Strategies for integrating design & construction and operations & maintenance supply chains in Singapore

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Abstract
Purpose –
This research investigates strategies for achieving better integration between the design & construction (DC) and operation & maintenance (OM) supply chains in Singapore. The specific objectives are to: discover the goals that stakeholders want to achieve in integrating the supply chains; identify the stakeholders that play important integration role in each supply chain; and investigate the effective strategies that may yield better integration of the supply chains.

Design/methodology/approach –
Data were collected using a structured questionnaire. The sampling frame was Singapore-based clients, consultants and construction firms involved in developing and managing built facilities.

Findings –
The most important strategies for integrating the supply chains are: sharing relevant information and addressing sustainability issues jointly with DC and OM teams; and integrating life cycle optimization options in DC and OM supply chains.

Research limitations/implications –
The limitations include low response rate, and the subjective nature of a Likert scale which was used to rate importance levels. The research implication is that activities in DC and OM supply chains can indeed be integrated, and this leads to higher value for all stakeholders.

Practical implications –
The practical implication is that stakeholders could adopt the effective strategies identified by this study to foster closer integration of the two supply chains in Singapore. Teams from both supply chains need to work jointly instead of consecutively. Sharing information through an online platform by setting up a web-based database may help in their collaboration. It is also important that common goals need be set out at the onset, preferably by clients of built facilities, with strong buy-in by main contractors and consultants, so as to achieve better value.

Originality/value –
The study revealed effective strategies for integrating DC and OM supply chains.

Keywords: stakeholders, built facility, design and construction, operations and maintenance, supply chain, goals.

Paper type: Research paper.

Introduction

The development and use of a built facility entails two major supply chains: Design & Construction (DC) supply chain; and Operations & Maintenance (OM) supply chain. DC and OM are separate supply chains, but due to increasing sustainability and lifecycle imperatives, should benefit from closer linkages, given their intuitive interdependencies (Kumaraswamy et al., 2012). A holistic approach to asset management can only take place effectively when the DC and OM supply chains are integrated.

The aim of this research is to investigate strategies for achieving better integration between the design & construction (DC) and operation & maintenance (OM) supply chains in Singapore. The specific objectives are to: discover the goals that stakeholders want to achieve in integrating the supply chains; identify the stakeholders that play important integration role in each supply chain; and investigate the effective strategies that may yield better integration of the two supply chains.

Singapore is a small and developed country, with a GDP per capita of US$51,709 (compared to the US' GDP per capita of US$49,965) (World Bank, 2013). Most of its built facilities are procured through the traditional design-bid-build approach, where integration between DC and OM supply chains are limited, and this reduces the strength of the supply chain network. Within the DC supply chain, main contractors subcontract extensively, and among the subcontractors, there is multi-level sub-contracting. In the OM supply chain, there is a mixture of in-house and outsourcing of facilities management function. These features result in ad-hoc approaches to managing cross cutting themes such as sustainability and life cycle cost and value optimization. In addition, hitherto, there is limited integration between the DC and OM supply chains, and stakeholders are neither unlocking nor optimizing the value they may derive from the built facility.

Literature review and conceptual framework

The literature review begins with a review of the different methods to integrate supply chains in general. This is followed by analyzing DC and OM supply chains separately. The specific techniques to integrate DC and OM supply chains are then operationalized from functional integration, relational integration and transactional integration types.

Supply chain integration methods

Integrating supply chains comprises the following (Fawcett and Magnan, 2002): internal, cross-functional process integration; backward integration; forward integration; and complete forward and backward integration. Internal, cross-functional process integration occurs within each supply chain. For example, a design needs to be buildable so that contractors could execute the work in an efficient manner. Backward integration happens with valued suppliers. For example, clients' facilities managers (from OM supply chain) give feedback to architects (in DC supply chain) on ease of maintenance of certain design features or materials that are selected in the DC stage. Forward integration takes place with valued customers. For example, mechanical and electrical subcontractors (from DC supply chain) provide Operations and Maintenance Manuals to clients' facilities managers (in OM supply chain). Complete forward and backward integration is integration from "supplier's supplier to the customer's customer", which is very rare, and exist more as a theoretical ideal (Fawcett and Magnan, 2002). In this study, integration between the two supply chains focuses on internal, backward and forward integrations.

DC supply chain

The DC supply chain of a built facility comprises the development processes which include: inception stage that arises due to initial demands; design and construction; maintenance; replacement and eventual demolition. This supply chain encompasses a chain of construction businesses with business-to-business relationships, and a network of multiple organizations and relationships, which includes the flow of information, the flow of materials, services or products, and the flow of funds between owners, designers, general contractors, subcontractors and suppliers, who populate this supply chain (Xue et al., 2005).

OM supply chain

The OM supply chain involves processes and activities that address the proactive management of built facilities, including: maintaining a systematic record; having a defined program for sustaining the aggregate body of assets through planned maintenance, repair and/or replacement; and implementing and managing information systems in support of these elements (Cagle, 2003). The built facility undergoes repeated repair and maintenance cycles, which occur until the point at which it fails to satisfy the owner's objectives and a refurbishment is performed (Jones, 2002). Even after refurbishment some residual obsolescence persists and this increases over repeated cycles of refurbishment until the obsolescence gap becomes overly large such that the objectives that are critical to the building owner cannot be met. At this point the owner relocates with the building demolished and replaced (Jones, 2002).

Integration of DC and OM supply chains

Traditionally, DC and OM supply chains have been operating as independent chains, with minimal collaboration with one another. However, Cheng et al. (2010) found that integration of the supply chains reduces cost, improves responsiveness to change, increases service level, facilitates decision making and sharing of information. Miles and Snow (2007) also identified that supply chain management has evolved from its primary focus on efficiency in its early days, to a more appropriate focus on effectiveness by incorporating the ideas and expertise of suppliers and partners into the management of the supply chain; and has further moved on to foster cross industry supply chains in addition to operating efficiently and effectively within industries.

Kumaraswamy et al. (2012) proposed three types of integration: functional integration; relational integration; and transactional integration. Functional integration indicates merging functions (like 'design' and 'construction' in D&B) under one organization. Relational integration denotes organizations in a supply chain collaborating well through co-operative relationships built on shared goals and values. Transactional integration signifies linking of organizations for specific transactions through formal means. The strategies for integrating DC and OM supply chains are operationalized from these three integration concepts/constructs.

Functional integration

Sharing relevant information between DC and OM teams: Information is required to facilitate the decision making process and poor information quality inevitably leads to poor decision making (Elonen and Artto, 2003). This is often exacerbated by the severe lack of information sharing. Information sharing in DC supply chain can significantly improve cost and time efficiency (Demiralp et al., 2012), while in the OM supply chain, information sharing has been found to improve response time and control (Wang and Xie, 2002).

