

Path Model of IT Enhanced Project Information Management in Construction: Development and Implementation

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Abstract

Information technologies (IT) are providing construction firms with new opportunities for enhancing communication, collaboration and information management processes. Some firms have successfully grasped the opportunities enabled by IT enhanced information management systems to improve competitiveness and profitability. However, not all proactive construction businesses have been satisfied with their IT investments, largely due to their limited ability to evaluate the degree of IT-induced value added to operational and business performance. This paper builds upon recently published work by the author, by empirically investigating the link between 'Construct IT' Balanced Scorecard (BSC) perspectives, utilising structural equation modeling. Furthermore, the validity of developed path equations for predicting IT-induced business performance and strategic competitiveness is reinforced through benchmarking studies, conducted on two large infrastructure projects constructed in Australia, where innovative web-based collaboration platforms were implemented. The findings support that firms which provide reliable IT systems will achieve higher IT-induced performance improvement in the operational, strategic competitiveness and benefit perspectives.

Keywords

Information Technology, Structural Equation Modeling, Balanced Scorecard, Project Information Management

1. Introduction

Innovative information and communication technologies are providing construction firms with new opportunities for enhancing communication, collaboration and information management processes (Bowden *et al.*, 2005). However, the majority of construction business processes are still heavily based upon traditional means of communication such as face-to-face meetings and the exchange of paper documents. This is due to a number of historical, industrial and market forces that perpetuate the industry's culture, thus affecting the extent of IT adoption in day-to-day business processes (Baldwin *et al.*, 1999). Competitive pressures and client requirements are beginning to erode this entrenched culture, forcing construction firms to find efficiencies in existing processes, especially those pertaining to how project information is exchanged, manipulated and managed (Hannus *et al.*, 1999; Peansupap and Walker, 2005).

In their quest for improved competitiveness and profitability, numerous construction firms have invested heavily into information and communication technologies (Betts, 1999). However, many of these firms are yet to realize the proclaimed benefits of IT and are largely dissatisfied by their IT investments (Pena-Mora *et al.*, 1999). In some circumstances, this dissatisfaction has resulted from a lack of strategic IT planning (Stewart *et al.*, 2002). In others, it is in part due to the difficulty in measuring operational

benefits leading to some concerns about the payoff from investments in information technologies (Irani and Love, 2001; Stewart and Mohamed, 2003). This IT productivity paradox prompted calls for new approaches to evaluate IT-related investments (Dos Santos and Sussman, 2000). The following section provides some background on the authors attempt to develop a robust IT performance evaluation framework for the construction sector.

2. 'Construct IT' BSC

Over the last decade some attempts have been made to examine the strategic implementation and performance evaluation of IT in construction. To overcome limitations of existing frameworks, the author recently conducted two extensive studies to empirically develop an IT performance evaluation framework for the construction industry (Mohamed and Stewart, 2003; Stewart and Mohamed, 2003). This 'Construct IT' BSC framework incorporates five robust IT-related performance measurement perspectives: (1) operational; (2) benefits; (3) user orientation; (4) strategic competitiveness; and (5) technology/system (Figure 1). These five perspectives and their associated 25 indicators were customised for the specific elements of IT and construction (see Stewart and Mohamed (2003) for the complete details of these perspectives and indicators). The interrelationship between these perspectives was also verified by the author in a subsequent study (Stewart and Mohamed, 2004).

In an attempt to better quantify these links, this article utilised Structural Equation Modeling (SEM) to establish path directions, coefficients and associated path equations. Following this, the validity of the developed path model was reinforced through investigations on two mega construction projects where web-based project information management systems were implemented. An overview of the research method for the study is provided in the following section.

