供應商涉入對建設公司產品生命週期管理之影響
Supplier Involvement in Product Lifecycle Management of Construction Firms

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摘要

本研究主要探討被視為組織策略性資源之供應商涉入對產品生命週期管理之影響，回顧文獻後由六大構念形成本研究架構，利用問卷調查方式，取得 203 家台灣建設公司資料，採用結構方程模式進行分析本研究假說，其結果發現，供應商涉入對於強化企業競爭能量是項重要因素，特別針對於 ETO 產業。

關鍵詞：供應商涉入，產品生命週期，ETO 產業

Abstract

This paper examines supplier involvement in product lifecycle management as an organizational strategic resource. The conceptual framework developed from the literature, is made up of six constructs. Data gathered from 203 Taiwan's construction firms using a benchmarking questionnaire are used to test the hypotheses through structural equation modeling analysis. Consequently, the results highlight that supplier involvement is a determinant factor in enhancing a firm's competitive capacity, especially in the engineer-to-order industry.

Keywords: supplier involvement, product life cycle, engineer-to-order industry

I. INTRODUCTION

There is growing interest in the adoption of product lifecycle management (PLM) in various industries, although PLM ultimately depends on the characteristics of the industry. The PLM concept combined with supplier involvement is applied to firms' operational management, specifically focusing on the engineer-to-order (ETO) industry. Construction firms are chosen as the sample for this empirical study. Businesses operating in the construction industry are known as contractors and subcontractors who may be companies, partnerships or self-employed individuals. There exist several classes of ETO environments where the variants are significantly different, not only differing by various parts of the product such as materials or components, but also by design and engineering. This is certainly the case for project-oriented construction activities.

The term "engineer-to-order" denotes a style of manufacturing rather than a specific industrial segment. The notion that ETO products require a life cycle orientation in terms of investment decisions has become widespread. It is also commonly understood that maintaining a sustained vision during the design phase and the demands of the other phases in the life cycle are vital. ETO companies typically have distinct characteristics in conducting business that differentiate them from repetitive manufacturers [1].

Construction companies build standard products and meanwhile create unique products designed to customer specifications [2]. Products are complex with long lead-times that typically take months or even years. Things are used to be made to order and made to fit. However, ETO products companies still face the challenges of providing "mass customization" of their products better, faster and cheaper than their competitors [3]. The potential for dramatically decreasing construction costs through standardization of construction processes is noted [4]. While concurrent engineering in the construction industry is gaining acceptance, some implementation efforts have not realized their full potential for reducing costs, reducing time and increasing efficiency in product development efforts [5].

If a component specified by the designer or client is not available, a purchaser may use a different component with better or similar specifications. In case the product requires a revised design, the manufacturing process needs to do the modifications, or the structure described in a drawing turns out to be awkward to produce, thus it increases the cost. To change designs quickly and inexpen-

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sively, producers win customers by targeting individual tastes and preferences. Construction firms make mainly customized products, competing for each order on the basis of price, technical expertise, delivery time and reliability in meeting due dates and using strategic alliances with their suppliers during different product life cycle (PLC) stages.

II. LITERATURE

1. Product lifecycle management

PLC issues related to the ultimate disposition of materials must be considered as an integral part of the purchasing and procurement process [6]. PLC has to do with the life of a product in the market with respect to business/commercial costs and sales measures; whereas PLM has more to do with managing descriptions and properties of a product through its development and useful life, mainly from a business/engineering point of view [7]. PLM is the process of managing the entire lifecycle of a product from its conception, through design and manufacture, to service and disposal [8]. Operational decisions spanning product design, procurement, manufacturing/assembly, packaging, logistics and distribution are highly connected with organizational practices. Considering PLC as a whole and striving for the total benefit as the target of optimization, not only life-time but also costs of operation assessed more effectively and with greater economy. The main stages include production, usage and disposal/reproduction [9]. PLC consists of a chain of processes including raw material extraction, production, transportation, use and disposal of the product [10]. The characteristics of ETO companies are described in terms of their markets, products, the internal processes of their organization and set in the context of current trends in supply chain management [11].

The process chain of operational activities in construction, starts from effective demand by client, through conceptual, construction, commission, running, maintenance and finally to refurbishment, replacement or de-commission and abandonment [12]. Accordingly, PLM within construction industry has the attributes of ETO products as illustrated in Fig. 1.

