Towards ICT-enhanced management support systems for optimising infrastructure procurement

Mohan M. Kumaraswamy[1], Ekambaram Palaneeswaran[1] and S. Thomas Ng[1]

ABSTRACT | Infrastructure procurement programmes of many public clients and large private developers, increasingly involve complex networks of stakeholders. Well balanced and 'fully informed' decisions are critical in optimising resources to achieve agreed objectives. A research project in Hong Kong is aimed at developing an ICT (Information and Communications Technology) – enhanced MSS (Management Support System). This will empower the formulation of more effective and efficient construction project procurement and delivery/ operational systems – for innovative and improved 'total' management of construction projects – from a large client's viewpoint. Web-based Decision Support Systems (wDSSs) are being developed to help achieve such objectives, by capturing, codifying and mobilising both expert and experiential construction industry knowledge. Furthermore, web interfaces are being designed to mobilise the collective expertise of the entire project supply chain in real-time collaborative formats. These decision aids will enable the often fragmented multi-disciplinary project teams to build on 'state of the science' knowledge, past 'lessons learnt' and present best practices, in making more informed managerial decisions that will help to optimise inputs and reduce wasted resources. Potential benefits of wDSSs are demonstrated in this paper, through examples from the integrated framework and prototype modules/ models that are under development and 'construction' in Hong Kong. These cover a cross-section of infrastructure programme management decision scenarios, i.e. in: (1) multi-purpose contractor registration-prequalification, (2) dynamic performance appraisal of contractors and (3) evaluating 'extension of time' entitlements. Interim outcomes included herein are the basic MSS framework, pilot models of items (1) and (2) above and prototype modules of item (3) above.

KEYWORDS | construction, decisions, infrastructure, Management Support System, procurement

1 Centre for Infrastructure and Construction Industry Development, Department of Civil Engineering, The University of Hong Kong

1 Introduction

Medium to long term infrastructure programmes, such as for new airports, railway developments and large housing developments, incorporate complex multi-project portfolios. These must mobilise complex clusters of interacting resources, the efficient management of which requires rapid and effective decisions for synergising inputs and optimising outputs. Creative, if not complex, solutions are increasingly needed to solve unstructured problems that are set in large multi-dimensional solution spaces. To enable such solutions, Distributed Artificial Intelligence (DAI) based systems are being developed to provide decision support in a variety of management scenarios in general (Turban and Aronson, 2001), and in infrastructure procurement programmes in particular, e.g. in e-procurement (Obonyo et al., 2001) and project management (Manivong et al., 2002). Web-based systems are being targeted for facilitating 'collaborative decision making' involving dispersed construction project teams, e.g. by Yang et al. (2001), who also used fuzzy logic to deal with imprecision and uncertainties during decision making, and by Anumba et al. (2002) in facilitating collaborative design exercises in particular.

In the above context, recent Decision Support System (DSS) research at the University of Hong Kong has also mobilised AI Aids, e.g. Artificial Neural Networks for empowering improved procurement in infrastructure projects (Kumaraswamy, 1999). A cluster of Web-based DSSs (wDSSs) are now being developed to mobilise the tremendous powers of ICT in general and the internet in particular. Benefits are boosted, for example by real-time sharing of information inputs from multiple sources, rapid information processing and collaborative decisions based on preset protocols.

This paper introduces three examples of wDSSs that are at different stages of development, in order to briefly illustrate the range of infrastructure programme and project decisions that can be improved by such purpose-built platforms, viz.:

1 for dynamic and multi-purpose 'contractor registration-prequalification' - double-handling (indeed, multiple-handling) of data and duplicated efforts can be minimised by deploying the proposed wDSS. Moreover, the 'dynamic' features enable continuous up-dates e.g. of current work-loads and resource pools, that would facilitate better informed decisions;
2 for 'dynamic performance appraisal' of contractors centralises real-time reporting up-dates. As discussed at a meeting with the Hong Kong ETWB (Environment, Transport & Works Bureau) officials, this may well key into the previous wDSS (for contractor registration-prequalification), to support 'performance potential' assessments based on up-dated performance levels; and
3 for better informed approaches to EOT evaluation - downstream decision support for many 'players' (e.g. clients, consultants, contractors and sub-contractors) is envisaged via a third wDSS that would provide initial advice on the eligibility and quantification of claims for extensions of time (EOT). This advice is designed to help standardise the surprisingly divergent approaches to EOT evaluation by different parties to the contract (Alkaas et al., 1996). These often lead to conflicting interpretations of the same contractual provisions and site incidents/ conditions scenarios (Kumaraswamy and Yogeswaran, 2003) and consequential disputes. The EOT evaluation wDSS is expected to facilitate more structured first-order (initial) evaluations that can help to reduce such disputes.