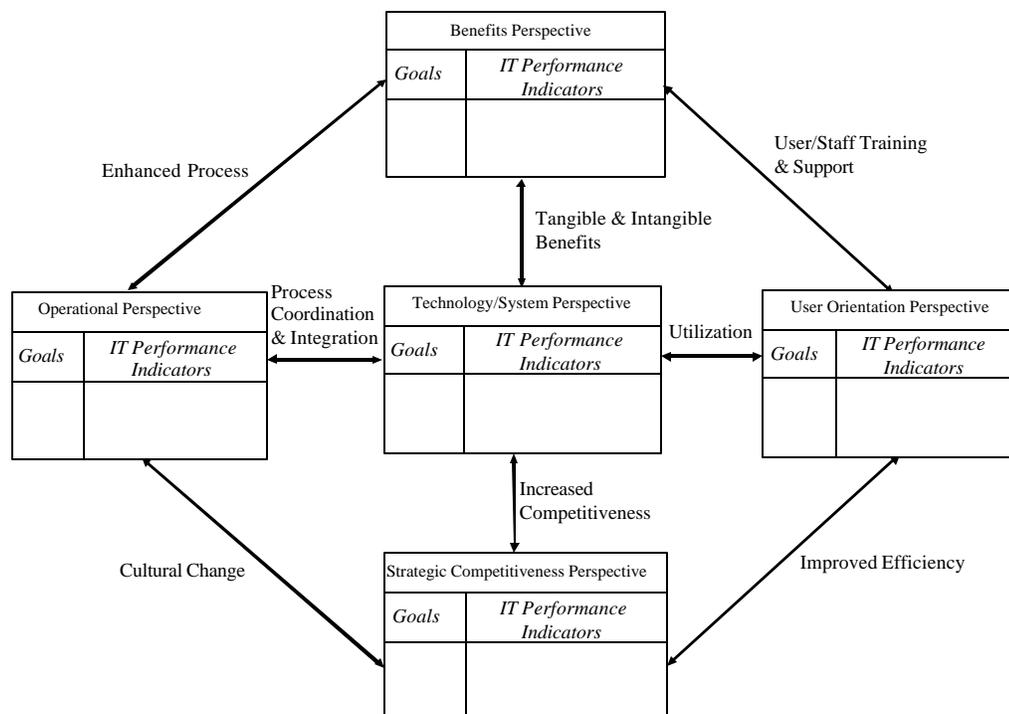


Fig. 1: 'Construct IT' BSC (Stewart and Mohamed, 2003)

3. Research Method

The research method for this project involved two key phases: (1) path model development; and (2) path model implementation. The first phase was concerned with developing a path model and associated prediction equations for evaluating the outcomes derived from implemented IT projects in construction businesses/projects. The objective of the second phase was to evaluate the IT-induced value added to the process of project information management on two mega construction projects and compare actual performance scores to those predicted by the standardised path equations developed in phase one of the research. This comparative analysis was conducted to reinforce the validity of the developed model.

3.1 Path Model Development

A questionnaire survey was selected as the most appropriate instrument for collecting the necessary data for the path model development. For the operational, benefits and strategic competitiveness perspectives the questionnaire asked respondents to rate the extent to which IT has helped a particular indicator compared to business as usual practices, on a five-point Likert scale ranging from [1 = significant detriment] to [5 = significant improvement]. For the technology/system and user orientation perspectives, the questionnaire asked respondents to rate their overall level of satisfaction with a particular indicator, in the context of information management, on a five-point Likert scale ranging from [1 = very low] to [5 = very high].

Large construction contracting and project management firms were predominately targeted in the survey as they were most likely to adopt innovative IT for project information management, thus, the professionals working for these firms would be better suited to evaluating the importance of presented perspectives and indicators. The questionnaire was sent to 322 construction project professionals from these organisations. Eighty-two ($n = 82$) positive and complete returns were received representing an average response rate of 25%. This data set was utilised for developing the path model described in later sections.

3.2 Path Model Implementation

Following the development of the structural model, two case studies were undertaken, where the value IT added to the process of information management in construction was evaluated. The research method comprised of two stages. The first stage involved mapping the newly implemented IT-based processes and developing appropriate questions (IT performance indicators) across the five 'Construct IT' BSC perspectives. It should be noted that these questions were very similar to those used for the development of the path model. Moreover, the same measurement scale was maintained.