The representation of construction flow is given, which starts from the specifications process through initial design, design/engineering, purchasing, production and service processes to creating organizational performance and back to the specifications process. Meanwhile, interactions exist between phases as shown by the arrow. An initial design is produced based on customers' specifications. Usually, this is a collaborative process as ETO firms often help the customer to develop specification, which may be derived from the basic structures of previous products, stored in the company's historical database. This structure is then modified and used through design, purchase, production and service. This flow chart emphasizes the importance of product specification activities in accordance with customer requirements. Fig. 1 also shows that suppliers play different but important roles in PLM, such as innovative input in initial design and design/engineering, material procurement in purchasing, manufacturing/storage facility in the production phase and transport vehicle/retailer/distribution in service activities. Since ETO firms depend upon the contractual structure of a project, the design is often produced by architects/consultants and then put out to tender. In other cases, to simplify the design, parts of the structure may not be included in a drawing and thus require a revised design; or the companies or in-house departments engaged in production phase may do the modifications on their own accord.

Construction firms have to contribute towards the client's satisfaction by adding greater value. In the initial design and design/engineering phases, firms focus on the "innovation" element and what needs to be done to improve the R&D capabilities of themselves and their suppliers. In the latter three phases -- purchasing, production and service, the emphasis is on reducing cost and reducing construction schedules. Therefore, further work in developing the buyer-seller relationship and assessing the construction supply chain is significantly emphasized. Accordingly, this study divides into PLM1 (covering initial design and design/engineering phases) and PLM2 (covering purchasing, production and service phases) according to different goals and functions.

This lifecycle orientation in design causes a slightly longer allowable time-to-market. In contrast, initial design is under more time pressure and places high demands on the

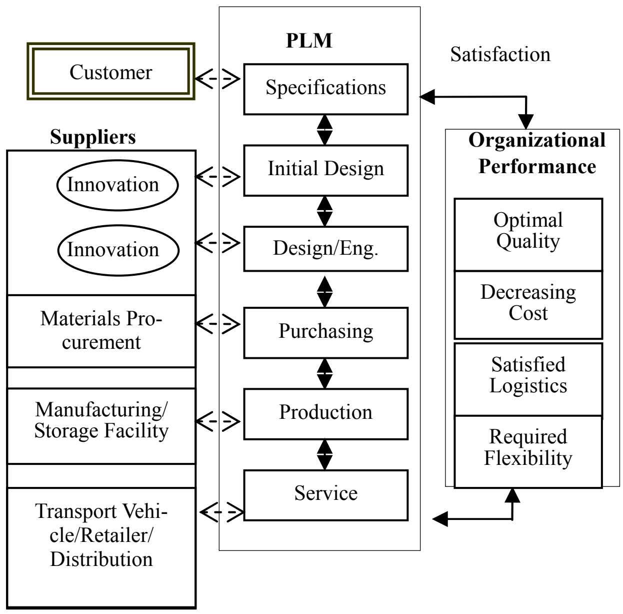

Fig. 1 Flow chart of the PLM in the construction industry

organization. All of the stakeholders have to recognize ETO context in the construction industry. CEOs and project managers need to build complete systems for repetitive manufacturing and extensive customization to adequately handle the complex and unique one-time requirements of custom-engineered products. This system should be designed from the bottom-up for maximum efficiency in project-oriented environments, including capabilities that enable superior estimating, measuring, controlling and reporting at department, project or task/work breakdown levels.

In an ETO context, all actual costs are allocated to a project and tracked against the original estimate. In most cases, aftermarket services continue throughout the life of the product. The engineered solutions based on customer requirements allow manufacturers to address the demand for mass customization by creating products designed within customer specifications. There is one way of providing the sales team with point-of-sale engineering automation tools that shorten sales cycles and engineering time on customized products. The firm captures and reuses expert engineering knowledge to model ETO solutions and complex interdependencies during the tendering stage, which is before the point of sale or sometimes at the point of sale. Iterative changes can be evaluated against the knowledge engineering methodology to optimize a solution without tying up valuable and expert resources [13]. In an efficient system, customer expectations are set correctly, crucial requirements are assessed accurately, engineered solutions are created and margins are protected -- all before a proposal is even submitted. The business can increase sales, operate with greater efficiency and maximize the value of existing technology investments through flexible deployment options.