Addressing sustainability jointly between DC and OM teams: In the DC supply chain, sustainability is addressed through active and passive design. One example is the use of green materials to promote the recycling of industrial and agricultural waste (Kinuthia and Nidzam, 2011). Another example is green design which incorporates use of solar energy and day-lighting system amongst many others to reduce the energy use by the completed building (Shi and Chew, 2012).

Having similar procurement protocols in DC and OM supply chains: Although, specific procurement protocols exist for the fulfillment of different project performance objectives, Eriksson and Westerberg (2011) have grouped these into three main categories: competition, ‘coopetition’; and cooperation. They observed an accelerated shift from traditional procurement protocols which focus on competition to cooperative procurement protocols due to identified benefits of collaboration. It is hypothesized that the implementation of similar procurement protocols, especially those of cooperative nature would serve to further extract better synergies between the two supply chains.

Integrating life cycle optimization options and opportunities in DC and OM supply chains: Life cycle optimizations largely revolve around selection of materials (Mroueh et al., 2001), costs (Li et al., 2012) and energy efficiency (Aye et al., 2012). While life cycle optimization strategies have been studied, the gap is the optimization opportunities between the two supply chains.

Using joint ICT tools between DC and OM teams: In each phase of a construction project, information is generated, stored and communicated by those who are involved in that phase. The different parties speak their own languages and have their own approaches. This problem is exacerbated by the constantly changing coalitions of firms working on a project. Having joint ICT tools may give rise to better integration. However, the barrier is that the construction industry is dominated by Small and Medium Enterprises (SMEs), which have relatively low sales. An Australian study showed that the annual sales of an organization have a negative effect on the uptake of ICT and training in ICT (Kajewski et al., 2004).

Relational integration

Overlapping DC and OM supply chain networks: To ensure that there are no gaps in service, the first step is to align, and then integrate the supply chains. The can be taken one step further to create some overlaps between the two supply chains.

The overlaps may be in terms of actors, resources and activities. Hertz (2006) found that the overlap between chains can be both positive and negative, and can be reversed over time. In addition, the overlap between supply chains may delay, hinder and increase costs to processes.

Arranging for some common/ linked resource pools and requirements between DC and OM supply chains: The types of resources that may be pooled include tangible resources such as material, labor and equipment (Sarker et al., 2012) and intangible resources such as knowledge and information (Jog et al., 2011). It may be difficult to link tangible resources due to existing business or contractual relationships that may not span both supply chains, and the significantly different job scopes in both chains. On the other hand, it may be possible to have a linkage in informational databases between the supply chains via collaborative knowledge (Dave and Koskela, 2009).

Integrating team building activities between DC and OM teams: As individual facilities are custom-built to clients' specifications (Bresnen, 1990), there is frequent formation and disbandment of bespoke teams. Moreover, bringing people together does not ensure that they will work together efficiently and make appropriate decisions. Selection processes have thus focused on organisations' individual professional capability rather than their collective ability to integrate and work together effectively (Baiden et al., 2006). Cross organizational coordination may prove to be a major challenge due to the differing training and backgrounds from which they hail (Barnes et al., 2006). To further compound this already complex issue, each construction project is very much a multi-ethnic setting, with laborers and professionals of different nationalities, hence speaking different languages and having different cultures, intensifying the problem of coordination (Ochieng and Price, 2010). Notwithstanding this, it is hypothesized that integrating team building activities between DC and OM teams should be carried out. This is because teams are beneficial as they outperform individuals acting alone, especially when performance requires multiple skill sets and judgments (Scarnati, 2001). Developing and managing a built facility requires different skills such as designing, engineering, constructing and facility-managing. These underscore the need for integrated teams (Gould, 2002) to develop and manage the built facility.

<u>Transactional integration</u>

Providing expanded long-term business opportunities for DC and OM teams: Securing long-term contracts offer security in terms of business continuity, thereby providing for a more stable business outlook, which is already prevalent in Chinese and Asian societies (Buck et al., 2010). With expanded business opportunities, cash flow volatility is reduced, while long-term profitability is conversely enhanced (Abdul-Aziz, 1994). Long-term buyer-supplier relationships could be established within the DC and OM supply chains or across these supply chains due to benefits such as substantial cost savings for the buyer (Cannon and Homburg, 2001) since discretionary expenses such as selling, general and administrative overheads are reduced for the supplier (Kalwani and Narayandas, 1995). There will also be an improvement in quality due to increased willingness by the supplier to invest in research and development (Krause, 1999).

Integrating business continuity management (BCM) practices between DC and OM teams: BCM needs to be considered because of the numerous business risks that are present in developing and using built facilities. Within the cluster of internal risks, clients (e.g. sudden bankruptcy), designers (e.g. defective design), contractors (e.g. accidents), subcontractors (e.g. poor performance) and suppliers (e.g. delay of material supply) are sources of risks (El-Sayegh, 2008). Sources of external risks include political (e.g. corruption), social and cultural (e.g. criminal acts), economic (e.g. currency fluctuation) and natural (e.g. unexpected inclement weather) risks (El-Sayegh, 2008). It is important to have integrated BCM practices so that when organizations in whichever part of the supply chains are exposed to risks, these risks will not disrupt operations, disaffect customers and compromise business credibility and revenue streams (Gibb and Buchanan, 2006).

Gaps in knowledge

The common goals in supply chains of built facilities include: common project goals such as cost, quality, time, safety; effective and efficient information sharing; lifecycle oriented project drivers, including overall sustainability concerns; lifecycle oriented project outcomes, including life cycle benefit-cost profiles; efficient resource utilization and management; expanded business opportunities; long term network building; relationship building and management; dispute minimization, management and resolution; organizational capacity building; and shared corporate social responsibility (Xue et al., 2005). The knowledge gap is that while common goals may be identified for built facilities, it is hitherto not known which of these goals are significantly important in helping a built facility achieve better value through the synergies that arise from the integration of the 'integretable' activities between the DC and OM supply chains in Singapore. The relative importance of these common goals needs to be determined as well.

The literature review shows several strategies/activities that may be used to integrate the two supply chains. The next knowledge gap is the lack of information on the effectiveness of these strategies in integrating the DC and OM supply chains in Singapore. The fieldwork was therefore undertaken to address and bridge the above knowledge gaps.

Research method

Led by the third author, a multi-country research project was undertaken in Hong Kong, Singapore, Sri Lanka and the UK to investigate ways to integrate DC and OM supply chains to achieve better value. Based on the literature review, a survey questionnaire was designed. The purpose of the survey was to identify the following: potential activities through which to achieve better synergies, types of integration to achieve better value, common goals in achieving better value and key stakeholders of DC and OM supply chains. The structured questionnaire had five main sections. The first section required respondents to rate the extent to which they agreed that the integration between DC and OM of the listed activities could yield better value. Respondents had to indicate which integration type could best achieve better value from exploitable synergies between DC and OM in the second section. The third section required respondents to rate the degree of importance of a list of common goals in achieving better value through synergies of DC and OM. In the fourth section, respondents were asked to rate how important each of the listed stakeholders is for deriving better value by mobilizing synergies between DC and

OM. The final section required respondents to provide some general information on themselves and their firms. Ratings were generally based on a 5-point Likert scale, e.g., where 1= not at all important/strongly disagree; 3= neutral; and 5= very important/strongly agree. The questionnaire is provided in the Annex. After the questionnaire was designed, it was piloted with three industry experts who are involved in both supply chains. They gave some feedback and the questionnaire was simplified and wordings made clear.

