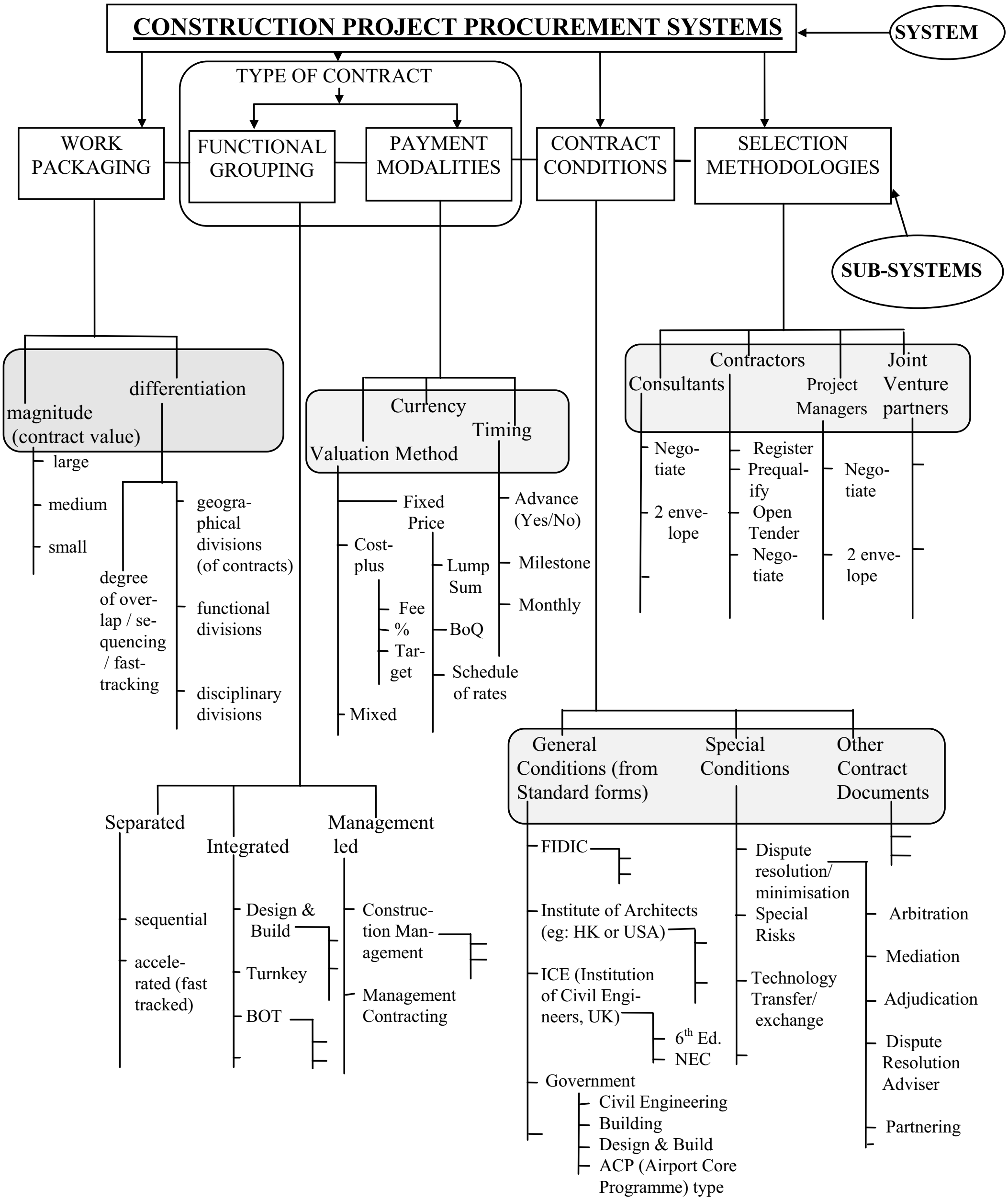


Figure 1. Proposed Template for assembling a project-specific Procurement System from various sets of options

NOTES:
contains the 'sub-sub-systems' within each sub-system (ie indicates a break-down of the sub-system)

Each sub-system has series of options as indicated above
All possible 'sub-sub systems' and options are not indicated here

1. ‘work packaging’ and ‘contract conditions’; were perceived to have a marginally greater influence on performance levels compared to the other three major procurement sub-systems, although even the others were important
2. the Hong Kong Government General Conditions of Contract were seen to have resulted in less cost and time overruns than those of the Hong Kong Institute of Architects
3. traditional procurement systems (with ‘design’ and ‘supervision’ separated from the ‘construction’ function) seemed more liable to cost over-runs than ‘design-build’ projects
4. less significant cost over-runs appeared likely where contractors were prequalified
5. Significant variables affecting cost over-runs were found to be ‘risk retained by client for quantity variations’, ‘client confidence in the construction team’, ‘construction complexity related to new technology’ and ‘payment modality’ (e.g.: whether ‘lump sum fixed price’ or ‘remeasure’)
6. Significant variables affecting time over-runs were found to be ‘level of design complexity’, ‘change orders/ variations’, ‘client type’, ‘client confidence in the construction team, ‘construction complexity due to sub-contracting’ and ‘project team motivation and goal orientation’.