2. Supply chain

A typical ETO manufacturing process is in fact a supply chain (SC) [11]. Many construction firms are already moving towards SC through the use of partnering, framework agreements and techniques to rationalize their supplier base [14]. Many construction companies have adopted concurrent engineering with the potential to make projects less fragmented, improve project quality, reduce project duration and total cost, while creating a more satisfied customer. To establish the readiness of the construction, SC is important for the option of concurrent engineering prior to its full implementation [5].

SC is an interconnected series of activities concerned with planning and controlling raw materials, components and finished products from suppliers to the final consumer [15], as well as the network of facilities and activities which perform the functions of product development, procurement of materials, movement of materials between facilities, manufacturing of goods, distribution of finished goods to customers and after-market support [16]. SC is an integrated manufacturing process wherein raw materials are converted into final products, then delivered to customers. An ontology-based approach supports decision-making for the design of ETO products using ontology as a technical solution to integrate heterogeneous systems [17]. The production planning and inventory control processes encompass the manufacturing and storage sub-processes and their interfaces. More specifically, production planning entails the design and management of the entire manufacturing process (including raw material scheduling and acquisition, manufacturing process design and scheduling, and material handling design and control). Inventory control entails the design and management of the storage policies and procedures for raw materials, work-in-process inventories as well as final products.

PLC processes are not limited to the framework of specifications, initial design, design/engineering, purchasing, production and service. Combinations of business processes lead to SC networks in which materials, financial values and information are dispatched and exchanged in a manner that involve all participating companies [18].

3. Organizational performance

Almost all the firms interviewed evaluate their organizational performance according to quality, cost and flexibility [19]. Nowak et al. [20] examine organizational performance according to product quality, service quality, cost efficiency, timeliness and overall customer satisfaction. The performance of SC management orientation is valuated using four criteria: cost, quality, delivery and flexibility [21].

To achieve organizational objectives, many companies adopt Total Quality Management (TQM) and Just-in-Time (JIT) or lean manufacturing programs. This study only focuses on TQM. Companies thrive only when they act as whole systems, including all stakeholders, and integrate TQM into their planning and operations [22]. TQM programs are based upon the notion that the company strives for continuous improvement, which includes the supplier's total environmental performance, e.g., water wastes, air emissions, solid wastes, and energy consumption. Clients should select, at the pre-qualification stage, suppliers complying with or certified to ISO 9000 [23]. In this paper, we define the performance of "optimal quality" in terms of two criteria: the implementation of TQM programs and compliance with ISO 9000.

Decisions with respect to costs made at the design and engineering stages have a significant impact on manufacturing and service costs, as well as the quality of the final product [24]. The operational costs associated with PLC stages potentially influence product design, operations and maintenance decisions, recycling and reuse activities, as well as disposal methods termed the "life cycle cost" [25]. To define the life cycle cost of the supplied component, managers have to consider purchase costs and all other costs that the company must bear during the PLC. These are related to: (1) costs for component disposal when these components have been used to achieve the final product, but have been detected as defective within the company's plants; and (2) costs for the disposal and/or recovery of the end-of-life components [26].

Based on the concept of the supply chain, organizational performance has traditionally focused on operational logistics activities measured by warehousing, transport, and inventories [27]. Logistics is that part of the supply chain process that plans, implements and controls the effective flow and storage of goods, services and related information from the point-of-origin to the point-of-consumption in order to meet customer requirements [28]. A series of research studies have examined the characteristics of companies which performed logistics well -- those organizations with supply chain processes which added value for customers and also aligned with their own cooperation [29].

Flexibility is regarded as a capability that must be planned for and built by a firm over a period of time along these constituent elements and dimensions; accordingly, the key aspects of manufacturing flexibility have been acquired and leveraged differently by different producers [30]. Here, flexibility means the degree to which the supply chain can respond to random fluctuations in the demand pattern [31]. Overall, flexibility allows significant improvements to be achieved in organizational performance, especially when the new capabilities stemming from the firm's flexibility are developed and implemented in association with a partner -- the appropriate supplier. This kind of flexibility is essential particularly for the suppliers in order to cope with the unpredictable order schedules of the purchasing companies and also for the end product manufacturers serving this market [32]. Normally, a company just performs acceptably for decades, showing admirable flexibility within its business model [33]. Thus, required flexibility level is dictated by the strategy of the organization.

Accordingly, we propose four indicators -- optimal quality, decreasing cost, satisfied logistics and required flexibility -- as indicators of a firm's organizational performance.

