DATA ENVELOPMENT ANALYSIS OF IT-ENABLED STRATEGY FOR CONSTRUCTION ORGANISATIONS

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The strategic impacts of Information Technology (IT) on the organisations' performance have been of interest to both managers and researchers for decades. This is partly because despite the massive investments in IT the findings on its contribution to organisation performance were inconsistent. Attempts to explain the reasons for the equivocal results were attributed to difficulties in modelling, choice and operationalisation of variables, data measurement and analysis and focus on an aggregate organisation level of analysis thereby ignoring the intermediate processes through which IT impacts on organisation performance. Furthermore, most of the previous studies were imprecise, theoretically unstructured and are not directly applicable to the construction industry. To mitigate some of these drawbacks a conceptual model for measuring IT business value in construction organisation is proposed. The model adopts three paradigms of process-based view, microeconomics-based view, and resource-based view as the theoretical framework to model the relationship between IT and firm performance. Using economic based view we derived a production function using a non parametric technique of Data Envelopment Analysis (DEA) to test the model empirically. The result could be used to benchmark and establish the relative competitive advantages of the construction organisations and provide support to managers in decision making on IT investments.

Keywords: data envelopment analysis, information technology, business value, performance measurement.

INTRODUCTION

For over two decades academic and business managers have argued and debated the strategic value of IT without reaching consensus. Thus, attempts to establish empirical evidence of the possible gains from IT investments produced what was termed 'productivity paradox' in some cases (Brynjolfsson 1993). Some of the reasons ascribed for the inconsistencies in the results of the previous IT business value research include difficulties associated with modelling and measurements of the return of IT investment, mode of data collection and sampling, industry type, and choice of dependent variables (Oh and Pinsonneault, 2007). Furthermore, most of the researches were carried out through imprecise and unstructured theoretical constructs; hence there is limited empirically validated frameworks and results (King *et al.*, 1989). To mitigate these Kassim *et al.*,(2009) proposed a conceptual model of IT business value in construction organisation through a web of intermediate levels of construction

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project activities, in line with the value-chain analysis suggested by Porter (1985) and organisation resource-based view (RBV) and core competence (Barney, 1991).

This paper extends Kassim's model by deriving a mathematical framework using non parametric technique of data envelopment analysis (DEA) for empirical testing. The paper is the second stage of a three-stage research process of developing and empirically testing a comprehensive integrated IT business value model that investigates the relationship between IT-enabled strategies and construction organisations' competitive advantage.

The rest of the paper is structured into the following sections: literature review, proposed theoretical framework, data envelopment modelling, methodology, and conclusion.

LITERATURE REVIEW

IT-enabled Competitive Strategies

IT-enabled strategy involves organisation's strategic moves of deploying IT resources to support the delivery of its value chain for sustainable improvement in its competitive position (Bharadwaj, 2000; Stratopoulos and Dehning, 2000). IT is variously referred to as a collective integration of computing technology and information processing; as something which include equipment, applications and services that are used by organisations to deliver data, information, and knowledge to individuals and processes (Mentor, 1997; Turk, 2000), refer to as IT resources. IT resources include both tangible and intangible organisation's assets that are related to the implementation of IT-enabled strategy such as IT infrastructure (ITI). ITI is conceptualisation in four dimensions: the shared technical components, IT Human competence, IT application and business process as in figure 1(Weill, 1993; Bhatt, 2000). IT-enabled strategy has been suggested to have a significant impact on construction organisations competitiveness (Skibniewski and Nitithamyong, 2004).

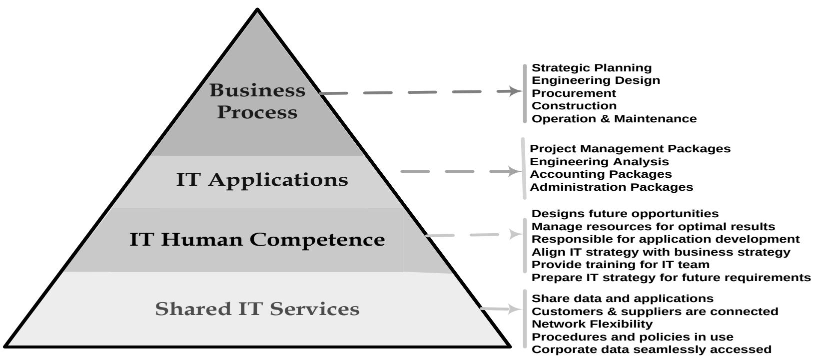

Figure 1: Conceptualisation of ITI

Results on previous research of impact of IT-enabled strategies on the performances of organisations have been equivocal. Some reasons for the inconsistencies include lack of contextualisation of the studies based on business specifics, choices of inconsistent variables, impact of lag between investment and outcome, and methods of data analysis (Kohi and Devaraj, 2003). Some of these drawbacks are highlighted below and mitigation incorporated in our model.