This paper reports one part of the research, focusing on Singapore's findings relating to common goals in achieving better value, key stakeholders of DC and OM supply chains, and activities in DC and OM supply chains that could be beneficially integrated to yield better value.

The population comprises experts who are familiar with built facilities during design, construction and occupation stages. These include building owners, project managers, consultants, contractors and facility managers. The sampling frame comprised members of the following: Real Estate Developers Association, Singapore Institute of Project Managers, Association of Property and Facility Managers, and International Facilities Management Association (Singapore Chapter). Samples were randomly selected from these associations.

The data collection method was a self-administrated email survey. The survey package comprised a structured questionnaire and an introductory email to explain the aim of the research, and invite participation. This form of transmission also represents inherent cost effectiveness and promptness. A self-administered survey was adopted as it reduces biasing error because there is no face-to-face interaction between respondents and researchers. The respondents also have more time to think before they answer. To overcome the problem of low response rate, each email was customized for the specific recipient. The respondents were given a month to reply.

After the statistical analyses were conducted, a simple case study was conducted to investigate the effort of integrating both supply chains to reveal more valuable information. Data were collected via onsite observation and discussion with senior management.

Data analysis

Data were analyzed using the SPSS software. Means were first calculated from the ratings. A higher mean value indicates the item is more important or strongly agreed by respondents. The significance level, α for this study was set at 0.05 following the conventional risk level (Cohen, 1992). This means that there was a 95% certainty that the result was not due to chance and that the finding was significant at the 0.05 level. The probability of mistakenly rejecting the null hypothesis, or committing a Type I error was 5% and the probability of accepting the null hypothesis when it was true was 95%.

The one-sample t-test was used to test the extent to which a common goal is significantly important, and a stakeholder plays a significant role and an activity gives rise to significant integration between DC and OM supply chains. The null and alternative hypotheses are set out as: H_0: $\mu \leq 3$; and H_1: $\mu > 3$. "3" was chosen as it represents the point of neutrality on the 5-point Likert scale (the "neutral" option). When $p < 0.05$, and the t value is positive, the null hypothesis is rejected and the alternative hypothesis is accepted. It is then concluded that common goal or activity is significantly important or the stakeholder plays a significant role.

Analysis of variance (ANOVA) was carried out to test equality of different population means. The test was undertaken to identify whether the effectiveness of the activities identified by two different groups of respondents (those predominantly involved in DC supply chain and those predominantly in OM supply chain) were similar.

Factor analysis was carried out to ascertain if there is any further association among the many activities to achieve better integration between DC and OM supply chains. Using the SPSS software, factor analysis is conducted to investigate whether the variables (X1 to X10) are related to a smaller number of factors. Table 5 provides details of the factor analysis. The factor loadings are the correlation coefficient between an original variable (the activities) and an extracted factor. Communality (h^2) is a measure of variance in the variables that have been accounted for in the factor analysis. The eigenvalue is a measure of how standard variables contribute to the principal component.

Characteristics of the sample

A total of 873 emails were sent out, and 32 completed responses were received, giving a response rate of 4%. Interviews were carried out with three late respondents (one each from client, consultant and contractor) to find out the reasons for this low response rate. They were each the last to submit within their sub-group of respondents. Having three respondents also enabled triangulation of the views. They all said that they took a long time to respond because of the lengthy questionnaire, and their lack of deep knowledge in both supply chains, since each knows about his own supply chain well but not both supply chains deeply.

While the comprehensive questionnaire was necessarily lengthy, the lack of knowledge of the 'other side' highlighted the importance of this research. Nonetheless, the robust statistical tests could still be carried out because in accordance with the generally accepted rule, the central limit theorem holds true when the sample size is no less than 30 (Ott and Longnecker, 2011). Ling et al. (2004) suggested that the adequacy of a sample size could be viewed as a proportion of the size of the construction industry in which the research was conducted. If a research from the US that collected 300 sets of data (eg. Konchar and Sanvido, 1998) from a construction industry with an annual output of about US$815 billion is considered adequate, then this study's 32 sets of data collected from Singapore's construction industry with an annual output of about US$24 billion is not unacceptable. Moreover, there is precedence from previous construction management research that small sample size is acceptable (eg. n=34 in Ling and Soh, 2005; n=30 in Low et al., 2012; and n=33 in Zhao et al., 2013).

Given the low response rate, the no response bias analysis was carried out. It is postulated that the views of non-respondents would approximate the late respondents. Hence, the median ratings given by the three late respondents described above were compared to the median ratings of the rest of the sample. It was found that there was no difference between their median ratings and the rest of the sample. This goes some way to suggest that those who did not respond may also have similar views as those who responded.

The characteristics of respondents are shown in Table 1. The experiences of the respondents vary vastly, ranging from 1 to 35 years, with an average of 8.9 years. The designations of the respondents are highly varied, with the majority being middle management and professionals. The sample has a good representation of clients who are involved in DC and OM supply chains (38%), consultants (28%) and contractors (28%) involved in DC, and facility management consultants involved in OM (6%). The majority have between 1 and 2 layers in their supply chains.

<Table 1 here.>

Results

The common goals that are important in achieving better value through the synergies that arise from the integration of the activities between the DC and OM supply chains are shown in Table 2. Eleven common goals are significantly important in increasing overall project whole life cycle value for stakeholders.

<Table 2 here.>

The most important common goal for clients and consultants is the common project goal triad (i.e., cost, time and quality/safety), which relate to the conventional definitions of project success. As for contractors, this is their second highest rated goal. The second most important goal for clients and consultants is effective and efficient information sharing. To achieve common project goals such as cost, quality, time and safety, relevant information needs to be shared among stakeholders in the DC and OM teams. Information is needed to facilitate decision making (Elonen and Artto, 2003). The third most important goal for clients and consultants is efficient resource utilization and management. This is rated as most important by contractors. As contractors have to undertake physical construction, they need resources to do so, and to utilize them to an efficient level to achieve project success.

When drilled down to individual groups of respondents, contractors did not regard ‘organizational capacity building’ as a significantly important common goal in increasing overall project whole life cycle value for all stakeholders (see Table 2). Capacity building for contractors is vastly different from consultants and clients as contractors build up capacity through acquisition of plant and equipment, skilled workmen and advanced construction technology. On the other hand, consultants’ capacity building is more knowledge-based.