4. Supplier involvement

Supplier involvement is touted as enhancing a firm's competitive edge, especially in its linkage with specific dimensions of manufacturing flexibility [34]. To cite one example, before initial prototyping begins, Toyota invites suppliers to its product design meetings. The suppliers not only design the components but also help develop new vehicle concepts. First-tier suppliers are treated as long-term partners. These partners invest in developing a variety of parts and present all the alternatives to Toyota before Toyota decides on its own vehicle concepts [35]. Early supplier involvement is important in the product development process to reduce the time-to-market of a new product introduction. Direct communication with suppliers is necessary to solve problems in the buying company's product development processes [36].

UK suppliers with partnership relations were able to contain cost increases and to defend a squeeze on profit margins better than non-partnership suppliers [37]. Since a supplier expects customers to help making necessary process improvements to match the competitor's expertise, the supplier provides customers with details of its manufacturing process steps for mutual interests. The importance of perceived interdependence or credible commitment for supplier involvement evolves into cooperation with customers/makers. One type of credible commitment is to enhance the competence trust between suppliers and customers by providing technical assistance [37].

5. Supplier innovativeness and PLM1

The ability to identify and target innovators/suppliers is critical for success in new technology innovation and organizational performance. Innovation includes in its meaning the process of long-term and progressive change, as well as dynamic processes [38]. One of the benefits manufacturers acquired from stronger relationships with suppliers has been increased external information on, and experience with, different technologies [39]. Innovation is about changing the yield of resources [40]. In ETO industry context, innovation refers to an evolution or revolution to support ETO products and processes. Innovation is viewed as a learning process necessitated by uncertainty and dynamism in a socioeconomic context. The process ensures the generation and transmission of knowledge and has both an adaptive and creative component [41].

When considering innovativeness in an industrial setting, studies have assessed the number of innovations that have been adopted. The process of innovation adoption includes awareness of innovation, attitude formation, evaluation, decision to adopt, trial implementation and sustained implementation [42]. Almost all studies of innovation adoption have assessed innovativeness at one point in time. Innovativeness is measured by determining changes in the mean number of innovations adopted over two periods of time [43]. Herewith, innovativeness is operationally measured in two dimensions: innovation capacity and decision involvement. Relevant to the innovativeness of suppliers, the suppliers' engineers are required to work at least 3 years in energy, high tech or related industries, as well as have 5-10 years preferable and abundant experience in electrical and mechanical engineering. Besides, they can prove their abilities in process, procedure development and contract management, strong negotiation skills and competency.

Supplier innovativeness has been a major contributing factor in cost reductions, and has also fueled many product improvement projects in which value analysis and value engineering [44]. Accordingly, this paper emphasizes that a crucial factor for selecting the best and most appropriate supplier is the ingenuity of the supplier. The development of supplier evaluation systems places significant weight on innovation capacity of influencing supplier activities [45]. Innovative capability is defined as the skills and knowledge needed to effective absorb, master and improve existing technologies, and to create new ones [46]. Firms require an adequate stock of technically qualified manpower to absorb new technologies, modify them, create and transfer new technological information, particularly scientists and engineers [47]. Thus, companies include a past innovation track record in their criteria for selecting material suppliers.

The suppliers/engineers are responsible for developing and implementing improvement initiatives to improve operational performance, as well as providing assistance to achieve operational goals and develop new projects. The responsibilities of the operations engineers are to assist in the achievement of all business unit targets for safety, availability, revenue and costs. In particular, they must assist in the development of an operational safety system to achieve zero accidents with operating assets, as well as innovate and lead the initiative to achieve targeted program availability. The suppliers/engineers assist in vendor performance monitoring and tracking. Additionally, they are accountable for all aspects of new projects for operations including lead-times on operations parts of new contracts, negotiations, as well as, they are also accountable for cost modeling of operations for new projects and management of site take-over systems for operations in conjunction with the field operations team.

Hypothesis 1: The higher the degree of suppliers' innovativeness, the better the product lifecycle management – initial design and design/engineering (PLM1) – of the construction firm.

Hypothesis 2: More effective adoption of PLM1 will allow the construction firm to achieve better organizational performance.