A representative sample of approximately five (5) per cent of the projects professional staff were selected to participate in the survey for both of these projects (Project 1: $n = 14$; Project 2: $n = 26$). These individuals worked across various sections (e.g. environmental, design, construction, client, etc.) of these mega projects so that a realistic representation of IT-induced performance improvement could be determined.

4. Model Development: Empirical Analysis

4.1 Respondent Profile

Respondents were classified into four categories: director/operations manager (30%), project manager/project engineer/construction manager (53%), IT professional (14%) and other (3%). The average work experience of respondents engaged in the survey is 13.4 years, with about 34% of respondents having

more than 20 years of experience. The survey demonstrated a high percentage of respondents utilising a variety of IT applications and tools including: intranet; internet; e-mail; local area networks; wide area networks; web-based project management applications; video conferencing; and on-line remote networks.

4.2 Evaluating Perspectives and Indicators

The questionnaire asked respondents to rate each indicator using the two different five point scales, explained previously. The mean value for all indicators in the questionnaire is 3.71 indicating that respondents are moderately satisfied with their IT portfolio and the benefits it has generated. For the complete details of mean value and standard deviation for the five perspectives and their associated twenty-five (25) indicators the reader is referred to Stewart and Mohamed (2003). Pearson correlation analysis (Table 1), along with stepwise regression, was undertaken between framework perspectives to establish a preliminary understanding of paths and interrelationships. This analysis was a necessary precursor to the development of the path model described in the next section.

Table 1: Correlation between Perspectives

Perspective	Mean	S.D.	OP	BE	SC	TS	UO
Operational (OP)	3.95	0.72	1				
Benefits (BE)	3.92	0.79	0.74***	1			
Strategic Competitiveness (SC)	3.81	0.72	0.66***	0.74***	1		
Technology/System (TS)	3.55	0.66	0.67***	0.70***	0.71***	1	
User Orientation (UO)	3.31	0.80	0.56***	0.59***	0.67***	0.81***	1

$n = 82$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

4.3 Path Model

The path model was developed through Structural Equation Modelling (SEM) utilising AMOS 5.0 software. This type of analysis dynamically evaluates the extent to which hypothesized relationships fit the observed data. One major limitation of the SEM method is that it requires large sample sizes; 15 observations for each item in the model. However, since previous studies (Mohamed and Stewart, 2003; Stewart and Mohamed, 2003) have reduced the 25 indicators (items) to five perspectives through exploratory factor analysis, a sample of 75 observations was required ($n = 82$). On the basis of the previous work the technology/system perspective was defined as the only exogenous (?) perspective. The perspectives concerning user orientation, operational performance, strategic competitiveness, and benefits was taken as endogenous perspectives (β). The causality relations considered are non-recursive.

Table 2 and Fig. 2 show the estimation of the values for the standardized coefficients of the parameters, significance levels and goodness-of-fit indices of the SEM. The model's overall fit proved to be good, as were the standardized loads, the indicators and their significance levels (all t values above 1.96, $p < 0.05$). Both the compound reliability and the extracted variance analysis surpassed the recommended limits of 0.70 and 0.50, respectively (Hair *et al.* 1998). Moreover, discriminate validity analysis did not uncover any correlated endogenous perspectives (Anderson and Gerbing, 1988). As expected, the implemented technology/system has a very significant influence on the user orientation perspective ($t = 12.60$, $p < 0.001$). Moreover, the technology/system perspective impacts on every other perspective of the framework. Reinforcing the results of the previous study (Stewart and Mohamed, 2004), one of the key outcomes of effective IT implementation, namely, strategic competitiveness is fairly evenly influenced by the three enabling perspectives. As per any commercial venture, the key requirement is quantitative benefits for the business/project. The results confirm that the primary direct influential impacts on the benefits perspective come from the operational ($t = 4.01$; $p < 0.001$) and strategic competitiveness ($t = 3.79$; $p < 0.001$) perspectives whilst both direct and indirect influences come from the technology/system

perspective ($t = 1.96$; $p < 0.05$). Surprisingly, the user orientation perspective did not have any significant influence on the operational perspective.