Industry type
The need to develop a framework that appropriately represents IT's value in a business context is recognised (Thouni *et al.*, 2008) as an important step in evaluating IT payoffs correctly. There were limited theoretical frameworks used in previous

studies to provide a basis for investigating the impact of IT on a firm's performance within a business context (Lee, 2001; Kohli and Devaraj, 2003). Therefore in order to understand the unique characteristics of IT business value in the construction industry, Kassim *et al.*(2009) developed a conceptual model using the typical industry value chain for examining the effect of IT through a ‘web of intermediate level contribution’(Barau *et al.*, 1995). Another factor that impacts on the outcome of the evaluation of the IT investment within any industry is the choice of the variables for analysis.

Choice of variables

The equivocal results from different IT payoff studies are also attributable to the use of inconsistent input and output variables (Weill, 1988). The contemporary IT investment evaluation approach has focused on variety and inconsistent quantitative financial assessment and appraisal methods (Chen *et al.*, 2006; Tallon and Kraemer, 2006). There was also emphasis on using dollar values in the form of IT related expenditure to represent independent variables. Sigala *et al.*, (2004) argue that using such financial metrics do not provide insight to the actual usage of the IT since the outcome is more likely to be dependent on the IT resources that are deployed and used. The impact of IT investment on the construction organisation performance is operationalised through a measure of availability, degree of usage and the level of integration of its IT resource as a complement to certain unique and heterogeneous resources such as work practices, organisational structure and culture residing in the organisation. However, data is required to empirically test any declaration of the relationship between the selected variables. Furthermore, the type of data and the method of analysis have significant impact on the outcome.

Data Collection and Analysis

The realisation of the benefits from IT investments may not be accounted for at the time of data collection due to maturity issues and the lag between the investment and the payoffs (Brynjofsson, 1993). Also Weil (1988) suggested that because of the time lags among the variables, a priori reasoning on the direction of causality is often difficult. The use of longitudinal or panel data in examining the impact of IT investment is suggested to improve the accuracy of the results, since it allows researchers to examine the lag effects (Devaraj and Kohli, 2000). With the difficulty in collecting longitudinal data; cross-sectional data to simulate a time series can provide good insight as suggested by Shafer and Bryd (2000). Thus, a cross-section data with projected growth is incorporated in the proposed model.

PROPOSED THEORETICAL FRAMEWORK

There is a strong argument for the need to investigate the impact of IT on the performances of organisations at process level (Barua *et al.*, 1995and Melville *et al.*, 2004). Therefore, Kassim *et al.*(2009) developed a model that adopts the three paradigms of economic-based view Porter (1985), process-based view (Barua, Krieble, and Mukhopadhyay, 1995) and resource-based (Barney, 1991) as theoretical frameworks. Using the Porter’s value chain concept satisfies the process-based view which hypothesised that IT investments create competitive advantages by improving operational efficiency of intermediary business processes which in turn, under the appropriate conditions, lead to better organisational-level performance (Qing and Jing, 2005; Newbert, 2008). The resource-based view (RBV) proposed that the deployment and exploitation of valuable, rare resources, and capabilities contributes to an organisation’s competitive advantage, which in turn contributes to its performance

(Barney, 1991). To satisfy this requirement complementary resources are incorporated in the model as independent variables. The economic view of IT value is that of input in the production function of a firm and there is a substituting effect between IT and other production factors (Dewan and Chung-ki, 1997). The concept allows estimation of the measure of IT resources usage as an economic production function, in this case using DEA concept. Using the process-based view the model proposed a typical construction value chain consisting of five primary activities: strategic planning, engineering design, procurement, construction and start up and operation and maintenance. Each of these activities were further broken down at the process level, e.g. strategic planning includes market research, bidding process, contract strategy, and manpower planning. These sub activities are referred to as work functions (WFs) (El-Mashaleh *et al.*, 2006). The level of IT utilisation and integration in executing the WFs is used to measure the extent of business application as IT business application resource, as depicted in Fig. 2.