Clients felt all the common goals are significantly important except for ‘expanded business opportunities’ and ‘shared corporate social responsibility’ (see Table 2). Clients of built facilities are generally not involved in construction related business.

Their business challenges and corporate social responsibilities are different from consultants and contractors. Therefore, they would not regard these two as important common goals that help to achieve better value.

From the respondents' ratings of the degree of importance of each stakeholder in deriving better value by mobilizing synergies between DC and OM supply chains, the mean for each stakeholder is calculated, and their importance ranked according to the mean ratings (see Table 3). The t-test of the mean was also conducted, and when t-value is positive and $p< 0.05$, the stakeholder is significantly important. As expected, all major stakeholders play a significantly important part. A project is a temporary coalition of stakeholders who come together to create the built facility. Hence contributions from a strong coalition of supportive and influential stakeholders are necessary to carry out a project successfully (Jepsen and Eskerod, 2009).

<Table 3 here.>

The top three most important stakeholders in both DC and OM supply chains as found from this survey, are in descending order: clients; main contractors and main consultants (see Table 3). Clients are the most important stakeholder for deriving better value by mobilizing synergies between DC and OM supply chains. Clients have more power over other stakeholders because they are on the demand side, requesting and paying for the built facility and associated services. Clients hire consultants and contractors, and as their paymasters, wield considerable power over them.

The general public does not play an important role in this context (see Table 3). This is consistent with Mitchell et al.'s (1997) finding that the general public lack power and legitimacy. Mitchell et al. (1997) describes them as 'mosquitoes buzzing in the ears' of managers, "irksome but not dangerous, bothersome but not warranting more than passing management attention, if any at all." (p.875)

Discussion

The aim of this research is to investigate strategies for achieving better integration between the DC and OM supply chains in Singapore. Table 4 shows that all the 10 activities are significantly effective in helping the two supply chains achieve integration (t values positive, $p< 0.05$). Figure 1 shows that the more important activities are X1, X4 and X2. The Anova results show that the respondents who are predominantly in-charge of DC supply chain and those in-charge of OM supply chain do not have significantly different views on the effectiveness of these activities (F values small, $p> 0.05$). Table 5 shows that the 10 activities may be categorized into 4 groups, suggesting that strategies for integrating DC and OM supply chains relate to integrating functions (factor 1), relationships (factor 2), IT tools (factor 3) and life cycle options (factor 4). The results in Tables 4 and 5 are discussed below.

<Table 4 here. Table 5 here. Figure 1 here.>

Factor 1: integrate functions

Online collaboration and web-based database

In a construction project, fast decisions are needed to allocate scarce resources efficiently. Information is required to facilitate the decision making process and poor information quality inevitably leads to poor decision making (Elonen and Artto, 2003; Blichfeldt and Eskerod, 2008). This is often exacerbated by the severe lack of information sharing. In addition, information gathering, reporting and management are uncoordinated and duplicated. This leads to time wastage, unnecessary costs, increased errors, and misunderstanding.

To enable the built facility to achieve better value, it is recommended that DC and OM teams share relevant information in an integrated way. In the DC supply chain, information sharing can significantly improve cost and time efficiency (Demiralp et al., 2012), while in the OM supply chain, information sharing has been found to improve response time and control (Wang and Xie, 2002). The information to be shared include specifications, as-built drawings, construction records, how sustainability is achieved, asset management performance data and facility management methods. The sharing of information also flows naturally from the Building and Construction Authority's (BCA) Building Information Modeling (BIM) Roadmap that aims for 80% of the construction industry to use BIM by 2015 (BCA, 2011a).

It is recommended that information sharing be carried out over a web-based database (following Forcada et al., 2010; Rezgui et al., 2011). Mounting information online allows multi parties to view and update information. As the OM teams are typically selected after the commissioning of the building, the web-database avoids the break in information transmission from DC to OM stages as information is stored online and those that join the project later can still have access to the full slate of information. This stored information could be used by the OM team to device facilities management plans.

A web-based database allows intangible resources such as knowledge and information to be linked between stakeholders. By having a linked information and knowledge network, numerous benefits may be reaped. For example, at the construction site, an information platform integrated with Radio Frequency Identification or Machine Vision Technology helps stakeholders to locate equipment (Jog et al., 2011). Between stakeholders, such as contractors and suppliers, having a linked database reduces the probability of a material shortfall (Xue et al., 2011). Such is also applicable to the OM supply chain, where the Building Automation System not only helps with the daily building management, but by linking it up with the information platforms of vendors of mechanical systems installed, response during breakdown will be more effective.

Another advantage of a web-based database that is accessible to all stakeholders is the presence of collaborative knowledge. There are 2 forms of knowledge, the explicit and the tacit, with the latter being more important. A significant amount of knowledge is generated in every project, yet most of this knowledge is stored in the minds of team members as tacit knowledge, hence not transferred within the organization much less throughout the industry, making knowledge capabilities difficult to be built up (Dave and Koskela, 2009). However, with a linked database, common problems can be solved by knowledge sharing, eliminating the cost of inventing the same solution (Goodman and Darr, 1998), thereby improving the industry's productivity, profitability and competitiveness.

Joint sustainability assessment

With the shift towards sustainable development, it is recommended that DC and OM teams address sustainability issues jointly. These include the relevant i.e. project-specific or program-specific types of green design and green materials. Green design may include active design and passive design to reduce water and energy consumption (Shi and Chew, 2012) while green materials are those that promote recycling of industrial and agricultural waste (Kinuthia and Nidzam, 2011).

It is important for OM teams to have information on how the built facility achieved sustainability at the DC stage, so that the OM team would replace relevant parts with green materials to ensure the built facility is also green at occupancy stage. When DC and OM teams work jointly, the OM team is able to advise the DC team to incorporate state of the art Building Automation System to optimize energy usage through efficient computerized controls that manage automated installations throughout the building (Dounis and Caraiscos, 2009).

The use of energy modeling software to optimize energy consumption necessitates cooperation between DC and OM teams because several parameters have to be manipulated and trialed virtually so that a building with the optimum energy efficiency can be designed and developed (Ryana and Sanquistb, 2012), yet some of the knowledge of these parameters resides with DC team members while others with OM people.

The web-based database may also be used to facilitate information sharing to address sustainability issues. All relevant stakeholders input relevant sustainability information of the facility such as green design, green materials and green facility management into the database.

Similar procurement protocols

To achieve better value, it is recommended that DC and OM supply chains adopt similar procurement protocols. The strong interdependencies between the stakeholders of the DC and OM supply chains (Jensen, 2009) indicate that decisions made by any one party will have far-reaching effects on the rest. Procurement needs exist consistently along the entire supply chain; from design to construction to facility management. One common point of contention is the dissimilar procurement protocols employed by individual stakeholders. Implementation of similar procurement protocols allows for proper project governance. This will serve to provide the structure for setting project objectives, determining the means to attain those objectives, and defining the means of monitoring performance (Turner, 2006), which in turn leads to better value. It is recommended that a more cooperative procurement protocol be adopted as collaboration has many benefits (Eriksson and Westerberg, 2011). The implementation of similar procurement protocols that are cooperative in nature would serve to further extract better value. Some cooperative protocols include selective tendering, incentive-based compensation, and partner selection based on task related attributes.