The results of the different indicators on the model's goodness-of-fit are good (NFI = 0.999, CFI = 1.000, RMSEA = 0.000, GFI = 0.999, IFI = 1.006 and AGFI = 0.994). This confirms that the equations that define the path model are representative of the sample. The remaining indices have values that are within the acceptable range. In short, these results validate the model formulated.

Table 2: Standardized Estimated Coefficients for the Final Path Model

Paths	Structural equations	Coefficient	t	R^2
TS ? UO	$Z_{UO} = 0.81(Z_{TS})$	$\beta = 0.81$	12.60***	0.66
TS ? OP	$Z_{OP} = 0.67(Z_{TS})$	$\beta = 0.67$	8.11***	0.45
TS ? SC	$Z_{SC} = 0.29(Z_{TS}) + 0.25(Z_{UO}) + 0.33(Z_{OP})$	$\beta = 0.29$	2.09*	0.59
UO ? SC		$\beta = 0.25$	2.05*	
OP ? SC		$\beta = 0.33$	3.45***	
TS ? BE	$Z_{BE} = 0.19(Z_{TS}) + 0.37(Z_{OP}) + 0.37(Z_{SC})$	$\beta = 0.19$	1.96*	0.67
OP ? BE		$\beta = 0.37$	4.01***	
SC ? BE		$\beta = 0.37$	3.79***	

Relative chi-square (χ^2/df) = 0.081; Goodness of fit (GFI) = 0.999; Adjusted goodness of fit (AGFI) = 0.994; Comparative fit index (CFI) = 1.000; Normed fit index (NFI) = 0.999; Incremental fit index (IFI) = 1.006; Root mean square error of approximation (RMSEA) = 0.000; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

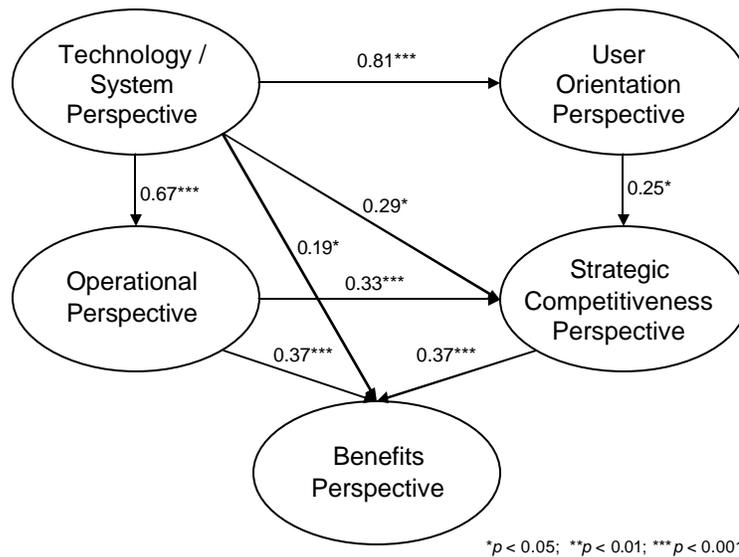


Figure 2: Final Path Model

5. Model Implementation: Case Studies

The developed structural equations derived from the path model were used to predict the IT-induced benefits and strategic competitiveness on two case studies. Actual performance scores were then compared against predicted values to reinforce the validity of the path model. The following two sections provide a brief description of the case study projects and evaluated IT tool. Additionally, the final section details the results of the comparative analysis study.

5.1 Case Studies Profile

Two large infrastructure projects (Project 1: $n=14$ and Project 2: $n=26$) constructed in Australia were selected for the case studies. Both of these projects were procured through a build-own-operate-transfer agreement and were valued in excess of one billion US dollars. Moreover, both projects utilised the same web-based collaboration platform described in the next section. Other IT applications and/or tools used on the project were not evaluated in this case study. As previously mentioned, a representative sample of professional staff from different disciplines, were requested to participate in this IT performance evaluation exercise.