6. Buyer-seller relationship and PLM2

Strictly speaking, the supply chain is not a chain of businesses with one-to-one, business-to-business relationships, but rather a network of multiple business relationships [28]. The impact of buyer-supplier interface management on supplier activities completed on time, and the subsequent impact of supplier activities on overall project are important in the product development process [48]. The buyer-supplier interface management includes variables such as time of supplier's involvement, supplier's design responsibility and buyer-seller communication. There is a statistically significant relationship between the supplier activities completed on time and overall product development delays [48]. This result supports that suppliers are actively involved in a new product development process.

The "contract" is the predominant method for managing the relationship between organizations that cooperate in a client's construction project. However, while contracts are a sufficient basis for the delivery of a completed project, they are not sufficient to complete a project efficiently at minimum cost in the right time. These are current areas of competitive advantage and success increasingly depends on openness, trust and commitment. Trust is expressed through faith, reliance and confidence in the supply partner. Collaboration requires high levels of trust, commitment and information sharing among supply chain partners [49].

Partners should also share a common vision of the future [50]. Companies need to capture and reuse expert engineering knowledge to model ETO solutions and their complex interdependencies at the right point of sale. An important constraint for construction firms is that they have many unique requirements that make traditional systems unsuitable. The ETO market is relatively small and the companies themselves tend to be small. The result is that the larger software suppliers are more focusing on the needs of the larger and more numerous repetitive manufacturers. Therefore, it is important that firms plan jointly and share technology with partners using supply chain integration. SC covers the short- and long-term collaboration of a company with other companies in order to develop and manufacture products with the required internal- and inter-company organization, planning, and control of flows of materials, financial value and information along the business processes [51]. In order to be successful, management strategies must be integrated into the value chain, which includes all of the operational life-cycle stages – product design, procurement, manufacturing and assembly, packaging, logistics and distribution [52]. Manufacturers have a number of suppliers at each operational stage. As suppliers involve customers in product/solution development, share more and more information with vendors and build wider and longer bridges with existing alliance partners, they are also developing more collaborative relationships among organizational sub-units, at every level [53].

Organizational activities are embedded in business operations [54]. The degree of organizational performance is, in part, dependent on friendly organizational practices in manufacturing organization [55]. While companies adopt proactive organizational strategies, they may focus efforts on making technology or process change toward friendly organizational practices in manufacturing [52]. Companies have to integrate other members of the SC into their management processes, whish is tantamount to "supply chain management" [56].

In developing supply chain management, they also addressed three main approaches: (1) maintaining close relationships with their main supplier; (2) obtaining a larger market share through competition with other domestic material suppliers by improving product quality and reducing costs; (3) ensuring the sustainability of their operations including reducing the organizational impact [56]. In this sense, a cooperative relationship with suppliers allows a firm to improve its organizational performance. Thereupon, we expect the following hypotheses will be supported. The conceptual framework for this research is developed from the literature (Fig. 2).

Hypothesis 3: The higher the degree of buyer-seller relationship, the better the product lifecycle management – purchase, production and service (PLM2) – of the construction firm.

Hypothesis 4: More effective adoption of PLM2 will allow the construction firm to exhibit better organizational performance.

III. METHODS

The methodology for this study was the Structural Equation Modeling (SEM) to test H_1, H_2, H_3 and H_4. Regarding the data collected, a random sample of 500 firms (CEOs/functional managers) was drawn from manufacturing organizations found in the Chinese National Association of General Contractors. Each CEO or manager was contacted by telephone and requested to take part in the study. On agreeing to do so, each CEO or manager was mailed an anonymous questionnaire together with cover letter and a stamped addressed envelop for its return. The design of the questionnaire facilitated the respondent sample providing a data source for other research topics unrelated to this one, thereby allowing significant research efficiency.

A total of 203 firms responded, representing a response rate of 40.6%. The sample comprised 35 CEOs, 65 designers/engineers, 26 purchase managers, 42 production managers, and 26 marketing/service managers together with 9 others from a range of areas of responsibility. Their average age is 42, the mean years of experience in the areas they managed is 9.7. They had held their present position for an average of 3 years and the mean number of employees in their areas of responsibility is 36. More specifically, respondents were requested to indicate the degree of their suppliers' involvement by answering questions relevant with supplier innovativeness, buyer-seller relationship, PLCM and organizational performance. Supplier innovativeness is measured by innovative capacity and decision involvement. The indicators of buyer-seller relationship include interdependence, commitment and collaboration. For example, regarding "commitment", the question items mention: (1) quality commitment: providing the quality compliance with the maker; (2) price commitment: maintaining reasonable price through negotiation or cooperation; (3) technology commitment: sharing technology/knowledge/know-how innovation with the other; (4) stable resources commitment: supplying the materials/components on time. Additionally, we use four metrics of organizational performance, covering optimal quality, decreasing cost, satisfied logistics and required flexibility.