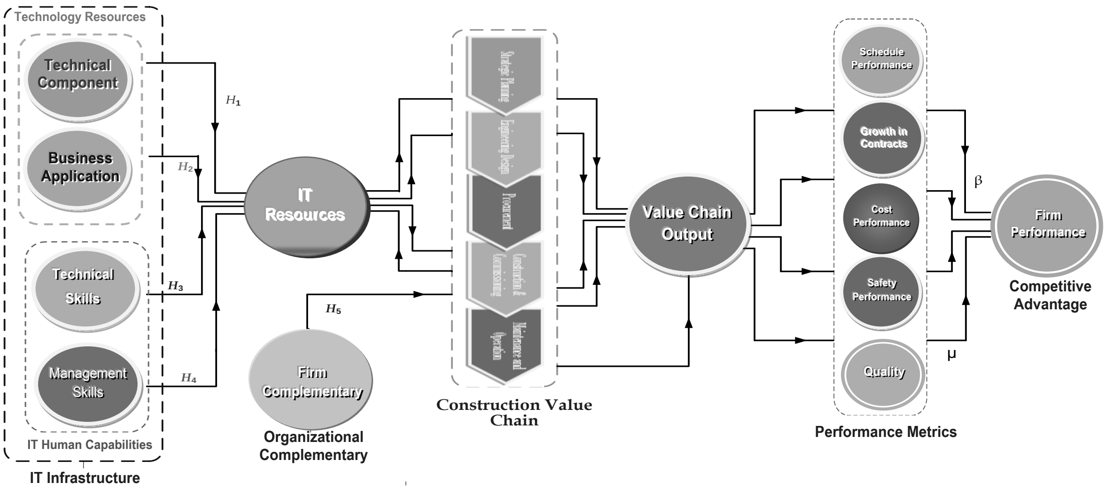

Figure 2. Conceptual IT business model for construction organisations, adopted from Kassim et al., (2009)

Based on content analysis of the literature the ITI as conceptualised above and complementary resources are used as independent variables to investigate their impact on the construction organisation performance though the value chain in form of the following hypotheses:

- The technological components of ITI are readily available in the marketplace, therefore will not have significant impact on competitive advantage of construction organisation.
- IT business applications will have positive impact on construction organisation performance.
- Superior IT human capabilities will have positive impact in providing a source for construction organisation's competitive advantage.
- Complementary organisational resources will have positive impact in creating IT business value in construction organisation.

Input Variables

The measure of the IT resources as input independent variables are conceptualised as the level of usage rather than their dollar value because of the difficulties in getting dollar value of organisation's IT investments (Kumar, 2004). The use of perception as a barometer of IT business value via a survey questionnaire is proposed as an instrument of data collection. Tallon and Kraemer (2007) established that a significant positive correlation exists between objective (performance measure) and perceptual measures of IT business value. The measure of the dimensions of ITI and complementary resources are used as input variables.

Output Variables

The output dependent variables for the model are a measure of the construction organisation performance metrics. The performance measurement in construction organisations is traditionally based on financial metrics alone, which is narrow and reactive (Bassioni *et al.*, 2004). Other metrics include the Foundation for Quality Management (EFQM) excellence model, key performance indicators (KPI), and the Balanced Scorecard. However, with the construction industry being project-oriented in nature, a focus on the aggregation from project performance to organisational performance has been recognised. Therefore, schedule performance, cost performance, customer satisfaction, safety performance, growth in contracts and profit are adopted as the output dependent variables (El-Mashaleh *et al.*, 2006 and Kassim *et al.*, 2009), that will sum up to the organisation's performance.

The dimensions for measuring the inputs and output variables for the empirical test of the model are presented in Table 1 below.

Table 1. Typical inputs outputs variables (Weill, 1993; Broadbent et al., 1999; Bhatt, 2000; Bruce et al., 2003)

Dimensions of Input Metric (x_i)	**Dimensions of Output Metric (y_i)**
Extent network connection and flexibility	Measure of Schedule performance
Proficiency of Head of IT and Technical Staff	Measure of projects cost performance
Level of system integration	Extent of customer satisfaction
Extent of implementation of business applications	Safety Index
Project Management competency	Contract growth
Measure of corporate culture	Overall organisational profitability

To empirically test the above hypotheses a mathematical model using a non parametric technique of Data Envelopment Analysis (DEA) is derived in the next section.