Overlapping supply chain networks

To enable stakeholders of built facilities to achieve better value, overlapping DC and OM supply chain networks is recommended. In order to overlap the networks, commonalities that provide opportunities for sharing between the networks need to be identified. An example is having the same supplier in the DC supply chain to continue supplying replacement parts required by the OM supply chain. Due to the different scope of work in DC and OM, difficulties in identifying such commonalities can be expected. Thus to encourage such exploration, an alignment of goals through incentives is crucial. It should be noted that there is an optimal point in overlapping the supply chains. There is a trade-off between the costs of integration in the focal chain and increasing costs arising from decreased integration in overlapping supply chains, and failure to consider the negative effects and the resistance caused by delays and dissolving relationships within overlapping supply chains can be detrimental (Hertz, 2006).

Factor 2: Integrate relationships

Linking resource pools

It is recommended that common requirements and resource pools between DC and OM supply chains be proactively probed and arranged, as this allows for optimal utilization of resources. Key tangible resources such as materials, equipment (Chen et al., 2012) and human resources (Cheng et al., 2006) are important to incease stakeholder value. Further resource optimization through collaborative efforts between the stakeholders could be exercised. A possible scenario would be for bulk procurement by stakeholders requiring the same material. Admittedly, this may be difficult to implement within the DC or OM supply chains due to existing business or contractual relationships and more so to implement it across the supply chains due to the significantly different job scopes.

Expanded long-term business opportunities

It is recommended that expanded long-term business opportunities for DC and OM teams be provided to derive better value. One of the ways to achieve this is to deliberately under-bid so as to secure an important client. The underlying intention is to gain access to the client's future projects.

When parties know that long term business opportunities exist, they may be more willing to sacrifice short-term gains in favour of benefits accruing to parties over the long run (Ganesan, 1993). They approach the relationship with a problem solving orientation and collaborative bargaining style that results in higher levels of performance and economic return over the long-term. Overall, the asset may then achieve better value.

Admittedly, this recommendation would be more applicable to consultants and contractors in the DC and OM supply chains, and not so much to clients, as Table 2 shows that clients do not view this as a significant goal. As explained, clients' core business may be significantly different from construction and facility management.

Integrated team building

Integrated team building activities between DC and OM teams is recommended to derive better value for stakeholders. The 'blame culture' exists whereby various team members seek to minimise their level of exposure to poor performance, rather than working together in a spirit of trust, cooperation and collaboration (Baiden et al., 2006). All of these accentuate the need to establish a strong team building programme. It is acknowledged that in the OM supply chain, teams could be more 'permanent' or less transient. However, the non-renewal of contracts between building owners and facility management vendors as well as the reshuffling of human resources within individual vendor organizations would also lead to transient teams albeit to a lesser extent.

The difficulties described above suggest that teams need to be built up carefully. Tannenbaum et al. (1992) suggested several approaches: goal-setting approach (establishing agreed upon output levels); interpersonal approach (improving the way teammates feel about each other); role approach (clarifying team members' roles and responsibilities); and problem-solving approach. The final approach is a general move to team building that improves team effectiveness.

It is important to appreciate that team-building exercises are not one-off events held at the onset of the project. Instead, due to the constantly changing team make-up, arising from changing project needs as well as turnovers, team building exercises must be implemented on a regular basis so as to integrate new team members. This ensures team integrity which is a crucial factor in facilitating the integration of the DC and OM supply chains.

Integrated business continuity management (BCM) opportunities

Integrating BCM practices between DC and OM teams is recommended so that stakeholders may achieve better value. As the DC and OM supply chains are impacted by similar sets of risks, significant value and synergy can be exploited if an integrated BCM program is collaboratively produced between teams in both supply chains. Some benefits include cost savings, cost sharing, experience sharing and experience tapping. An integrated BCM program amongst all stakeholders will allow for the contingencies to be better dealt with as opposed to having separate and different BCM programs being carried out simultaneously by individual stakeholders in response to a crisis that impacts all stakeholders.

DC and OM teams should come together to draw up an integrated BCM program. The phases of program development include program initiation, project initiation, risk analysis, risk mitigation strategy selection, monitoring and control, implementation, testing, education and training, and review (Gibb and Buchanan, 2006).

Factor 3: Integrate IT tools

It is recommended that ICT tools be used jointly between DC and OM teams in order to yield better value. The benefits of joint ICT tools include an increase in the quality of documents, higher speed of work, better financial control and communications, and simpler and faster access to common data as well as a decrease in documentation errors (Forcada et al., 2010; Rezgui et al., 2011; Demiralp et al., 2012). To encourage widespread usage of BIM, Singapore's regulatory agencies encourage and accept e-submissions of one building model which contains all of the information when stakeholders apply for regulatory approvals (BCA, 2011b). This facilitates joint ICT effort because at the DC stage, consultants and contractors are already working on one single building model on the BIM platform.

Collection, analysis and real-time communication of information is essential for detecting time, cost and quality deviations from planned performance and responding to problems and disputes. Joint ICT tools thus provide opportunities for stakeholders to have real-time access to information and this improves coordination and collaboration among them.

In order to increase adoption of ICT, personal and external motivation need to be in place (Adriaanse et al., 2010). Personal motivation to accept joint ICT is influenced by the perceived benefits and disadvantages of joint ICT platforms. This mechanism is moderated by perceived time pressures as it influences the personal motivation to adopt joint ICT tools because of the time investment required to learn to use the platform. External motivation is influenced by the availability of contractual arrangements regarding the adoption of joint ICT and the presence of a requesting stakeholder, usually the client. The lack of knowledge and skills and opportunities are some factors inhibiting the adoption of joint ICT by stakeholders (Adriaanse et al., 2010).

Factor 4: Integrate life cycle options

The final recommendation to yield better value for stakeholders of built facilities is to integrate life cycle optimization opportunities in DC and OM supply chains. In order to uncover and act on life cycle optimization opportunities over the life of a building, three key criteria are proposed: informative formulation (information availability); clear evaluation (pertinent decision contents); and quick re-formulation (alternative proposals) (Kam and Fischer, 2004). The employment of a web-based database which is accessible by stakeholders of both the DC and OM supply chains, could be used to deliver these criteria. The information recorded in the online database would be readily available, and easily retrievable for decision making and the information will aid in the formulation of alternative proposals and also allow decision makers to evaluate their feasibility. A web-based database is therefore crucial for the capitalization of life cycle optimization opportunities.