The above variables emerged as significant in the model equations derived from the step-wise multiple linear regression that started with all relevant variables, and is described by Dissanayaka and Kumaraswamy (1999a; 199b). The predictions of the derived cost over-run and time over-run models were tested using six sets of project data. The observed errors - MAPE (Mean Average Percentage Error); and RMSE (Root Mean Square Error) - appeared reasonably low; and improved further when the derived significant variables were used as inputs into artificial neural network models. The accuracy /error levels in the predictions are indicated in Table 1 below. The observed larger divergences in predictions of cost over-runs, compared to time over-runs, may possibly be attributed to the increasing importance attached to regaining lost time in Hong Kong building projects, even at considerable expense, for example through ‘acceleration’ by deploying extra resources, given the very high land costs. The variability in construction ‘costs’ is therefore likely to be higher than that in ‘time’ aspects.

The relevant findings from this study thus point to the importance of both non-procurement variables such as client type, project complexity and project management, as well as of procurement decisions such as those related to project packaging, contract conditions, payment modalities and better selection of the project teams. This study may be considered to be a ‘precursor’, that inspired the pilot study which is focused upon later in the paper.

3.2 Project Durations and Delays

A Hong Kong based investigation into factors causing delays in construction projects was conducted in parallel with the above study. This investigation included a questionnaire survey that elicited 147 responses from a total of 400 targeted clients, consultants and contractors on the perceived importance of 83 delay factors. These 83 factors were postulated on the basis of the first phase of this particular study. Chan and Kumaraswamy (1997) described the findings which ranked the 83 factors and 8 ‘factor categories’ (into which the factors had been categorised) according to their relative importance as perceived by the respondents. Table 2 provides an example of one set of summarised results - relating to the perceived relative importance of delay factor categories in civil engineering projects in Hong Kong. The importance ratings of each factor category were averaged into a ‘relative importance index’ that could vary from 0 (lowest) to 1 (highest). The average perceptions of client, consultant and contractor subgroups within the sample were derived both separately and together, as indicated in Table 2 below.

The ‘contractor-related construction management’ factor category was found to be ranked first and the

Table 1. Comparisons of Error levels in Predictions from the derived models

ERROR INDICATOR	TIME OVER-RUN INDEX by MLR *	TIME OVER-RUN INDEX by ANN **	COST OVER-RUN INDEX by MLR	COST OVER-RUN INDEX by ANN
MAPE:	6.98	2.57	13.69	11.05
RMSE:	6.18	4.77	16.73	5.99

* ***MLR*** - Multiple Linear Regression; ** ***ANN*** - Artificial Neural Network
MAPE - Mean Average Percentage Error; **RMSE** - Root Mean Square Error

Table 2. Perceived 'Relative Important Indices' (RII) and Ranks (R) of different factor categories - in contributing to delays in Hong Kong Civil Engineering Works

RESPONDENT GROUP:	Clients		Consultants		Contractors		'Average' *	
FACTOR CATEGORY	RII	R	RII	R	RII	R	RII	R
Construction Management#	0.701	1	0.701	1	0.632	4	0.680	1
Design Team-related	0.639	3	0.681	2	0.677	1	0.666	2
Labour	0.665	2	0.680	3	0.643	3	0.664	3
External Factors	0.605	5	0.618	6	0.672	2	0.630	4
Project-related	0.619	4	0.646	4	0.615	5	0.628	5
Plant & Equipment	0.604	6	0.645	5	0.574	6	0.610	6
Client-related	0.526	7	0.610	7	0.571	7	0.570	7
Materials	0.520	8	0.591	8	0.555	8	0.556	8

R = 'Rank'; RII = 'Relative Important Indices'; * Weighted Average; # Contractor-related Construction Management

'design team - related' category second, implying the importance of appropriate selection of contractors and consultants who are more likely to perform better (rather than just being cheaper). This finding reinforces the importance of incorporating the 'selection methodology' sub-system in the proposed procurement system model (as shown in Figure 1).

Specific factors such as more effective communications between teams and faster decision making were also seen to be critical. These could be initially addressed through the 'functional grouping' sub-system that is derived from the 'type of contract' (as shown in Figure 1), for example in non-traditional procurement such as 'design and build' or 'management-led' systems. These specific critical factors can thus be addressed by choosing appropriate procurement variables (options) at the outset. In addition, it may be noted that non-procurement related factors need to be well managed later, in order to maximise benefits from the right procurement choices. For example, since 'communication' and 'decision-making' are operational activities, the operational procedures and relationships need to be properly managed in the context of the project environment as well.

3.3 Reviewing Risk Allocation in Standard Civil Engineering Contract Conditions

The third previous and parallel Hong Kong based study focused on eliciting the common sources and causes of construction claims arising from civil engineering contracts based on the standard Hong Kong Government Conditions of Contract (1993 edition). The findings indicated the highest significance of the sources 'unclear documentation' and 'inadequate documentation' (Kumaraswamy and Yogeswaran, 1998). Such sources were in turn traced to 'root causes' of 'unfair' or 'unclear' risk allocation at the outset.

A 'Claims Focus Indicator' tool was developed, based on an analysis of a database of past project data, to focus management attention on particular areas of procurement and/or operations (e.g.: in documentation or issuing instructions) that appeared to be specially vulnerable to claims and disputes. This was based on the perceived frequency, magnitude and avoidabilities of past claims in such areas, as derived from a database of 91 civil engineering projects (Kumaraswamy and Yogeswaran, 1998). Furthermore, particular ambiguities, omissions or non-specificities in standard contracts were identified for specific attention.