To evaluate the relative importance of different constructs, each respondent was also asked to specify the relative importance on a 7-point Likert scale, indicating whether relative importance was very low (1) or very high (7). Then, we examined the collected data and conducted an empirical analysis using the LISREL.

IV. RESULTS

1. Reliability measures

In this study, the method of reliability measures adopts Cronbach's coefficient α. Cronbach's coefficient α is calculated for each of these factors to assess the internal consistency of the model constructs. A standard coefficient α of 0.60 or higher generally is considered acceptable when using a measure [57]. If statistical significance is not achieved, the research may need to eliminate the indicator or attempt to transform it for better fit with the construct. However, the values of Cronbach's coefficient α of latent variables and observed variables all exceed 0.70 and that of some constructs even exceed 0.90 (Table 1). This indicates that the research has a good consistency and stability.

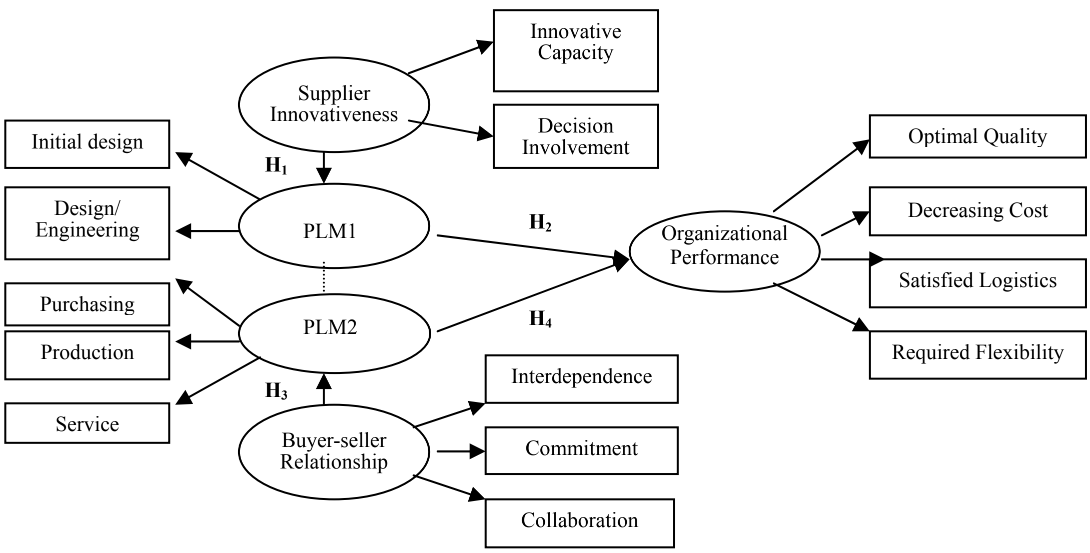

Fig. 2 The research conceptual framework

Table 1 Measurement model parameter estimates

Latent Variable	Observed Variable	Cronbach's α	λ_x and λ_y	Error Variance(δ_x,ε_y)	Latent Variance(ζ_y)
Supplier Innovativeness (ξ_1)		0.80			—
	Innovative Capacity (x_1)	0.73	0.705***	0.502	
	Decision Involvement (x_2)	0.75	0.657***	0.569	
Buyer-Seller Relationship (ξ_2)		0.82			—
	Interdependence (x_3)	0.85	0.827***	0.316	
	Commitment (x_4)	0.72	0.959***	0.079	
	Collaboration (x_5)	0.78	0.664***	0.560	
PLM1(η_1)		0.93			0.647
	Initial Design (y_1)	0.89	0.600***	0.640	
	Design/Engineering (y_2)	0.89	0.715***	0.489	
PLM2 (η_2)		0.95			0.769
	Purchasing (y_3)	0.92	0.705***	0.502	
	Production (y_4)	0.89	0.698***	0.513	
	Service (y_5)	0.94	0.881***	0.223	
Organizational Performance (η_3)		0.94			0.775
	Optimal Quality (y_6)	0.87	0.798***	0.364	
	Decreasing Cost (y_7)	0.89	0.875***	0.234	
	Satisfied Logistics (y_8)	0.87	0.787***	0.381	
	Required Flexibility (y_9)	0.91	0.929***	0.138	

Level of significance: ***p<0.001

2. Measurement model result

The manifest variables collected from the respondents are indicators of the measurement model, as we use them to measure, or indicate, the latent constructs. The most obvious difference between the measurement model and factor analysis is that the former has a much smaller number of loadings and resembles the exploratory mode of factor analysis. Researchers can specify a measurement model for both exogenous constructs and endogenous constructs.