DATA ENVELOPMENT MODELLING OF IT BUSINESS VALUE

The use of parametric techniques such as linear regression in modelling IT business value has led to errors due to specification and assumption of linear direct functional relationships between the variables (Sigala *et al.*, 2004) as in the case of parametric technique, where a form of distribution defining the functional relationship has to be assumed. In order to mitigate this drawback among parametric techniques, a non-parametric technique called Data Envelopment Analysis (DEA) is adopted to model the IT business value for construction organisations. The technique is used in evaluating operational performance by measuring the relative efficiency of a set of similar enterprises, usually referred to as decision making units (DMUs) introduced by Charnes *et al.* (1978). Unlike the parametric technique, DEA does not need a priori assumption on the functional relationships between IT investment and organisation performance (Zhu, 2002). Also using DEA there is no need to assign weights to the different inputs and outputs as they are derived directly from the data and thereby avoids arbitrary and subjective weightings. Furthermore, the measurement units of the different inputs and outputs need not be congruent (El-Mashaleh, 2007). Another major strength of the DEA approach is its relative simplicity in requiring simply the output and input without needing to include cost of IT investments. This allows the use of measure of the IT resource usage in place of dollar value of the IT resources to evaluate the payoffs.

Edvardsen (2004) applied DEA to analyse the performance efficiency of Norwegian construction firms in 2001, and then used the bootstrapping method to test estimated results. El-Mashaleh *et al.* (2005) used a conceptual approach with DEA application to measure and compare construction subcontractor productivity at the organisational level. Thus, researchers in a number of fields have quickly recognised that it is an excellent and easily used methodology for modelling and evaluating enterprises' operational performance including the IT ' productivity paradox' (Shafer and Byrd 2000; El-Mashaleh *et al.*, 2006).

Data Envelopment Analysis Equation

The original DEA model was introduced by Charnes, Cooper and Rhodes thus the name CCR model was coined from the initials of the authors' surnames. The model proposed that the relative efficiency of an enterprise can be evaluated as the maximum of a ratio of weighted outputs to weighted inputs, subject to the condition that the same ratio for all enterprises must be less than or equal to one (Charnes *et al.*, 1978). The model also evaluates both technical and scale efficiencies via the optimal value of the ratio. An enterprise is scale efficient when its size of operation is optimal and is technically efficient if it maximises output per unit of input used. The term 'envelopment' reflects the fact that DEA measures efficiency within a production possibility set which 'envelops' all input-output correspondences.

$$\text{Technical Efficiency} = \frac{\sum \text{weighted ouput}}{\sum \text{weighted input}} \qquad \ldots\ldots 1$$

The weights are specified as a mathematical programming problem:

$$\left.\begin{array}{l} \max\ \psi_0 = \dfrac{\left(\sum_{r=1}^{s} \mu_r y_{rj_o}\right)}{\left(\sum_{i=1}^{m} \alpha_i x_{ij_o}\right)},\ \text{subject to}\ \left(\sum_{r=1}^{s} \mu_r y_{rj}\right) - \left(\sum_{i=1}^{m} \alpha_i x_{ij}\right) \le 1 \\ j = 1, 2, ..., n,\ \mu_r,\ \alpha_i \ge \varepsilon,\ i = 1, 2, ..., m; r = 1, 2, ..., s \end{array}\right\} \quad \ldots\ldots 2$$

ψ_o is the relative efficiency of the j_o^{th} decision making unit DMU; α_i is the weight for the input; μ_r is the weight for the r[th] output; M the number of inputs; S is the number of outputs; N is the number of DMUs; j_o is the index of the DMU being evaluated; x_{ij} represents observed amount of the i[th] input for the j[th] DMU, (i=1, 2, . ., M; j=1, 2, .., j_o ., . ., N); ε is non-Archimedean infinitesimal value for forestalling weights to be equal to zero.