A decision aid type module which incorporates experiential knowledge in such areas (including updated 'Claims Focus Indicators'; and significantly 'troublesome' conditions/ clauses/ documentation problems) would be useful in tailoring a procurement system for a new project. For example, vulnerable 'loopholes' may be plugged, common ambiguities clarified and functional relationships / communication channels rationalised in advance so as to avoid common problems. This may be achieved through both Special Conditions of Contract and operational guidelines. The decision support on these aspects would thus relate to both the 'type of contract' and 'contract conditions' sub-systems of the procurement framework (shown in Figure 1).

4 Proposed Decision Support Framework

4.1 Consolidating the Needs and Possibilities

Previous research by others and relevant findings from the three previous Hong Kong - based studies that are scanned in the foregoing section, support the postulated importance of the contributions of the selected procurement system to project performance levels. They therefore justified the need for the fourth study that investigated how best such procurement decisions may be facilitated. The holistic conceptualisation of a procurement system, as in Figure 1 provides a template for assembling various combinations of chosen procurement options as may be selected within each of the five sub-systems. Kumaraswamy (1998) illustrated the further break-down of two of these additional sub-systems and more potential options within each sub-sub-system. Of course, in assembling a complete project-specific procurement system, it would be appreciated that the contributions of the selected options from each sub-system (and sub-sub-system) should be synergistic at best, but compatible at the very least in targeting the desired performance levels.

The proliferation of options and the lack of experience with various combinations in different scenarios, indicates the need for powerful tools to aid clients and their advisers in formulating appropriate procurement systems. It also appears that other factors need to be considered in parallel: viz. (a) compatibilities of various procurement options with 'non-procurement' variables (e.g.: client and project characteristics); and (b) the effects of both 'procurement' and 'non-procurement' variables on other dimensions (criteria) of project performance (e.g.: 'quality levels' and 'dispute minimisation') as evident from the previous studies. The evident need for knowledge-bases incorporating relationships between this multitude of interacting variables led to a search for powerful decision-support tools that could incorporate the necessary expertise and experience to deal with the full range of possible scenarios.

4.2 Outline of Data Collection and 'Knowledge Mining' in the Pilot Study

A fresh (fourth) study was therefore launched to draw together the foregoing threads and to test the potential for developing the proposed knowledge-based advisory system. This study focused on building projects in Hong Kong, with a view to obtaining detailed data from a small sample of projects. 38 potentially important performance criteria were initially postulated based on the literature survey, preliminary interviews and the industrial experience of the researchers, as being more likely to be of importance. The following 11 performance criteria (PC) were next chosen from the above 38, based on focused interviews with five 'expert'/ very experienced practitioners involved in formulating procurement systems for clients, two being from the private sector (one with a property developer, the other with a consultant) and three from the public sector (one with a government organisation overseeing works departments, another with one of the major works departments and the other from a statutory body with a large building programme):

(PC1) Lower capital cost
(PC2) Lower life cycle costs
(PC3) Cost certainty
(PC4) Shorter pre-construction duration
(PC5) Time certainty
(PC6) Shorter construction duration
(PC7) Effective & efficient communication
(PC8) Higher quality
(PC9) Effective & efficient decision making
(PC10) Dispute Minimisation
(PC11) Overall client satisfaction (also including other aspects)

These eleven project performance criteria were incorporated in a detailed survey that used two 13 page data-sheet type questionnaires. The first questionnaire elicited the experience-based perceptions of the more experienced practitioners on the effects/ impacts on each of the above criteria in turn, of each of the listed (in the questionnaire) procurement-related and non-procurement-related variables. Two lists of variables were structured: (i) under the five previously identified procurement sub-systems (e.g. payment modality) as shown in Figure 1, and sub-sub-systems (e.g. valuation method), with opinions sought on each of the different options (e.g. fixed price lump sum); and (ii) under six non-procurement related factor categories, i.e., those encompassing factors related to the project, client, designer, contractor, management and external conditions. An average of about twelve (ranging from nine to fourteen) factors were listed under each of those six factor categories. Appendix I compresses indicative extracts from this 13 page first questionnaire into one page.

The second questionnaire (as per extracts shown in Appendix II), was designed to collect information from specific projects on the effects of the same procurement and non-procurement-related variables - on the performance levels attained - against the same set of eleven criteria. Additional questions were designed to extract the project profile in terms of basic parameters, as well as the client priorities. 50 experienced practitioners in Hong Kong were identified and approached with requests to assist in completing either one or both of these data-sheet type questionnaires. 22 'experienced-based' and 18 'project-specific' data-sheets were completed after (or at) an interview session with a trained Research Assistant.