In addition to the above three DSSs introduced in this paper, other ICT-enhanced MSSs are under development at the Centre for Infrastructure & Construction Industry Development of The University of Hong Kong. These include (1) a Time-Cost optimisation model (Zheng et al., 2004) that uses a Genetic Algorithm based 'evolutionary' AI tool, which 'iterates' rapidly through improving (as in genetic evolution) alternative project time-cost combination solutions; and (2) a Web-based quality MSS that operates at both the project (micro) level and the programme/organisational (macro) level (Ng, 2004).

However, both systems theory and recent experiences confirm the futility of ad hoc attempts to separately optimise any such sub-system (e.g. safety, quality or productivity) by itself and independently of the whole system. An integrated MSS framework is therefore being developed to synergise the envisaged suite of interlocking wDSSs and MSSs that could significantly enhance the quality and speed of infrastructure programme and project decisions.

2 Over-arching integrative MSS framework

The multi-dimensional objectives of multiple stake-holders need to be integrated into a manageable multi-criteria decision scenario. An over-arching MSS framework was formulated in this research project to cater to both short and longer term objectives, e.g. including environmental sustainability, 'whole life' (infrastructure life-cycle) considerations, human resource, technological and construction industry development, all of which will in turn eventually feed into regional and national development.

Figure 1 illustrates the conceptual framework that also incorporates longer term human resource, organisational/institutional and technological development systems. 'Procurement systems' are taken to include five up-stream strategic sub-systems, while 'delivery' encompasses the downstream managerial/ operational sub-systems, as shown in Figure 2. Briefly, in terms of the procurement system: after the front-end demarcation of an infrastructure programme into work packages (WP) or projects, the functional grouping (FG) involves decisions on whether the design, construction, project management and financing (and various components of all these functions), are handled separately by different organisations, or integrated to different degrees e.g. in different types of Design & Build, BOT-type public-private partnerships, Joint Ventures, alliances or other arrangements. The choice of payment modalities (PM) includes decisions on (a) the basis of payment i.e. whether on measured/ re-measured work done, or on lump sum or other terms; (b) the timing and currency of the payments etc. The contract conditions (CC) sub-system requires decisions on the general and special conditions of contract that would facilitate the implementation of the FG and PM sub-system choices. Selection methodologies (SM) cover the selection of all supply chain organisations / members, including joint venture partners, consultants, constructors, sub-contractors and suppliers. The many options and interactions within and across these sub-systems are described by Kumaraswamy (1998). An extension into initial approaches to optimising decisions when selecting appropriate project-specific procurement systems is described by Kumaraswamy and Dissanayaka (2001).

The interactions between the delivery sub-systems identified in Figure 2 are self-evident, hence underlining the importance of designing them to be synergistic, or at least compatible from the outset.

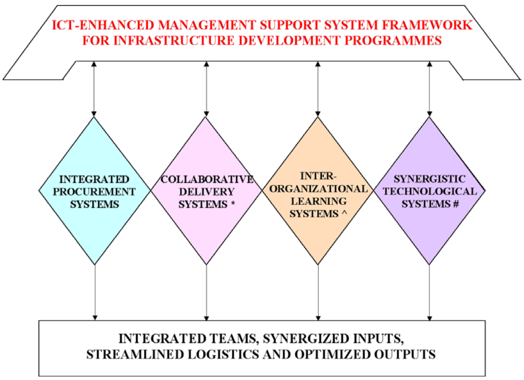

Figure 1. Proposed Management Support System Framework

* includes cost, safety, information and claims management
^ includes training & development and knowledge management
# includes design, construction, operational and maintenance systems

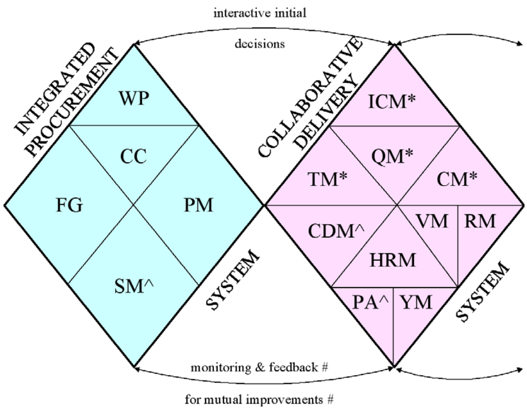

Figure 2. Interacting collaborative Systems and Subsystems

^ sub-systems **discussed** in this paper
* sub-systems **referenced** in this paper
# e.g. organizational Performance Appraisals provide feedback to improve future Selection and lessons learned in CDM provide feedback for drafting clearer & more rationalized CC

Procurement sub-systems
CC – Contract Conditions
FG – Functional Groupings
PM – Payment Modalities
SM – Selection Methodologies
WP – Work Packaging

Delivery sub-systems
CDM – Claims & Disputes Management
CM – Cost Management
HRM – Human Resources Management
ICM – Information & Communication Management
PA – Performance Appraisal
QM – Quality Management
RM – Risk Management
TM – Time Management
VM – Value Management
YM – Safety Management

Furthermore, as shown in Figure 2, multiple feedback loops help to continuously improve relevant sub-system performance levels e.g. in the case of (a) performance appraisals of contractors (in PA) feeding back to the contractor selection sub-system (in SM) and (b) contract document ambiguities and conflicting interpretations uncovered during the assessment of claims and resolution of disputes (in CDM), feeding back to up-grade future contract conditions (in CC).