Case study

The case study was conducted to validate the findings of the statistical analysis. The case is an institution of higher learning (IHL) in Singapore. The IHL was selected for study because its campus comprises old and existing buildings and new developments, thereby allowing DC and OM activities to be observed. Its DC projects are for capacity building, campus rejuvenation and sustainability, and space optimization. On a daily basis, OM activities are carried out to meet the needs and expectations of its approximately 40,000 users. The IHL has a Campus Infrastructure Division (CID) led by a vice president. This division is structured into various offices headed by directors. The relevant offices for this study are: estate development; facilities maintenance; safety and health; campus sustainability; and faculty housing.

The DC and OM supply chains are well integrated in this IHL because the CID integrates the functions of the various offices. All the offices adopt the same procurement protocols. All development projects are subject to design reviews which are attended by representatives from the different offices. The sharing of information takes place in these meetings whereby the other offices provide the estate development office with their feedback, observations and requests relating to safety, health, maintenance and end users' needs in a formal manner using checklists and lessons learnt. In these meetings, sustainability issues are also addressed jointly, and life cycle opportunities are explored. Campus wide, the IHL uses one common network system and SAP software. This ensures that DC and OM teams have access to the same set of data which is available online.

As the offices report to the same vice president, relationships among staff from DC and OM supply chains are developed in an integrated manner. The vice president's office organizes team building activities for all the staff under his charge. These offices also share services such as human resource management, finance and communications. The projects move from estate development (during DC) to facilities maintenance (OM) in a smooth and continuous manner.

The findings from the case study show that DC and OM supply chains are well integrated in the IHL. The strategies adopted by the IHL are in line with the statistical results.

Conclusion

The purpose of this research was to investigate the common goals that could help in achieving better value, identify stakeholders that play important roles in mobilizing synergies between DC and OM supply chains, and recommend activities that help stakeholders achieve better value in their built facilities. It was discovered that 11 common goals are significantly important in achieving better value (see Table 2), with the three most important relating to common project goals (time, cost, quality, safety), information sharing and resource utilization and management. Key stakeholders in both the DC and OM supply chains, namely the client, main contractor and designers/main consultants have been found to be essential in mobilizing the integration (see Table 3).

Ten activities are found to be effective in extracting better value from the integration of the DC and OM supply chains (see Table 4). Information sharing between DC and OM teams is the most important activity that enables the built facility to yield better value for all stakeholders (see Figure 1). The study proposed online collaboration through a web-based database to allow sharing of information among stakeholders in both supply chains. The web-based database can also serve to promote better life cycle optimization opportunities as information is made available for the identification of opportunities and subsequently the formulation of alternatives to capitalize on such opportunities. Lastly, such a web-based database also serves to facilitate linking of resource pools, in particular that of tacit knowledge, hence allowing common problems to be solved by knowledge sharing, eliminating the cost of re-inventing the same solution.

One of the limitations of this research is the small sample size which limits the scope for generalization of the respondents' perceptions to the overall population. Within the sample, the percentage of OM representative is also a minority. Client respondents who straddle both DC and OM supply chains make up 37.5% of the sample, suggesting that there is a sizeable portion of respondents who do not have the relevant experiences in both supply chains. As such, the results established from the statistical analyses must be interpreted with care, giving due considerations for potential under coverage bias and to reliability issue. However, in the absence of other studies from Singapore, the findings provide some guidance on the activities and strategies that DC and OM practitioners could consider. In future, research could be undertaken on a larger sample of DC and OM practitioners in Singapore, and using other data collection methods such as Delphi method to elicit higher responses. However, the findings are not expected to be significantly different as the parallel study in Hong Kong which had a large sample size of 52 yielded quite similar results (Wong et al., 2014). The online collaboration and web-based database could be designed, and tested in future studies.

This study contributes to knowledge by showing that it is possible to integrate DC and OM supply chains through the adoption of specifically useful integrating activities. The strategies and activities to reduce the dichotomy between DC and OM supply chains were identified. The research implication is that integrating DC and OM supply chains could increase value for all stakeholders of built facilities. The contribution to practice is the explanation of how integrated activities could be targeted and implemented across DC and OM supply chains. This will lead to increased overall project whole life cycle value for all stakeholders.

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REFERENCES

Abdul-Aziz, A.R. (1994), “Global strategies: a comparison between Japanese and American construction firms”, *Construction Management and Economics,* Vol. 12 No. 6, pp. 473-484.

Adriaanse, A., Voordijk, H. and Dewulf, G. (2010), “The use of interorganisational ICT in United States construction projects”, *Automation in Construction,* Vol. 19 No. 1, pp. 73-83.

Aye, L., Ngo, T., Crawford, R. H., Gammampila, R. and Mendis, P. (2012), “Life cycle greenhouse gas emissions and energy analysis of prefabricated reusable building modules”, *Energy and Buildings,* Vol. 47 pp. 159–168.

Baiden, B. K., Price, A. D. and Dainty, A. R. (2006), “The extent of team integration within construction projects”, *International Journal of Project Management,* Vol. 24 No. 1, pp. 13-23.

Barnes, T. A., Pashby, I. R., & Gibbons, A. M. (2006). “Managing collaborative R&D projects development of a practical management tool”, *International Journal of Project Management,* Vol. 24 No. 5, pp. 395-404.

BCA. (2011a), “All set for 2015: The BIM roadmap”, *Build Smart*, Vol. 9, p. 2.

BCA. (2011b), “The world’s first BIM e-submission system”, *Build Smart*, Vol. 9, p. 4.

Blichfeldt, B. S. and Eskerod, P. (2008), “Project portfolio management — there's more to it than what management enacts”, *International Journal of Project Management,* Vol. 24 No. 4, pp. 357–365.

Bresnen, M. (1990), *Organising Construction: Project and Organisation Matrix Management*, Routledge, London.

Buck, T., Liu, X. and Ott, U. (2010), “Long-term orientation and international joint venture strategies in modern China”, *International Business Review,* Vol. 19 No. 3, pp. 223–234.

Cagle, R. F. (2003). *Infrastructure Asset Management: An Emerging Direction*, Jones and Goudling, Inc, Jordan.

Cannon, J.P. and Homburg, C. (2001), “Buyer-Supplier relationships and customer firm costs”, *Journal of Marketing,* Vol. 65 No. 1, pp. 29-43.

Chen, S.M., Griffis, F.H., Chen, P.H. and Chang, L.M. (2012), “Simulation and analytical techniques for construction resource planning and scheduling”, *Automation in Construction,* Vol. 21 pp. 99-113.

Cheng, M.Y., Tsai, M.H. and Xiao, Z.W. (2006), “Construction management process reengineering: Organizational human resource planning for multiple projects”, *Automation in Construction,* Vol. 15 No. 6, pp. 785-799.

Cheng, J. C., Law, K. H., Bjornsson, H., Jones, A., & Sriram, R. (2010), “A service oriented framework for construction supply chain integration”, *Automation in Construction,* Vol. 19 No. 2, pp. 245-260.