4.3 Outline of Data Analysis and Knowledge Representation in the Pilot Study

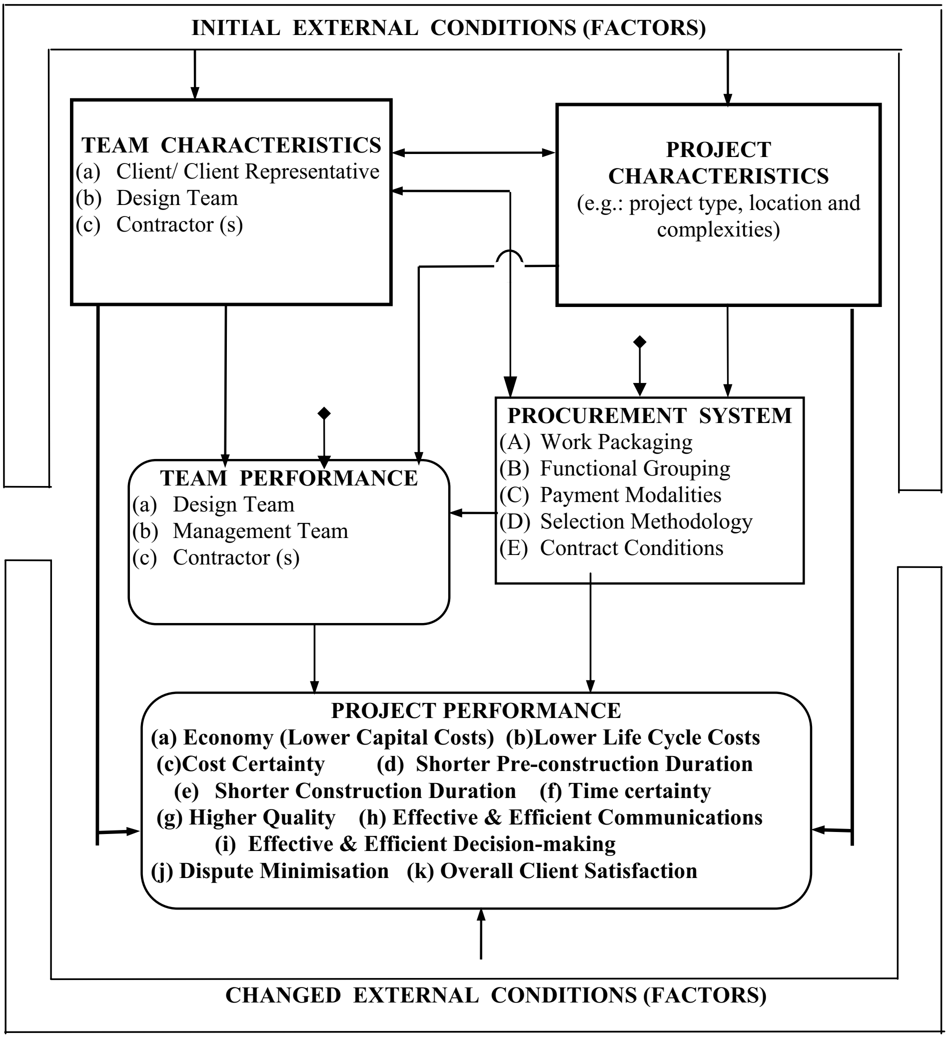
The data were next consolidated in a specially designed hierarchy of inter-linked spreadsheet formats. Multiple linear regression and artificial neural networks (ANNs) were used for analysis and testing. While length limitations preclude detailed descriptions in this paper, the basic types and formats of regression plots are illustrated in those derived for predicted vs actual cost (and time) indices in the 'precursor' study by Dissanayaka and Kumaraswamy (1999a). The methodology and outcomes of the ANN applications in that study are described separately by Dissanayaka and Kumaraswamy (1999b). The relationships model formulated for this follow-up pilot study was an improved version (over that originally formulated for the precursor study criteria (Kumaraswamy and Dissanayaka, 1996). The refinements were based on the conclusions of both the above study and the other two previous parallel studies that were reported in the last section. The new model incorporates the significant relationships and criteria pertaining to project performance as shown in Figure 2.

This model formed the basis for predicting performance outcomes (in terms of different criteria), or for guiding client's procurement decisions - towards meeting their priorities against particular performance criteria. Observations from the present study enabled development of a comprehensive decision-support model. Figure 3 indicates the structure that integrates the foregoing aspects into a knowledge-based client advisory system. Having modeled the project profile through a series of questions and inputs (at stage I1, as in Fig. 3), the expert-system front-end is expected to provide a set of tool-kits in the form of guidelines, checklists and flow-charts that would guide project-specific procurement decisions. Such tool-kits would include checklists of significant factors derived from time and cost over-run models and 'Claims Focus Indicators' as described in the previous section; as well as flow-charts, checklists of criteria and corresponding evaluation 'indicators' for selecting contractors or joint-venture partners, as for example demonstrated by Kumaraswamy (1998). The positioning of three parallel knowledge-bases at the core of the system (as shown in Fig. 3) was based on: (a) basic relationships modelled in Fig. 2; (b) conclusions from the previous studies and (c) interim conclusions from this present pilot study.

A series of statistical computation exercises were carried out in analysing and consolidating the experiential 'knowledge' derived from the 22 experience-based data-sheets. For example, in the first exercise, the average impact values (and standard deviations) of each procurement option were computed against each (in turn) of the 13 performance criteria. A total of 50 procurement options were incorporated in the questionnaire, including for example 5 within the 'work packaging' sub-system and 8 within the 'functional grouping' sub-system. However, some of these 50 options were discarded, based on low response levels against particular options. For examples BOT (Build-Operate-Transfer) and BOO (Build-Own-Operate) options under the 'functional grouping' sub-system were discarded, leaving 6 options therein. In a subsequent consolidation exercise, the overall impact values of each procurement option were computed against a typical consolidated performance criterion; the latter having been derived by weighting each criterion by project-specific client priorities in each of the 18 (taken in turn) project-based data-sets. The highest ranked procurement options for each sub-system on each project as derived from these exercises were compared with those actually chosen in the respective projects. The above first set of exercises was designed to develop a pilot module of the knowledge-base (2) shown in Figure 3 - in respect of Hong Kong based building projects in the first instance.