The solutions to equation 2 involve finding values of α and μ such that the efficiency measure of the j_o DMU is maximised, subject to the constraint that all efficiencies must be less than or equal to one. Furthermore, the fractional linear programming formulation above assumes that a proportional increase in inputs results in a proportionate increase in outputs referred to as constant return to scale. To take into account variable returns to scale (VRS) between inputs and outputs, Banker *et al.* (1984) extended the CCR model. Banker, Charnes and Cooper developed BCC model (named after them) which assumes that an increase in unit inputs production does not produce a proportional change in its outputs. Using this model the Impact of IT resources has been derived as inputs to construction organisation processes, while their performance of the organisations based on metrics of projects performance as the output variables. The model will define an efficient frontier for benchmarking the organisations. The efficiency frontier is the envelope representing "best performance" that is made up of organisations in the data set which are most efficient in transforming their inputs into outputs.

Thus, consider N number of construction organisations under investigation of their IT business value, each with a set of inputs and output variables as defined above (Table 1). Then assume that for each construction organisation (CO) under consideration co_j (for j=1,2,….,N) will have M set of inputs denoted by x_{ij} (i=1, 2,….,M) and S set of outputs given by y_{rj} (r=1,2,….,S). Using the BCC input oriented (BCC-I) model the efficiency of the j_o construction organisation under consideration (co_o) could be evaluated by solving the following linear programming problem:

$$\left.\begin{array}{l} \max\ co_o = \sum_{r=1}^{S} \mu_r y_{rj_o} \\ subject\ to: \sum_{i=1}^{M} \alpha_i x_{ij} = 1\ and\ \left(\sum_{r=1}^{S} \mu_r y_{rj}\right) - \left(\sum_{i=1}^{M} \alpha_i x_{ij}\right) \geq 0 \\ j = 1,2,..,j_o,..,N;\ \mu_r, \alpha_i \geq \varepsilon;\ i = 1,2,..,M;\ r = 1,2,..,S \end{array}\right\} \quad \ldots 3$$

where co_o is the relative efficiency of j_o^{th} organisation, while $x_{ij}, y_{rj} > 0$ represent indexes of IT and other resources and performance metrics as inputs and outputs of the j^{th} construction organisation respectively, α_i and μ_r μr are the input and output weights (also referred to as multipliers). x_{io} and y_{ro} represent the inputs and outputs of co_o. Equation 3 needs solving N times, once for each organisation, to get the relative efficiency of all the construction organisations in a data set.

METHODOLOGY

The overall research process consists of three-phase approaches that are methodologically triangulated. The first phase undertaken by Kassim *et al.*, (2009) involved a comprehensive literature review in the field of IT business value, construction management and strategic management; identification and operationalisation of IT resources on the construction project value chain; and establishing and defining project performance metrics as the major components of the conceptual IT business value model for construction organisations.

The current phase involves extending the conceptual model into mathematical form using data envelopment analysis. The next phase will validate the model through a case study which will then be followed by a full empirical analysis using a wide sample via a survey questionnaire based on the operationalised variables.

CONCLUSIONS AND FURTHER WORK

The literature review in the fields of IT business value, strategic management and construction management has identified that the equivocal results of the previous studies of IT business value were attributed to the difficulties in modelling and measurement of the return of IT investment, lack of structured theoretical constructs, data availability and choice of dependent variables among others. This study is aimed at contributing to the process of mitigating these drawbacks; and also defining an efficient frontier for benchmarking organisations' performance.

This paper extends the Kassim *et al.*, (2009) conceptual model to provide a better framework for the empirical testing of the model using data envelopment analysis.

The two dominant theories of Porter and RBV in the strategic management literature were used as the theoretical construct in developing the conceptual model. Applying Porter's value chain constructs allows for examining the intermediate and context related variables of IT resources and their impacts on the performance of construction organisations. The RBV sets the basis of how complementary resources are used to support the IT-enabled strategy to achieve competitive advantage. This conceptual model is used in this paper to further develop the mathematical model of IT business value in construction organisation using DEA with the aim of mitigating some of the difficulties identified in the literature.

A case study will be conducted to rectify the assumptions in the conceptual model and test the mathematical DEA model. A survey questionnaire will then be carried out to establish the empirical values of the mathematical model. The limitation of DEA methodology include being sensitive to measurement errors which does not account for statistical noise. The filtered inefficient organisation through DEA shall be modelled using stochastic frontier analysis (SFA), thus maintaining the best qualities of each method and avoid many of their respective disadvantages.

The final outcome will provide tool 1) for benchmarking construction organisations IT-induced performance, 2) for continuous improvement in the deployment of IT resources and 3) a platform for investigating construction organisation IT readiness

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