Cohen, J. (1992), “Statistical power analysis”, *Current Directions in Psychological Science*, Vol. 1 No. 3, pp. 98-101.

Dave, B. and Koskela, L. (2009), “Collaborative knowledge management – A construction case study,” *Automation in Construction,* Vol. 18 No. 7, pp. 894-902.

Demiralp, G., Guven, G. and Ergen, E. (2012), “Analyzing the benefits of RFID technology for cost sharing in construction supply chains: A case study on prefabricated precast components”, *Automation in Construction,* Vol. 24, pp. 120-129.

Dounis, A.I. and Caraiscos, C. (2009), “Advanced control systems engineering for energy and comfort management in a building environment - A review”, *Renewable and Sustainable Energy Reviews,* Vol. 13 No. 6-7, pp. 1246–1261.

Elonen, S. and Artto, K.A. (2003), “Problems in managing internal development projects in multi-project environments”, *International Journal of Project Management,* Vol. 21 No. 6, pp. 395–402.

El-Sayegh, S.M. (2008), “Risk assessment and allocation in the UAE construction industry”, *International Journal of Project Management,* Vol. 26 No. 4, pp. 431-438.

Eriksson, P.E. and Westerberg, M. (2011), “Effects of cooperative procurement procedures on construction project performance: A conceptual framework”, *International Journal of Project Management,* Vol. 29 No. 2, pp. 197-208.

Fawcett, S.E. and Magnan, G.M. (2002), “The rhetoric and reality of supply chain integration”, *International Journal of Physical Distribution and Logistic Management*, Vol. 32 No. 5, pp. 339-361.

Forcada, N., Casals, M., Fuertes, A., Gangolells, M. and Roca, X. (2010), “A web-based system for sharing and disseminating research results: The underground construction case study”, *Automation in Construction,* Vol. 19 No. 4, pp. 458-474.

Ganesan, S. (1993), “Negotiation strategies and the nature of channel relationships”, *Journal of Marketing Research,* Vol. 30 No. 2, pp. 183-203.

Gibb, F. and Buchanan, S. (2006), “A framework for business continuity management”, *International Journal of Information Management,* Vol. 26 No. 2, pp. 128-141.

Goodman, P.S. and Darr, E.D. (1998), “Computer-aided systems and communities: mechanisms for organizational learning in distributed environments”, *MIS Quarterly,* Vol. 22 No. 4, pp. 417-440.

Gould, F.E. (2002), *Managing the Construction Process*, Prentice Hall, New Jersey.

Hertz, S. (2006), "Supply chain myopia and overlapping supply chains", Journal of Business & Industrial Marketing, Vol. 21 No. 4, pp.208 – 217.

Jensen, P.A. (2009), “Design integration of facilities management: a challenge of knowledge transfer”, *Architectural Engineering and Design Management,* Vol. 5 No. 3, pp. 124-135.

Jepsen, A.L. and Eskerod, P. (2009), “Stakeholder analysis in projects: Challenges in using current guidelines in the real world”, *International Journal of Project Management,* Vol. 27 No. 4, pp. 335-343.

Jog, G.M., Brilakis, I.K. and Angelides, D.C. (2011), “Testing in harsh conditions: Tracking resources on construction sites with machine vision”, *Automation in Construction,* Vol. 20 No. 4, pp. 328–337.

Jones, K. (2002), “Sustainable building maintenance: challenge for construction professionals”. In J. Kelly, *Best Value in Construction* (pp. 280-301), Blackwell Science, London.

Kajewski, S., Weippert, A., Remmers, T. and McFallan, S. (2004), “ICT in the Australian construction industry: status, training and perspectives”, Proc. *CRC CI International Conference*, CRC, Surfers Paradise.

Kalwani, M.U. and Narayandas, N. (1995), “Long-term manufacturer-supplier relationships: do they pay off for supplier firms?”, *Journal of Marketing,* Vol. 59 No. 1, pp. 1-16.

Kam, C. and Fischer, M. (2004), “Capitalizing on early project decision-making opportunities to improve facility design, construction, and life-cycle performance—POP, PM4D, and decision dashboard approaches”, *Automation in Construction,* Vol. 13 No. 1, pp. 53-65.

Kinuthia, J.M. and Nidzam, R.M. (2011), “Towards zero industrial waste: Utilisation of brick dust waste in sustainable construction”, *Waste Management,* Vol. 31 No. 8, pp. 1867–1878.

Konchar, M and Sanvido, V. (1998), “Comparison of US project delivery systems”, *Journal of Construction Engineering and Management*, Vol. 124 No. 6, pp. 435-444.

Krause, D.R. (1999), “The antecedents of buying firms' efforts to improve suppliers”, *Journal of Operations Management,* Vol. 17 No. 2, pp. 205-224.

Kumaraswamy, M., Wong, K.K.W. and Mahesh, G. (2012), “Integrating teams for built asset development and management: a Hong Kong perspective”, in *ASEA-SEC-1* Conference on *Research, Development, and Practice in Structural Engineering and Construction,* Ed. Vimonsatit, V., Singh, A., Yazdani, S., in Perth, Australia, 28 Nov. – 02 Dec., Research Publishing Services, Singapore, pp. 865-870.

Li, W., Zhu, J. and Zhu, Z. (2012), “The energy-saving benefit evaluation methods of the grid construction project based on life cycle cost theory”, *Energy Procedia,* Vol. 17 No. A, pp. 227–232.

Ling, Y.Y., Chan, S.L., Chong, E. and Ee, L.P. (2004), “Predicting performance of DB and DBB projects”, *Journal of Construction Engineering and Management*, Vol. 130 No. 1, pp. 75-83.

Ling, F.Y.Y. and Soh, L.H. (2005), “Improving the design of tall buildings after 9/11”, *Structural Survey*, Vol. 23 No. 4, pp.265 – 281.

Low S.P., Deng X. and Lye, L. (2012), “Communications management for upgrading public housing projects in Singapore”, *Structural Survey*, Vol. 30 No. 1, pp.6 – 23.

Miles, R. E. and Snow, C. C. (2007), “Organization theory and supply chain management: An evolving research perspective”, *Journal of Operations Management*, Vol. 25 No. 2, pp. 459–463.

Mitchell, R.K., Agle, B.R. and Wood, D.J. (1997), “Toward a theory of stakeholder identification and salience: defining the principle of who and what really counts”, *The Academy of Management Review,* Vol. 22 No. 4, pp. 853-886.

Mroueh, U.M., Eskola, P. and Laine-Ylijoki, J. (2001), “Life-cycle impacts of the use of industrial by-products in road and earth construction”, *Waste Management,* Vol. 21 No. 3, pp. 271–277.

Ochieng, E. G. and Price, A. D. (2010), “Managing cross-cultural communication in multicultural construction project teams: The case of Kenya and UK”, *International Journal of Project Management,* Vol. 28 No. 5, pp. 449-460.

Ott, R.L. and Longnecker, M. (2001), *An Introduction to Statistical Methods and Data Analysis*, Duxbury, Pacific Grove.