The following three sections provide insights into specific sub-systems that are being developed to fit into the envisaged framework. The three proposed sub-systems are being developed in the Hong Kong context e.g. taking into account relevant Hong Kong Environment, Transport & Works Bureau Technical Circulars and the 2002 Contractor Management Handbook (in respect of contractor selection and appraisal), the Hong Kong Government General Conditions of Contract (in relation to time extension entitlements); as well as the previous initiatives towards Electronic Services Delivery (ESD), and the recently conceived 'Works Projects Communication Platform' and 'Works Projects Information Standards' for infrastructure projects. Key players in these initiatives are being currently interviewed in collecting relevant information for the system development.

3 wDSS for dynamic multi-purpose contractor registration prequalification

A series of high-powered probes into construction industries in many countries/ regions (e.g. in Australia, Hong Kong, Singapore, South Africa and UK) have recently sought solutions to persisting problems that have lowered productivity, quality, safety and client satisfaction (De Saram et al., 2001). One of the common sources of such problems has been generally agreed as the awarding of contracts to the lowest bidder with little, if any, attention to their potential performance levels. Despite repeated rhetoric, and recent guidelines (including Technical Circulars in Hong Kong) encouraging decision makers to 'factor in' the technical capacities of bidders, public sector officials are particularly handicapped by the lack of widely accepted alternative contractor selection methodologies that would facilitate reliable (and 'defensible') choices. To address this shortfall, Kumaraswamy and Walker (1999) and Palaneeswaran and Kumaraswamy (2000) compared the performance of some internationally emerging 'better' public sector practices in contractor selection, in an extensive desk study that fed into the system development.

A focus on the initial stages of contractor selection – i.e. on (a) general 'registration' (as in 'registered lists maintained by large public clients e.g. Works Bureau and Housing Authority in Hong Kong) and/or (b) prequalification for particular projects – unearthed specific shortcomings in many present systems. For example, registration of contractors in a few (e.g. three) bands (e.g. <$ 10 m., $ (10-50) m. and > $ 50 m.) does not differentiate between two contractors perceived to be capable of handling $ 11 m. and $ 49 m. contracts, whereas it unrealistically elevates the former by a big step above another who is seen to be capable of a $ 9 m. contract. Palaneeswaran and Kumaraswamy (1999) proposed (a) 'point-scores' for each contractor's perceived capacity that would replace such coarse 'banding', thereby enabling closer (fine-tuned) comparisons; and (b) regular (dynamic) up-dates e.g. of residual financial capacities and resource availabilities (e.g. after being awarded a new contract).

Notwithstanding the evident advantages in theory, practical difficulties of such dynamic data collection and processing seemed to be formidable. However, a wDSS framework has been formulated to overcome these difficulties by utilising ICT to rapidly collect and centrally process all relevant contractor data for multiple uses. For example, this would be made available to subscribing construction clients, who would thereby not have to maintain separate registered lists nor call for 'full' prequalification for each project. Contractors would also be saved the trouble of multiple submissions to different clients at various points of time (Ng et al., 2002).

Figure 3 displays a screenshot of a 'weighted scoring module' for one of the criteria to be considered i.e. 'financial strengths'. The 'weighting' of sub-criteria can be input by the particular client user, or alternatively, (s)he may use the suggested default values. The scores of this contractor ('XYZ Construction Co.') against each sub-criterion are calculated from the submitted financial data according to preset protocols e.g. formulae, for this particular criterion. The weighted score for each criterion will then be computed. These will then be weighted in turn (based on another set of weightings between criteria) and combined with each other. Other proposed (default) criteria, apart from 'financial strength' include 'organisation and management system', 'past performance', 'past experience', 'human resources', 'teamworking potential', 'safety and health

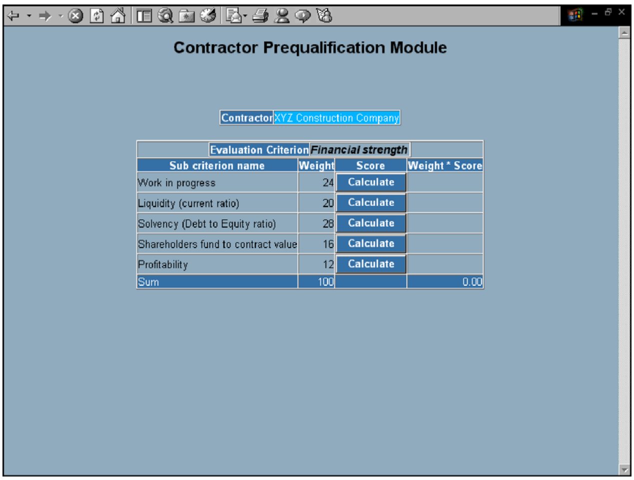

Figure 3. Sample screenshot of a weighted scoring module in the prototype wDSS for Contractor Registration-Prequalification

aspects' and 'environmental aspects'. The combined 'performance potential' scores of each potential/ candidate contractor can then be compared. Next, a shortlist can be prepared of those with scores above a chosen threshold before inviting specific bids.