Table 1 presents λ_x and λ_y coefficients from a LISREL analysis of a hypothesized causal model of new venture success. All the coefficients are moderately high, approximately 0.600 or more. All the loadings are statistically significant. The strong statistically significant correlation between the factor and their measures suggest the presence of convergent validity. It may be concluded from these results that each of the three latent factors is well defined.

3. Structural model results

Table 2 shows the path analyses of supplier innovativeness, buyer-seller relationship, PLM1, PLM2 and organizational performance. The four hypothesized paths are supported at a significant level (less than 0.05). The data demonstrate that there is a significant correlation between supplier innovativeness and PLM1 (path coefficient =0.585). In addition, there is a significant correlation between buyer-seller relationship and PLM2 (path coefficient =0.497). Moreover, both PLM1 and PLM2 are statistically, significantly and positively related to organizational performance (path coefficient=0.581, 0.509).

4. Overall model fit

The fit of the model was evaluated with various measures [58, 59]. A Chi-square test is reasonable when the study involves a large sample [60]. The first measure is the likelihood ratio Chi-square statistic. While the value has a statistical significance level above the minimum level of 0.05, the statistics support the argument that the differences between the predicted and actual matrices are insignificant, indicative of an acceptable fit. The Chi-square value (15.87 with 10 df) has a statistical significance level of 0.08, indicating an excellent fit. The model fit assessment approach is involved, using several diagnostics to judge the simultaneous fit of the measurement and structural models to data collected for this study. Goodness-of-fit index (GFI) is another measure and Adjusted goodness-of-fit index (AGFI) is an extension of the GFI, adjusted by the ratio of degrees of freedom for the proposed model to the degrees of freedom for the null model. GFI is 0.967 and AGFI is 0.955.

Other types of fit measures include Comparative-Fit Index (CFI), Normed Fit Index (NFI), Root Mean Square Residual (RMR) and Standardized Root Mean Square Error

Table 2 The coefficients of constructs

Hypotheses	Relation between Constructs	Direction	Coefficient	*t*-value	Results
H_1	Supplier Innovativeness→PLM1	+	0.585	8.24^{***}	Accepted
H_2	PLM1→Organizational Performance	+	0.581	4.53^{***}	Accepted
H_3	Buyer-Seller Relationship→PLM2	+	0.497	7.11^{***}	Accepted
H_4	PLM2→Organizational Performance	+	0.509	8.33^{***}	Accepted

Note: $^{***}p<0.001$

of Approximating (RSMEA). We use CFI to explain the difference between the model and the independent model without co-variables. The closer the value is to 1, the better the model fit. The CFI of the model is 0.964, indicating a fairly good fit. It is quite similar to the parsimonious NFI and a recommended acceptance level is a value greater than or equal to 0.90. This model has a NFI value of 0.912, which means that 91.2% of the observed measure covariance is explained by the composition model. Further, RMR is the square root of the mean of the squared residuals -- an average of the residuals between observed and estimated input matrices. The two diagnostics for this model include RMR=0.047 and RMSEA=0.021. The structural model results in Fig. 3 show that the overall model fit is within an acceptable level.

V. DISCUSSION

This study makes two contributions to the field of supplier management. First, it explores the significant effect of supplier involvement (supplier innovativeness and buyer-seller relationship) on PLCM. Secondly, it identifies that PLCM positively influences organizational performance. Consistent with our initial hypotheses, the findings show there are significant correlations between the five factors: H_1, H_2, H_3, and H_4 are all supported. Increasing competition has encouraged many companies to become more customer-oriented; they are reducing response time to customer requests, improving quality, as well as placing more emphasis on teamwork and management over the long-term.