5.2 Evaluated IT tool

The evaluated IT tool in these case studies was a web-based collaboration tool used for all project communication and the real-time management of all project documents and drawings. It supports the interactive design process within and between organisations and manages the work-flow between architects, engineers, consultants, subcontractors and the construction site. Documents are stored centrally in a secure data centre, so version control can be managed effectively and users can be certain that they are dealing with the latest document. The business case for the construction consortium implementing the web-based collaboration platform was numerous and included the following: reduction in paper copying costs; enhanced document control; increased audit capabilities; to name a few.

It should be noted that senior management supported the implementation of the web-based system. Utilising the web-based information management system was deemed mandatory for all employees. Clauses were written into subcontractors and design consultants contracts stating that the system was the only recognised vehicle for document and drawing exchange. The IT tool was supported by dedicated IT training and support staff. However, working against this commitment, was the relative immaturity of the system and the limited familiarity of its users. This was reflected by the relatively low 'actual' scores obtained for the two projects, particularly, in the technology/system and user orientation perspectives (see Table 3).

5.3 Prediction Comparative Analysis

To reinforce the validity of the path model a comparative analysis between the collected actual mean scores for each perspective of the 'Construct IT' BSC and the predicted scores derived from the path standardized prediction equations was conducted. To achieve this, actual scores obtained from the case studies were converted to an equivalent Z score (standardized value) on the original Australia-wide distribution. Single or combinations of Z scores were utilised in the appropriate standardized equations to predict the Z score, and ultimately the actual score, for endogenous perspectives. The calculated $Z_{SC} = -0.46$ score equates to a predicted strategic competitiveness value of 3.48, representing a difference of 0.05 or 1.46 per cent from the actual score (see Table 3). As expected, functions with only one dependent variable less accurately predicted the dependent variables i.e. $UO = f(TS)$ and $OP = f(TS)$. Table 3 details the extent of the difference between the actual project scores and the standardized predicted value. Figure 3 illustrates the linear standardized trend line for each paths respective structural equation (see Table 2) and the predicted actual values for Projects 1 and 2.

In summary, the developed path model reasonably accurately represents the results obtained from the two case studies, especially for the outcome-focused perspectives (i.e. SC and BE). However, from the analysis it became evident that the actual results collected from the case studies were predominately slightly lower than those predicted. Moreover, Project 1 results were generally more accurately predicted. These two outcomes may be due to a number of causes. Firstly, due to the large contract value of the projects a high percentage of contract staff were mobilized who were mostly first-time users of the web-based collaboration tool, thus the distribution of scores was lower than the original sample. Secondly, the

IT performance evaluation exercise was undertaken in the early stages of procurement for Project 2 and the later stages for Project 1, giving the latter respondents more time to familiarize themselves with the IT system, thus their mean scores were slightly higher.

Table 3: Prediction Comparative Analysis

Prediction Equation	Project 1 (n = 14)				Project 2 (n = 26)			
	Predicted	Actual	Diff.	%	Predicted	Actual	Diff.	%
TS	*	2.97	*	*	*	2.97	*	*
UO = f(TS)	2.74	3.13	-0.39	-12.46	2.74	3.13	-0.39	-12.46
OP = f(TS)	3.53	3.26	0.27	8.28	3.53	3.26	0.27	8.28
SC = f(TS, UO, SC)	3.36	3.40	-0.04	-1.18	3.36	3.40	-0.04	-1.18
BE = f(TS, OP, SC)	3.34	3.17	0.17	5.36	3.34	3.17	0.17	5.36