It is planned to provide one option to purely follow relevant guidelines from identified ETWB (Environment, Transport and Works Bureau) Technical Circulars e.g., 22, 23, 36, 41, 42, 47, 49 and 53 of 2002 and 8 of 2003; and the 2002 Contractor Management Handbook. A second option would superpose additional features, criteria and sub-criteria as have been distilled from overseas and Hong Kong 'best practice'. A third option would provide for merely the latter 'best practice' route, i.e. catering to clients not at all constrained by public sector regulations or guidelines. Of course a manual over-ride would be available for all elements in all options.

4 wDSS for dynamic performance appraisal

Results from the foregoing contractor registration–prequalification wDSS will be enhanced by reliable and speedy updates of contractor performance on recent and ongoing projects. Many large construction client organisations have developed their own contractor performance appraisal systems, e.g. the HKSAR ETWB has developed a 'Contractors' Performance Index System', as in their Technical Circulars 2/2000 and 23, 24/ 2002, based on criteria such as: workmanship, progress, site safety, attendance to emergencies and attitude to claims. Meanwhile, the Hong Kong Housing Authority has been steadily upgrading its 'PASS' (Performance Assessment Scoring System) that evaluates both contractor inputs and outputs (Kumaraswamy, 1996); and Singapore has similarly developed and also re-oriented its 'CONQUAS' (Construction Quality Assessment System) to provide incentives for better performing contractors (Lam et al., 2002).

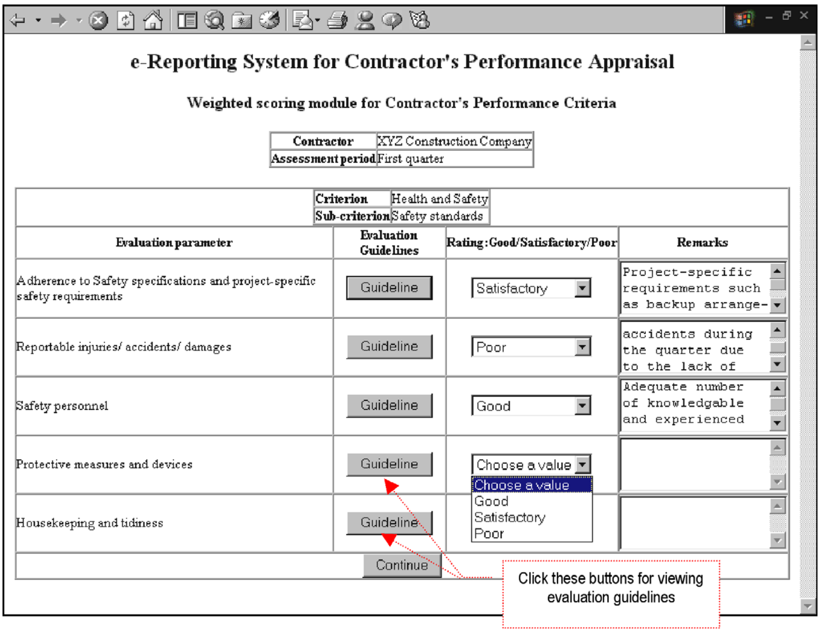

Figure 4. Sample web-based input structure for the Performance Appraisal wDSS

Based on a pilot investigation that included another extensive literature review, Ng et al. (2002), a framework was developed for a more comprehensive 'dynamic e-Reporting system for contractor's performance appraisal'. This includes the conceptual framework, basic system design, 14 performance criteria, sets of associated sub-criteria, two levels (primary and secondary) of data recording/ reporting, the format of a project performance e-report and the format for comparing consolidated contractor's scores (in a 'performance score league') over time. Both (a) the different 'functionality obligations' and (b) the varying levels of 'access rights' of different stakeholders have also been proposed. As an example, Figure 4 provides a sample of a reporting frame for the 'safety standards' sub-criterion under the 'Health and Safety' criterion. This wDSS will be developed to incorporate and provide optional 'extras' to improve on, or by-pass (in the case of private sector developers or quasi-governmental bodies), the above basic guidelines of the ETWB.

5 wDSS for time extension claims

This DSS was developed on a web-based platform to provide online decision support for evaluating Extension of Time (EOT) entitlements. The development was based on a questionnaire survey that uncovered the need for such a DSS, given the conflicting approaches to EOT evaluation and the woeful lack of guidance on evaluation strategy selection. The results of this survey are reported by Kumaraswamy and Yogeswaran (2003); while the initial interviews with experts that led to the system formulation are described by Kumaraswamy et al. (2001). The prototype wDSS was then developed based on the knowledge distilled from relevant literature, domain experts and experienced practitioners.