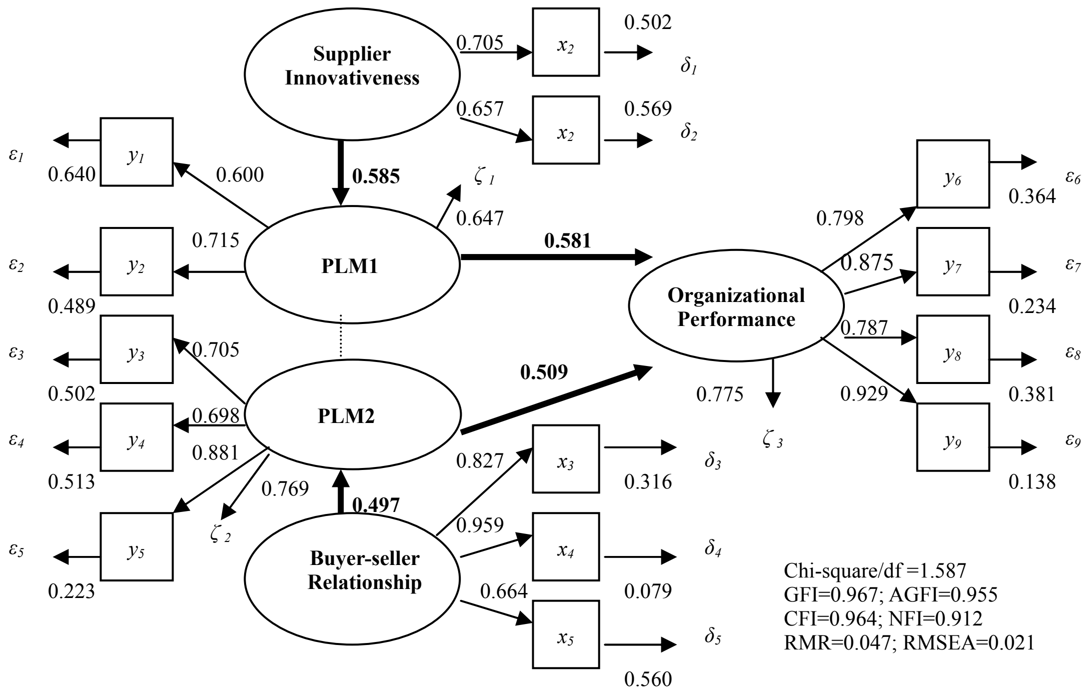

Fig. 3 Structural model results

The construction industry possesses highly fragmented characteristics [61, 62]. For example, the separation of design and construction, lack of coordination and integration between various functional disciplines, poor communication, etc., are the important impact factors causing performance-related problem, such as low productivity, cost and time overrun, conflicts, and disputes. In order to overcome those shortcomings, the appropriate supplier involvement could further improve the performance of PLM.

In other words, the involvement of a supplier in product life cycle management (initial design, design/engineering, purchasing, production and service) allows construction firms to verify how they perform with respect to effective operational practices and organizational performance. No differences between assemblers, direct suppliers, and indirect suppliers are found in regard to the importance placed on technological innovation and organizational management issue [48]. Consequently, the need to continuously improve corporate organizational performance will force firms to involve suppliers in the operational stages of their PLC programs.

The related analyses identify challenges for the construction industry and drivers of change, as well as a future roadmap to help companies address the issues created by the quick evolution and growth of embedded systems [5]. The approach is two pronged. It offers a business view in which construction companies must work to assess and change the way they operate both internally and with suppliers. It also offers a technical view in which companies must adapt technology to support evolving business activities.

Consumer expectations, technological innovations, competition, product differentiation and legislation are leading to the increased use of embedded systems in the construction industry. As the electronic and software content in construction engineering increases, so does complexity. As embedded systems are becoming more complex, many problems are also encountered by construction. Today's embedded systems often miss their mark. Faulty electronics and quality problems contribute to rising warranty costs. The life cycle mismatch between construction and embedded systems can render electronics functionality outdated. Original equipment manufacturers and suppliers find that their ranks are short on the skill sets needed to support the growth of increasingly specialized software. Lastly, the construction industry's reuse of parts, subsystems, designs and architectures related to embedded systems is limited.

On the whole, the supplier's involvement in construction firms, especially for engineer-to-order industry, places a greater emphasis on organizational technology and innovation. In light of these issues, construction firms pursuing a proactive strategy must consider a supplier's contribution. The construction firms need to verify whether the supplier will be able to work with them to carry out more effective supply chain management. Overall, the results of this paper emphasize the importance of supplier involvement as a determinant factor in enhancing the comprehensive competitive capacity of the engineer-to-order manufacturer.

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