Interestingly, the results of this first set of exercises by themselves (taken independently) suggested a fair degree of 'mismatch' between the theoretically (modelled) superior procurement options and those actually chosen in a given project. For example, the 'Design & Build' option was perceived to surpass all other 'functional grouping' sub-system options in meeting each of the eleven chosen performance criteria. This appeared contrary to the relatively low present usage of the 'Design & Build' route by many Hong Kong clients, who often preferred the traditionally separated functions in the Design-Bid-Build route. However, this apparent discrepancy between perception and practice strengthened the previous hypothesis that other client-related, project-related and external conditions should also be considered before deciding upon an apparently (theoretically) superior procurement option. In these cases such client/ project related and external factors may have militated against choosing 'Design & Build' in those scenarios.

The above observations confirmed the importance of the second set of similar exercises that was designed to develop modules of knowledge-bases (1) and (3) - as seen in Figure 3 - which would complement knowledge-base (2) by drawing in the other important varia-

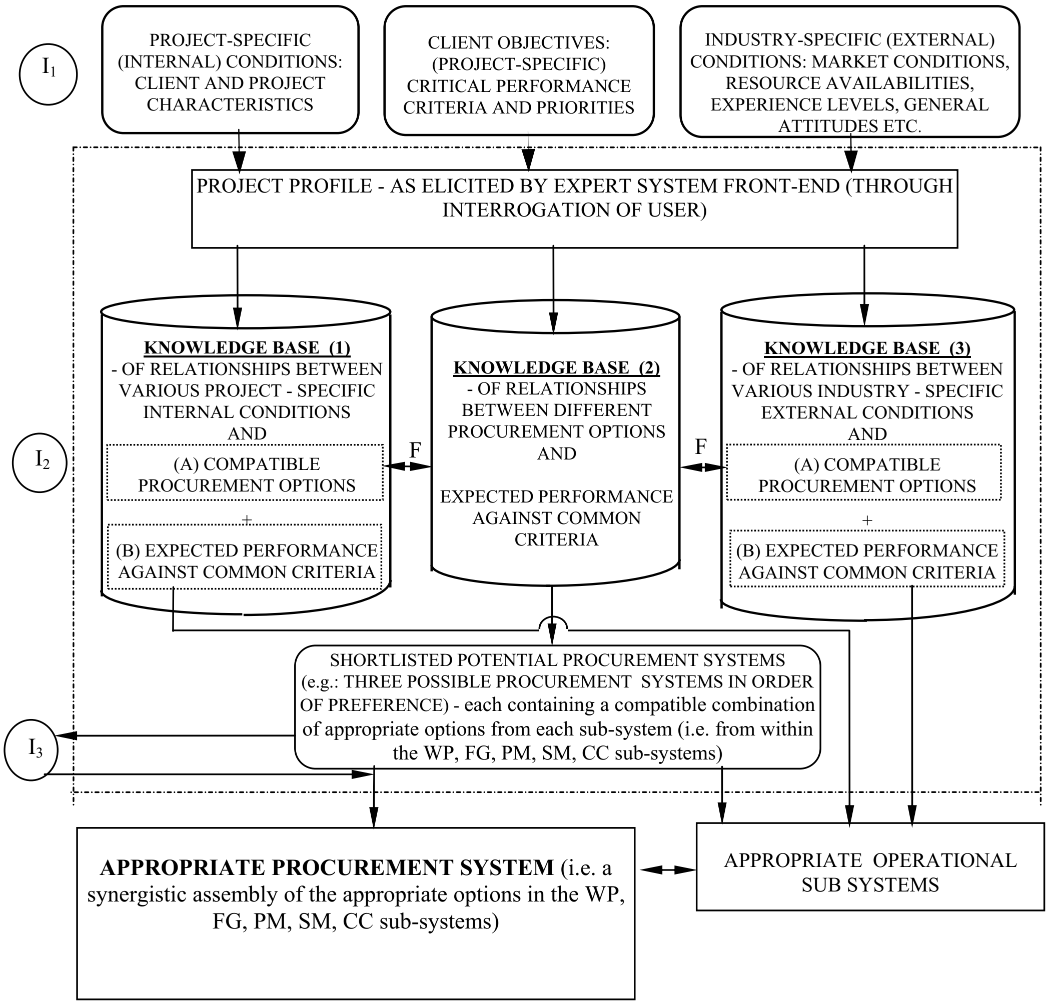


Notes:-

Management Team = either client's team or independent project manager/ consultant (or the design team itself, in the absence of the former) who manage the project for the client

= other inputs/ relationships e.g.: from external conditions

Figure 2. Model of basic linkages between project performance and procurement & non-procurement related variables



ABBREVIATIONS

CC - CONTRACT CONDITIONS
PM - PAYMENT MODALITIES
WP - WORK PACKAGING
FG - FUNCTIONAL GROUPING
SM - SELECTION METHODOLOGIES

Key:

I - USER INPUTS
I_1 - MODELLING PRESENT PROJECT PARAMETERS
I_2 - CHECKING WHETHER ANY PROJECT PARAMETERS (INTERNAL OR EXTERNAL CONDITIONS) COULD CRITICALLY AFFECT THE EFFECTIVENESS OF CERTAIN PROCUREMENT OPTIONS (These are temporary input requirements at the 'F' interfaces, which will be later replaced by additional knowledge base modules)
I_3 - RE - CHECKING THE COMPATIBILITIES AND ANY POSSIBLE SIDE-EFFECTS OF THE SHORTLISTED PROCUREMENT OPTIONS
---- - EXPERT SYSTEM BOUNDARIES
F - FOR FUTURE KNOWLEDGE BASE DEVELOPMENT

Figure 3. Model of proposed Decision Support System for Optimising Procurement Protocols with parallel Managerial Sub-systems

bles. Knowledge-bases (1) and (3) incorporated 'internal' non-procurement-related variables (e.g. under groupings of 'client characteristics' and 'project characteristics'), as well as 'external' non-procurement-related variables (e.g., project complexity) respectively. Average impact values of each of these non-procurement variables were consolidated against each performance criterion, by combining the responses in the 22 experience-based data sheets, as in the first exercise for the procurement related variables described earlier.

The more significant variables (factors) were then identified - by allocating both procurement and non-procurement factors into five bands, based on their perceived average impacts on each performance criterion in turn. The average impact values were assessed on a scale from -3 (extremely negative impact) to +3 (extremely positive impact), 0 being 'no impact'. The average impact values were those statistically derived (for each 'factor' in turn) from the data /'knowledge' derived from the experience-based data - sheet questionnaire. The bands were categorised as follows:

Very high impact - for average impact value > 2.5
High impact - for average impact value from 2.0 to 2.5
Moderate impact - for average impact value from 1.5 to 2.0 (excluding 2.0)
Low impact - for average impact value from 1.0 to 1.5 (excluding 1.5)
Very Low impact - for average impact value < 1.0

Table 3 contains an extract from the set of spreadsheets developed for comparing 'non-procurement' and procurement factors impacting on just the 'cost certainty' performance criterion (the certainty of not exceeding the original budget/ estimate). Variables with 'very low impact' and 'low impact' are excluded in this extract. This exercise was repeated against each of the 11 procurement criteria in turn. Such juxtapositions as above, facilitated the comparison and identification (within bands as above) of the more important non-procurement and procurement related variables (factors) in terms of their relative influence.

Table 3. Identifying factors influencing ('moderate impact' and above) the 'cost certainty' (not exceeding budget) performance criterion - as extracted from the combined pilot knowledge-base

Non Procurement Related Variables (Factors)			'Average Impact Value' Bands	Procurement related Variables (Factors)		
Factor Category	**Factor**	**Average Impact Value**		**Average Impact Value**	**Option**	**Sub System**
			2.5-3.0 (Very High)			
			2.0-2.5 (High)			
Client Characteristics	1. Lower possibilities of requirement changes during construction	1.50	1.5-2.0 (Moderate)			
Designer Characteristics	2. Less changes in design 3. Less mistakes in design documentation	1.64 1.50		1.55	Design and Build	Functional Grouping
Contractor Characteristics	4. Effectiveness of cost control systems	1.59		1.50	Fixed Price Lump Sum	Payment Modality - Valuation Method

The above exercise provided useful insights by juxtaposing the procurement and non-procurement variables in terms of their impacts on each performance criterion in turn. But it did not consider all criteria together. Neither did it incorporate the assigned project-specific priorities of each criterion. Since statistical models alone could not model these complex interactions, it was next decided to model performance-oriented procurement choices through an Artificial Neural Network (ANN) by making use of the available (18) project data-sets. The ANN shell 'Neuroshell 2' (of the Ward Systems Group) was used. 14 data-sets were used for training the ANN model, and 4 for testing it by comparing the predicted/ recommended choices with the actual procurement choices in those 4 data-sets.

The first trial used only 11 input variables, these being the client priorities as measured (on a scale from 1-10) against the eleven chosen performance criteria. The second trial used 26 input variables, incorporating the previous 11 (criteria priority levels), as well as 5 project characteristic variables (e.g., 'ease of site access'); 5 client characteristic variables (e.g., 'client experience'); and 5 external condition variables (e.g., 'availability of manpower'). The latter 15 'internal' (10) and 'external' (5) variables were chosen on the basis of their previously determined significance, this having been assessed by identifying those variables with the higher relative impact levels above a chosen cut-off value (e.g. 'moderate' and above, i.e. $\geq$ 1.50 as for example in Table 3) from each grouping.

The tested ANNs used (a) two hidden layers - which were found to yield better results after an initial set of experiments with just one hidden layer; (b) five nodes in each layer - as derived from the default suggestions within the software itself during the ANN construction; and (c) four outputs - relating to three (of the four) procurement sub-systems (with one sub-system being broken into two sub-sub-systems) - where the decisions were (i) more 'visible'; i.e., excluding the initial higher-level 'work packaging' decisions; and also (ii) more variable i.e. excluding the 'selection methodology' options which did not significantly diverge in the small sample obtained in this pilot study. These four outputs thus related to: (1) Functional Grouping (FG) where the 3 possible options (outcomes for 'output variable' 1) were taken as 'traditional sequential', 'traditional fast-track and 'design-build'; (2) Payment Modality-Valuation Method (PMV), where these could have 3 possible options (e.g., Fixed Price Lump Sum); (3) Payment Modality-Timing (PMT), where these could have 2 possible options ('Milestone' or 'Monthly); and (4) Contract Conditions (CC), where there were 5 possible options (e.g., Hong Kong Institute of Architects conditions of contract). The foregoing target options (possible outcomes for each of the four outputs) were selected according to those commonly chosen in the 18 project-specific data sets obtained from the Hong Kong-based building project sample.