The target users of the wDSS include contractors, clients, and claims consultants. The users will be asked for relevant project information when interactively seeking initial advice on the viability of potential EOT claims. The system architecture incorporates an APACHE web server, web browsers capable of handling hypertext markup language, style sheets and Java scripts (e.g. Internet Explorer, Netscape Navigator), HTML codes, cascading style sheets, PERL scripts, Java scripts and CSV (comma separated variables) files.

At present, this wDSS is designed to provide decision support for time extension claims under the Hong Kong General Conditions of Contracts for Civil Engineering Works (1999). The structured basic model and object oriented strategy developed for the prototype will be used as a basis for extending the DSS to cater to other Conditions of Contracts (e.g. Hong Kong Government Conditions of Contracts for Building Works, the international FIDIC Conditions of Contracts and the Engineering Construction Contract of the Institution of Civil Engineers, UK).

Figures 5 and 6 provide an overview of the wDSS structure. The key modules are: (1) TEECS (Time Extension Eligibility Checking System); (2) QMS (Quantification Method Selector); and (3) QUANTECS (Quantification of Time Extension Claims). Furthermore, clarifications of common terms and relevant practices, links to useful web sites, feedback forms, and other hyperlinks are being provided for convenience. The TEECS module provides initial advice on the 'eligibility of time extension claims based on contract-specific/'listed' causes such as 'Inclement Weather', 'Typhoon Signal 8', 'Black Rainstorm Warning', 'Variation Order', 'Late Site Possession', and 'Suspension of Works by Engineer'.

Moreover, general advice on other causes (that are not 'listed' in the Standard Conditions of Contract) is being added where possible. The QMS module will provide initial advice to the users in selecting a suitable quantification method for time extension claims, depending on the project circumstances. However, users have an option to by-pass this advice, and directly

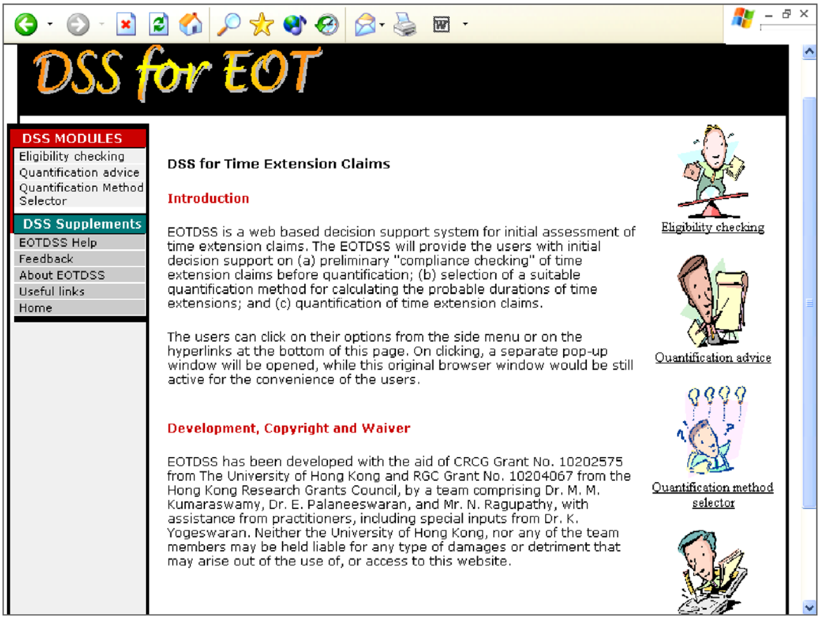

Figure 5. Part of the opening screenshot from the wDSS for time extension claims

select their own preferred quantification method. The QUANTECS module will provide decision support advice for quantification of time extension claims using proven methods e.g.: (a) 'As Planned Impacted Programme'; (b) 'As Built But For'; (c) 'As Planned vs. As Built' and (d) 'Windows Analysis'; these being the methods presently incorporated into the QMS module.

The finalised EOTDSS platform will have multi level security (e.g. unrestricted, partially restricted and restricted access) and could be implemented as a