* Exogenous perspective

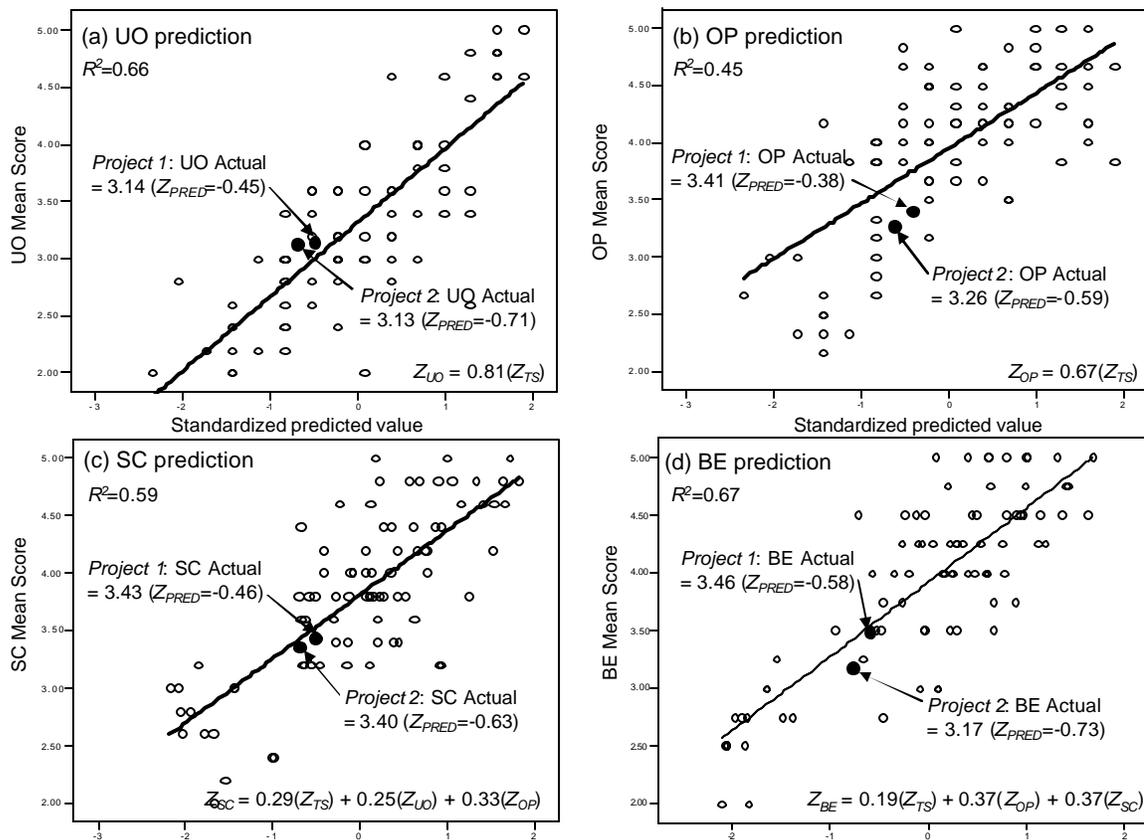


Figure 3: Standardized Prediction Value (Project 1 and 2)
 (a) UO = f(TS); (b) OP = f(TS); (c) SC = f(TS, UO, OP); (d) BE = f(TS, OP, SC)

6. Concluding Remarks

The empirical link between ‘Construct IT’ BSC perspectives was established utilizing structural equation modeling. Moreover, the validity of the developed path model was reinforced through IT benchmarking studies conducted on two mega infrastructure projects constructed in Australia, where innovative web-based collaboration systems were implemented. Specifically, findings suggest that the framework can be

used as a tool for monitoring the IT-induced value creation process. Undoubtedly, the model provides evidence that firms which provide reliable IT systems that are well-supported and user-friendly will achieve higher IT-induced performance improvement in the operational, strategic competitiveness and benefits perspectives. Accordingly, construction businesses are encouraged to closely monitor indicators from the user orientation and technology/system perspectives. A slack in these indicators often signals retarding performance in the outcomes-based perspectives. In conclusion, it is hoped that this study will encourage construction firms to adopt the proposed framework to assist with the measurement and management of implemented IT projects. Last, but not least, it should be noted that the 'Construct IT' BSC framework should be regarded as a template only and needs to be carefully adapted to suit the individual needs of construction firms and the portfolio of IT tools and/or systems implemented.

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