Table 4(a) below juxtaposes the Trial 1 ANN testing set outputs - representing predicted/ recommended options - against the actual options chosen in the 4 projects used for testing. Table 4(b) shows that Trial 2 yielded a closer match (than Trial 1) between the predicted/ recommended and actual choices. This may be explained by the fact that 15 non-procurement related factors were added in Trial 2, to the 11 input variables used in Trial 1, again supporting the hypothesis of the need to incorporate both procurement and non-procurement variables in the decision support model aimed at performance-oriented procurement.

The relatively low levels of divergence between the two sets of 'outputs' shown in Table 4(b) was encouraging, given that only 14 project data-sets were used for training the ANNs, compared to the 26 input variables in Trial 2 and the 4 output variables. These results increased confidence in the potential for refining the model further with the incorporation of more data sets. While 4 out of 16 variables were not chosen as may have been recommended had this pilot model been used, other considerations may have influenced the choices. Further investigations indicated that contract conditions chosen in projects A and B were constrained by client preferences, while unfamiliarity with Design-Build (as discussed in the previous section) may have militated against that choice in project C. No further relevant information was available from project D. It is worth noting that when only procurement variables were used as inputs in Trial 1, 9 out of the 16 variables were different, indicating considerable improvements in Trial 2. However, it is clear that many more data sets must be incorporated, and more testing done before this pilot model can be developed for use.

It is not possible to present all the detailed observations from the above pilot study in this paper, given the vast volume of data processed and the many exercises involved. More details of the statistical and modelling approaches will therefore be presented separately. The intention of this and the previous sub-section is to provide an insight into the approaches used and the relevant overall conclusions reached viz. (a) that knowledge-bases (1), (2) and (3) - as shown in Figure 4 - need to be mobilised in parallel, in order to obtain realistic results i.e., for sound procurement advice; (b) that the proposed decision support model was capable of being built; and (c) that its applications would be very useful, in improving the efficiency and effectiveness of construction procurement decisions.

Table 4(a). Comparison of ‘Chosen’ and ‘Predicted’ Options in the 18 Project data-sets - in Trial 1

	Chosen Options (Actual Decision ‘Outputs’)				Predicted/ recommended options (ANN Outputs)			
Sub-(sub-) system:	**FG**	**PMV**	**PMT**	**CC**	**FG**	**PMV**	**PMT**	**CC**
Project A	1	1	1	3	1	1	1	5
Project B	1	3	1	1	1	1	2	5
Project C	3	1	1	4	1	1	2	5
Project D	1	1	1	1	1	2	1	3

Table 4(b). Comparison of ‘Chosen’ and ‘Predicted’ Options in the 18 Project data-sets in Trial 2

	Chosen Options (Actual ‘Outputs’)				Predicted/ recommended options (ANN Outputs)			
Sub-(sub-) system:	**FG**	**PMV**	**PMT**	**CC**	**FG**	**PMV**	**PMT**	**CC**
Project A	1	1	1	3	1	1	1	4
Project B	1	3	1	1	1	1	1	3
Project C	3	1	1	4	1	1	1	4
Project D	1	1	1	1	1	1	1	1

FG: Functional Grouping: with 3 possible options, coded from 1 to 3 (e.g., 3 = Design-Build)
PMV: Payment Modality-Valuation Method: 3 possible options, 1 to 3 (e.g. Fixed Price Lump Sum)
PMT: Payment Modality-Timing: 2 possible options ‘Milestone’ (1) or ‘Monthly’ (2)
CC: Contract Conditions: with 5 possible options, coded from 1 to 5

5 Conclusions

The literature reviewed and initial studies confirm that the assembly of appropriate procurement systems would contribute to enhanced performance levels in construction projects. The findings from the Hong Kong based studies demonstrate the viability of a decision support system based on a holistic and synergistic approach to procurement as outlined in this paper e.g. also including front-end project packaging and participant selection methodology decisions. An expert system is found to be useful in modelling the project scenario, comparing it with the previously assembled knowledge-bases and then applying the encapsulated 'expert knowledge' to derive useful advice. This advice would relate to both procurement decisions and complementary operational sub-systems that are needed to enhance project performance, given the overwhelming evidence that non-procurement variables also affect performance levels. The proposed knowledge-based decision support system (as in Fig. 3) is designed in this pilot study in response to these needs.

While the viability of the overall structure and of individual modules has been demonstrated in the pilot study, a wider initiative is needed to collect data from more projects and to develop other modules of the proposed system. It is envisaged that guidelines, checklists and other tools can then be developed and incorporated to provide specific advice relevant to particular scenarios. Clients and their advisers/ consultants can then benefit from a vast body of experiential knowledge that would be incorporated in the decision support system.