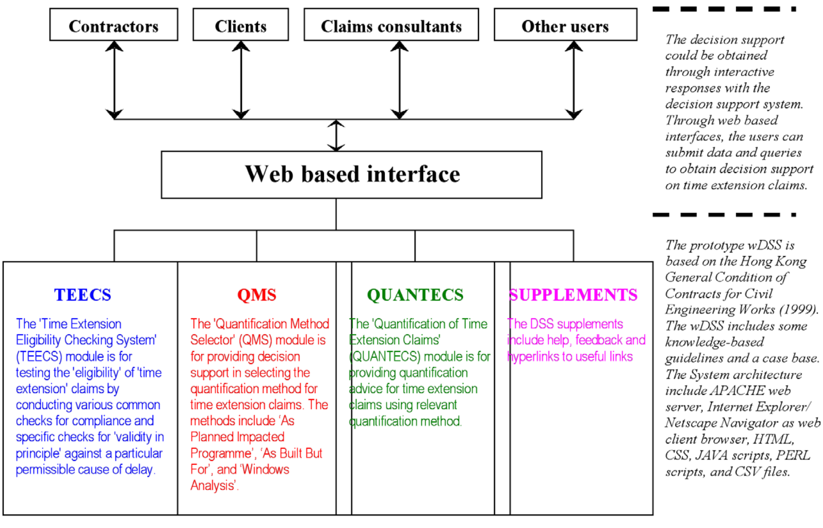

Figure 6. Conceptual framework of the wDSS for time extension claims

subscription based service, if decided as appropriate. Furthermore, suitable integration with project management software (such as Microsoft Project and/ or Primavera) is being explored. Kumaraswamy et al. (2001) provide information on the TEECS module structure, including samples of the decision tree logic derived from the Hong Kong Government Conditions of Contract.

Prototypes of the TEECS and QMS modules were demonstrated in January 2003 to a small group of domain experts from Hong Kong and the UK at a presentation in Hong Kong. The very favourable comments received strongly encouraged further development along the above directions. Specifically, the UK experts remarked that they had not encountered any system that could fulfill such functions and that they would be interested in participating in the development.

6 Further discussions and concluding observations

In terms of evaluation, feedback and refinement, exercises similar to the above (on the EOT evaluation modules), are planned for each module and overall sub-system - through a series of demonstrations to relevant key industry personnel who are experts with experience in each of these areas.

Integrating the specialised wDSSs discussed above within a coherent and comprehensive MSS framework needs detailed systems and process analyses, to identify linkages and interactions. For example, the feasibility of integrating the proposed contractor 'registration-prequalification' and 'performance appraisal' wDSSs into a comprehensive selection system has already been successfully tested and validated during a Ph.D. research project that focused on contractor selection for design-build projects (Palaneeswaran, 2000). This integration of the wDSSs with a comprehensive MSS platform is the ultimate target of this R&D exercise. Synergies generated from such integration are at the core of the proposed DSS for formulating better informed decisions on infrastructure procurement and delivery systems, that will also be compatible with each other, as envisaged in the Figure 2 framework.

Apart from the other wDSS presented here (for evaluating EOT), and others referenced in this paper (e.g. for broader procurement system selection, time-cost optimisation and quality management), other wDSSs/ MSSs are also being developed to address related critical issues: (a) in selecting other key members of the supply chain (Kumaraswamy et al., 2000; Rahman et al., 2003) and (b) in integrating their inputs and outputs through improved collaboration (Kumaraswamy et al., 2002; Palaneeswaran et al., 2003), and ICT enablers for such collaboration (Ugwu et.al., 2003a). The latter would provide practical mechanisms for accelerating the various 'partnering' and 'alliancing' initiatives that are being advocated to create and co-ordinate 'virtual project teams' that span across organisational boundaries, transcending narrow short-term and short-sighted objectives, in boosting performance on infrastructure programme and project management. Furthermore, another family of MSSs is being developed to assist designers of infrastructure such as highway bridges and road pavements, who must address 'durability assurance' and life-cycle issues in their designs (Ugwu et al., 2003b).

The value of such endeavours in general, is corroborated by parallel exercises that are also targeting more informed and 'intelligent' decision support for infrastructure programme and project management elsewhere, e.g. by El-Diraby (2002), as well as by John Christian (2002) in Canada; by Al-Jibouri et al. (2002), as well as by McCaffer & Hassan (2002) in Europe; and by Molenaar (2002), as well as by Liu & Erickson (2002) in USA. In addition, Ribeiro and Lopes (2002) provide specific insights into recent applications of web-based systems across construction project supply chains that span complex networks of multiple organisations. Any relevant lessons drawn from such parallel initiatives and studies will be valuable in reducing the learning curve in the present Hong Kong exercises, if selectively and carefully adapted to the local scenario.

Barriers to the adoption of IT in the construction industry in general (CIRC, 2001), and Web-based tools in particular (Tam, 1999) have been found in the past. However, it appears that some of these barriers are being gradually dismantled, for instance, with the increased pervasiveness of Web-based systems e.g. for on-line day-to-day procurement. This is borne out by an ongoing 'needs analysis' and 'communication mode preferences' survey in a parallel (independent but also ongoing) R&D project for developing information systems for Small & Medium Contractors (Rahman et al., 2004).

Still, such ICT-enabled MSSs can only provide a level of support that is limited by (a) the extent of expertise and experience encapsulated, and (b) the culture of collaboration and degree of co-operation ultimately generated within the programme and project supply chains. Furthermore, rapidly ongoing advances in managerial systems and technologies require wDSSs/ MSSs to be updated regularly in order to retain their relevance. The ultimate decisions must still be made by the management personnel on a particular project, who can 'factor in' project-specific priorities, parameters and phenomena that can not always be incorporated in such pre-structured support systems. However, they would have the advantage of readily accessing and building on the expertise and experience of others, while achieving synergies and savings through this suite of wDSSs/ MSSs which are planned to be developed in a series of inter-locking exercises, and incorporated in stages into a comprehensive ICT-enabled MSS framework for optimising infrastructure programme and project procurement.

Acknowledgements

The MSS project described in this paper is supported by a grant from the Hong Kong Research Grants Council (HKU 7011/02E). The support of this grant and of the industry partners is gratefully acknowledged. So is the contributory/ related work of Eddie Sze, Motiar Rahman and Onuegbu Ugwu - all affiliated to The University of Hong Kong based Centre for Infrastructure & Construction Industry Development <http://www.hku.hk/cicid/>.

REFERENCES

[1] Al-Jibouri, S.H., Mawdesley, M.J. and Al-Mohamdi (2002) *An Intelligent Decision Support System for Project Managers*, 1st International Conference on Construction in the 21st Century, Miami, USA, 95-102.

[2] Anumba, C.J., Ugwu, O.O., Newnham, L. and Thorpe, A. (2002) *Collaborative Design of Structures using Intelligent Agents*, Automation in Construction, 11, 1, 89-103.

[3] Alkass, S., Mazerolle, M. and Harris F. (1996) *Construction delay analysis techniques*, Construction Management and Economics Journal, 14, 375-394.

[4] Christian, J. (2002) *An overview of Systems utilising Information & Communication Technologies:* five research case studies, 18th Annual ARCOM Conference, Newcastle, UK, 2, 485-492.

[5] CIRC (2001) *Construct for Excellence*, Report of The Construction Industry Review Committee, Hong Kong, HKSAR Government, Hong Kong, China.

[6] De Saram, D.D., Rahman, M.M. and Kumaraswamy, M.M. (2001) *Setting Targets and Selecting Tools for Construction Industry Development*, Proceedings of the Conference on "Engineering Management for Accelerated Development in South and South East Asia", Colombo, Sri Lanka, October 2001, Institution of Engineers, Sri Lanka, 43-53.

[7] El-Diraby (2002) *e-Coordinating Infrastructure Decisions*, 1st International Conference on Construction in the 21st Century, Miami, USA, 589-592.

[8] Kumaraswamy, M.M. (1996) *Contractor Evaluation and Selection:* A Hong Kong Perspective, Building and Environment Journal, 31, 3, 273-282.

[9] Kumaraswamy M.M. (1998) *Industry Development through creative Project Packaging and Integrated Management*, Journal of 'Engineering, Construction and Architectural Management', Blackwell Science, 5, 3, pp. 228-238.

[10] Kumaraswamy M.M. (1999) *Uncommon Sense and Artificial Intelligence for Re-engineering Procurement Systems*, 2nd Construction Industry Development Conference, Singapore, October 1999, Proceedings, Vol. 1, pp. 173-181.

[11] Kumaraswamy, M.M. and Walker, D. (1999) Multiple performance criteria for evaluating construction contractors, chapter in the CIB book entitled '*Procurement systems in construction: A guide to best practice in construction*', E&FN Spon, 228-251.

[12] Kumaraswamy, M.M. and Yogeswaran, K. (2003) '*Substantiation and Assessment of Claims for Extensions of Time*', International Journal of Project Management, 2003, Vol. 21, pp. 27-38.

[13] Kumaraswamy, M.M., Palaneeswaran, E. and Humphreys, P. (2000) *Selection matters - in Construction Supply Chain Optimisation*' International Journal of Physical Distribution and Logistics Management, 30, 7/8, 661-680.

[14] Kumaraswamy M.M. and Dissanayaka, S.M. (2001) *Developing a Decision Support System for Building Project Procurement, Building & Environment* Journal, Vol. 36, No. 3, pp. 337-349.

[15] Kumaraswamy, M.M., Nadarajah, E., Palaneeswaran, E. and Rahman, M.M. (2001) *Dealing with Delays in Evaluating Extensions of Time*', Proceedings of the 2001 ARCOM Conference, 2, 753-764.

[16] Kumaraswamy, M.M., Rahman, M.M., Palaneeswaran, E. and Ng, S.T. (2002) *Innovative Initiatives in Integrating Construction Supply Chains*, 1st International Conference on Construction in the 21st Century, Miami, USA, 589-592.

[17] Lam, P.T.I., Chan, A.P.C. and Shea, W.C.Y. (2002) *Construction Quality Assessment System (CONQUAS)*: the Singapore Experience, 1st International Conference on Construction in the 21st Century, Miami, USA, 303-309.

[18] Liu, L.Y. and Erickson, C. (2002) *Engineering and Construction Collaboration using Information Technology*, 1st International Conference on Construction in the 21st Century, Miami, USA, 521-528.

[19] Manivong, K.K., Jaafari, A. and Gunaratnam, D. (2002) *Tools and Techniques for Intelligent Project Management Information Systems:* heralding a new Project Management paradigm, 1st International Conference on Construction in the 21st Century, Miami, USA, 617-623.

[20] McCaffer, R. and Hassan, T.M. (2002), *Changes in large scale Infrastructure arising from ICT developments*, Journal of Building and Construction Management, 7, 1, 1-8.