Meanwhile: (a) the significance is noted of particular procurement-related sub-systems (such as 'work packaging', 'payment modality' and participant 'selection methodology'; including specific variables such as 'sub-contracting') - from their prominence in the derived cost and time over-run prediction models; and (b) the importance is also noted of particular project characteristics (such as 'building type'), client characteristics (such as 'client experience') and external conditions (such as 'availability of manpower'). Clients and their advisers should be guided to select appropriate and synergistic options in choosing procurement sub-systems and complementary operational sub-systems, according to client and project priorities/ characteristics and particular contextual conditions. Expert advice may therefore be mobilised and managerial attention focussed on synergistic procurement choices that address these particularly sensitive/ significant areas, pending the further development of the proposed decision support systems. The complexities of the interacting web of variables and relationships may otherwise cloud areas needing particular attention and divert energies to less significant tasks, hence the added importance of the interim findings from the pilot study, on sensitive variables and their relationships, apart from the proposed model itself.

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APPENDIX I. Extracts from the 13 page General Experience-based Data-sheet type Questionnaire
- as extracted from pages II-2, III-3, and III-5 (ie from portions of Parts II and III

EXTRACTED FROM PART II, PAGE II-2 ON **PROCUREMENT SUB-SYSTEM: FUNCTIONAL GROUPING**

Sub-sub-system (or main option)	**Options**	**Impact on performance against Criteria below**										
		Lower capital costs	Lower life cycle costs	Cost certainty (not exceeding budget)	Shorter pre-construction duration	Shorter construction duration	Time certainty (not exceeding programmed duration)	Higher quality	Effective and efficient communica-tions	Effective and efficient decision-making	Disputes minimi -zation	Overall client satisfac -tion
		Please indicate the impacts of each option (on the left) of the sub-sub-systems upon each of the above project performance criteria 1 – Extremely negative impact; 2 – Negative impact; 3 – Slightly negative impact; 4 – No Impact; 5 – Slightly positive impact; 6 – Positive impact; 7 – Extremely positive impact										
Integrated (functions)	• Design-and-build	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )
	• BOT (Build Operate-Transfer)	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )
	• BOO (Build-Own-Operate)	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )

Only one sample row is shown above - extracted from a full page table (and two sample rows each are shown below - extracted from 2 other tables)

EXTRACTED FROM PART III, PAGE III-3 ON NON PROCUREMENT ITEM (C) **Factors related to the DESIGNER**

• CRITERIA: • FACTORS:	**(Impact on Performance against Criteria as tabulated above)**										
• In-house design team (as against external)	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )
• Higher design team experience levels	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )

EXTRACTED FROM PART III, PAGE III-6 ON NON PROCUREMENT ITEM (F): **EXTERNAL FACTORS**

• Greater availability of appropriate designers and consultants	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )
• Greater availability of (construction) manpower	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )	( )
• Lower inflation rate	( )	( )	( )	( )	( )	( )	( )	(*)	( )	( )	( )

✲ Assumed to be irrelevant/ no need to 'rate'

APPENDIX II. Extracts from the 13 page Project-specific Data-sheet type Questionnaire

- as extracted from page II-1, II-2 and II-5 of Part II (on **Project Data**) *ie excluding Part I (1 page on general Organisation information) and Part III (7 pages on 'project-specific information on effects of non-procurement related factors)*

(A) PROJECT CHARACTERISTICS (will remain confidential)
……
7. Quality of workmanship required: ❑ very high ❑ high ❑ average

8. Information flows (on formal communications) experienced between
- client and architect/engineer: ❑ fast ❑ normal ❑ slow
- architect/engineer and contractor: ❑ fast ❑ normal ❑ slow

9. Speeds of decision-making experienced
- involving all project teams: ❑ high ❑ average ❑ low
- within client's team: ❑ high ❑ average ❑ low
- within …etc

10. Contract cost data:
…… *(basic estimates and final costs with breakdowns are obtained in a structured format here)*

Causes of main variations: ❑ client requirements ❑ design changes ❑ additional works ❑ unforeseen ground conditions ❑ obstruction by public utilities ❑ other (please specify)

(B) PROCUREMENT SUB-SYSTEMS
……
(B.2) FUNCTIONAL GROUPING

1. Type of contract: ❑ traditional sequential (construction starts after complete design)
❑ traditional accelerated (fast-tracking by dividing into work packages)
❑ design-and-build ❑ management contracting
❑ construction management ❑ other (please specify) ____________________

(B.3) PAYMENT MODALITIES

1. Valuation method: ❑ fixed price lump sum ❑ remeasured Bill of Quantities
❑ cost plus fee ❑ other (please specify) ___________________________

2. Fluctuations / Escalations: ❑ totally reimbursed ❑ partially reimbursed ❑ not reimbursed

3. Timing of payment: ❑ monthly ❑ milestone
❑ other (please specify) ___________________________
……
(D) IMPORTANCE OF VARIOUS PERFORMANCE CRITERIA
1. To what extent would the selected procurement options match with client's criteria and project conditions?
❑ very high ❑ high ❑ average ❑ low ❑ very low

2. What were the client's priorities against the following criteria throughout the project?

No.	Client's criteria	Priorities * (on a scale of 1 to 10, where 10 is highest)	
		At start of project	Later in project
1	Economy (lower capital costs)		
2	Lower life cycle costs		
3	Cost certainty (not exceeding budget)		

* As explicitly and implicitly conveyed
……similarly for remaining 8 (total of 11) criteria considered

(E) INDIVIDUAL PERCEPTIONS ON PERFORMANCE CRITERIA
When compared with similar building projects,
……
2. do you consider the pre-construction duration of this project to be:
❑ very long ❑ long ❑ similar ❑ short ❑ very short
……etc.