[21] Molenaar, K.R. (2001) *Web-based Decision Support Systems:* Case Study in Project Delivery, Journal of Computing in Civil Engineering, 15, 4, 259-267.

[22] Ng, S.T., Palaneeswaran, E. and Kumaraswamy, M.M. (2003) *A web-based Centralised Multi-Client Cooperative Contractor Registration System*, ASCE Journal of Computing in Civil Engineering, 17(1), 28-37.

[23] Ng, S.T., Palaneeswaran, E. and Kumaraswamy, M.M (2002) *A Dynamic e-Reporting System for Contractor's Performance Appraisal, Advances in Engineering Software journal*, 33, 339-349.

[24] Ng, S.T. (2004) *An integrative project-oriented quality management system for construction using the Internet technologies*, Proceedings: INCITE 2004 - The World IT Conference for Design and Construction: Designing, Managing and Supporting Construction Projects through Innovation and IT Solutions, February 18-21, Berjaya Beach Hotel, Langkawi, Malaysia, (ed. P. Brandon, H. Li, N. Shaffii & Q. Shen), 553-558.

[25] Obonyo, E.A., Anumba, C.J., Thorpe, A. and Parkes, B. (2001) *Agent-based Support for Electronic Procurement in Construction*, Artificial Intelligence in Construction & Structural Engineering Conference, Loughborough, UK, 99-113.

[26] Palaneeswaran, E. (2000) *Contractor Selection Systems for Design-Build Projects*, PhD Thesis, The University of Hong Kong.

[27] Palaneeswaran, E. and Kumaraswamy, M.M. (1999) *Dynamic Contractor Prequalification*, Proceedings of ARCOM 1999 Conference, Liverpool, UK, 2, 615-624.

[28] Palaneeswaran, E. and Kumaraswamy, M.M. (2000) *Benchmarking Contractor Selection Practices in Public-Sector Construction* - A proposed Model, Engineering, Construction & Architectural Management journal, 7, 3, 285-299.

[29] Palaneeswaran, E., Kumaraswamy M.M., Rahman, M.M. and Ng, T.S.T. (2003) *Curing congenital Construction Industry concerns through Relationally Integrated Supply chains*, Journal of Building and Environment, April 2003, Vol. 38, N0. 4, pp. 571-582.
[30] Rahman, M.M., Kumarswamy, M.M. and Ng, T.S.T. (2003) *Re-engineering Construction Project teams*, ASCE Construction Research Congress, Hawaii, USA, March 2003, Proceedings, Editors: K.R. Molenaar and P.S. Chinowsky, in CD Rom, 9 pages.
[31] Rahman, M.M., Kumaraswamy, M.M., Ng, T., Lam, E., Ho, E., Lee, S., Palaneeswaran, E. and Ugwu, O.O. (2004). *Needs of SMCs in Hong Kong:* Information Management and IT, International Conference of CIB 102, April 27-28, Toronto, accepted for presentation and publication in the conference proceedings.
[32] Ribeiro, F.L. and Lopes, J. (2002) *An approach to e-Business in Construction*, 18th Annual ARCOM Conference, Newcastle, UK, 2, 445-484.
[33] Tam, C.M. (1999) *Use of the Internet to enhance Construction Communication:* Total Information Transfer System, International Journal of Project Management, Vol. 17, No. 2, 107-111.
[34] Turban, E. and Aronson, J.E. (2001) *Decision Support Systems and Intelligent Systems*, Prentice Hall, USA.
[35] Ugwu, O.O., Kumaraswamy, M.M., Rahman, M.M. and Ng, S.T. (2003a) *IT Tools for collaborative working in Relationally Integrated Supply Chains*, Proceedings of the 2nd International Structural Engineering and Construction Conference, Rome, Sept. 2003, editor: F. Bontempi, A.A. Balkema, Netherlands, ISBN 90 5809 599 1, Vol. 1, pp. 217-222.
[36] Ugwu, O., Kumaraswamy, M. and Kung, F. (2003b) *Understanding the Economics of Durability Design for Highway Bridges*, Proceedings of the 3rd International Conference on Current and Future Trends in Bridge Design, Construction and Maintenance, (Barr B. I. G, Shaopei L, Frangopol D. M, Xila L, Lark R. J, Renjie M, Nowak A. S, & Zhen H Eds.) China, Shanghai, China, 29 September - 1 October 2003, pp 150-158, Institution of Civil Engineers (ICE), UK.
[37] Yang, H., Anumba, C.J. and Carrillo, P.M. (2001) *Evaluation of a Fuzzy Logic-based collaborative Decision-making System for Construction Project Teams*, Artificial Intelligence in Construction & Structural Engineering Conference, Loughborough, UK, 86-98.
[38] Zheng, D.X.M., Ng, S.T. and Kumaraswamy M.M. (2004) *Applying a GA-based Multiobjective approach for Time-Cost Optimization*, Journal of Construction Engineering and Management, ASCE, 130(2), 168-176.