Rezgui, Y., Boddy, S., Wetherill, M. and Cooper, G. (2011), “Past, present and future of information and knowledge sharing in the construction industry: Towards semantic service-based e-construction?”, *Computer-Aided Design,* Vol. 43 No. 5, pp. 502-515.

Ryana, E.M. and Sanquistb, T.F. (2012), “Validation of building energy modeling tools under idealized and realistic conditions”, *Energy and Buildings,* Vol. 47, pp. 375-382.

Sarker, B. R., Egbelu, P. J., Liao, T. W. and Yu, J. (2012), “Planning and design models for construction industry: A critical survey”, *Automation in Construction,* Vol. 22 No. 1, pp. 123-134.

Scarnati, J.T. (2001), “On becoming a team player”, *Team Performance Management,* Vol. 7 No. 1-2, pp. 5-10.

Shi, L. and Chew, M.Y. (2012), “A review on sustainable design of renewable energy systems”, *Renewable and Sustainable Energy Reviews,* Vol. 16 No. 1, pp. 192-207.

Tannenbaum, S.I., Beard, R.L. and Salas, E. (1992), “Team building and its influence on team effectiveness: an examination of conceptual and empirical developments”, *Advances in Psychology,* Vol. 82, pp. 117-153.

Turner, J.R. (2006), “Towards a theory of project management: The nature of the project governance and project management”, *International Journal of Project Management,* Vol. 24 No. 2, pp. 93-95.

Wang, S. and Xie, J. (2002), “Integrating Building Management System and facilities management on the Internet”, *Automation in Construction,* Vol. 11 No. 6, pp. 707-715.

Wang, X. and Huang, J. (2006), “The relationships between key stakeholders’ project performance and project success: Perceptions of Chinese construction supervising engineers”, *International Journal of Project Management,* Vol. 24 No. 3, pp. 253-260.

Wong, K.K.W., Kumaraswamy, M., Mahesh, G. and Ling F.Y.Y. (2014), “Building integrated project and asset management teams for sustainable built infrastructure development,” *Journal of Facilities Management*, (in press).

World Bank. (2013), “GDP per capita (current US$)”, available at: http://data.worldbank.org/indicator/NY.GDP.PCAP.CD (accessed October 10, 2013).

Xue, X., Li, X., Shen, Q. and Wang, Y. (2005), “An agent-based framework for supply chain coordination in construction”, *Automation in Construction,* Vol. 14 No. 3, pp. 413-430.

Xue, X., Shen, Q., Tan, Y., Zhang, Y. and Fan, H. (2011), “Comparing the value of information sharing under different inventory policies in construction supply chain”, *International Journal of Project Management,* Vol. 29 No. 7, pp. 867-876.

Zhao X., Hwang, BG. and Yu, G.S. (2013), Identifying the critical risks in underground rail international construction joint ventures: Case study of Singapore”, *International Journal of Projet Management*, Vol. 31, pp. 554-566.

ANNEX

Survey on Practices/Activities to Integrate Design and Construction stage and Operations and Maintenance stage to achieve better value

Instructions: Please fill up the questionnaire by putting a cross in appropriate boxes or filling in the blanks.

Section 1: Activities/items to achieve better value/synergies

Please indicate to what extent you agree that the appropriate integration of the following activities/ items between 'Design & Construction (D&C)' and 'Operations & Maintenance (O&M)', when appropriately mobilized, can yield better value / synergies	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. Sharing relevant information (e.g. building specs, as-built drawings, construction records, O & M performance data, etc.) - between D&C and O&M teams can yield better value/synergies.	5	4	3	2	1
2. Addressing Sustainability issues more effectively through sharing of relevant information above can yield better value/synergies.	5	4	3	2	1
3. Similar Procurement protocols between D&C and O&M can yield better value/synergies.	5	4	3	2	1
4. Better/integrated 'life cycle optimization' options/ opportunities (e.g. when Designers have more knowledge of O&M issues *and* Asset Managers have better understanding of design intent and material/ equipment choices) can yield better value/synergies.	5	4	3	2	1
5. Overlapping Supply Chain Networks delivering D&C and O&M can yield better value/synergies.	5	4	3	2	1
6. Arranging for some common/ linked resource pools and requirements (e.g. in material types, human resources) between D&C and O&M can yield better value/synergies.	5	4	3	2	1
7. Expanded long term business opportunities can yield better value/synergies.	5	4	3	2	1
8. Integrated team building (Human resource capacity improvement) can yield better value/synergies.	5	4	3	2	1
9. Joint use of ICT tools (e.g. in BIM - Building Information Modelling) can yield better value/synergies.	5	4	3	2	1
10. Integrated business continuity management opportunities can yield better value/synergies.	5	4	3	2	1

Section 2: Achieving 'Value' through Integration

Please indicate which of one of the three integration types (Functional, Relational, Transactional) as defined above can potentially best achieve 'better value' from the following exploitable synergies between Design and Construction (D&C) and Operation and Maintenance (O&M)	Functional	Relational	Transactional
1. Better value/ synergies from sharing relevant information (e.g. building specs, as-built drawings, construction records O&M performance data, etc.) - between D&C and O&M teams.			
2. Better value/ synergies to address sustainability issues more effectively through above sharing of relevant information.			
3. Better value/ synergies from similar procurement protocols between D&C and O&M			
4. Better value/ synergies from better (integrated) 'life cycle optimization' options/ opportunities e.g. when Designers have more knowledge of O&M (and other Sustainability-impacting) issues *and* Asset Managers have better understanding of design intent and			

material/ equipment choices			
5. Better value/ synergies from overlapping Supply Chain Networks delivering D&C and O&M			
6. Better value/ synergies from arranging for some common/ linked resource pools and requirements (e.g. in material types, human resources) between D&C and O&M			
7. Better value/ synergies from expanded long term business opportunities			
8. Better value/ synergies from integrated team building (Human resource capacity improvement)			
9. Better value/ synergies from joint use of ICT tools (e.g. in BIM - Building Information Modelling)			
10. Better value/synergies from integrated 'business continuity management' opportunities			

Section 3: Common goals in achieving better value

Please indicate your opinion of the degree of importance of the following common goals in achieving 'better value' through above synergies	Very Important	Important	Neutral	Not so Important	Not Important at all
1. Common project goals such as cost, quality, time, safety	5	4	3	2	1
2. Effective and efficient information sharing	5	4	3	2	1
3. Lifecycle oriented project drivers, including overall sustainability concerns	5	4	3	2	1
4. Lifecycle oriented project outcomes, including life cycle benefit-cost profiles	5	4	3	2	1
5. Efficient resource utilization & management	5	4	3	2	1
6. Expanded business opportunities	5	4	3	2	1
7. Long term network building	5	4	3	2	1
8. Relationship building and management	5	4	3	2	1
9. Dispute minimization, management & resolution	5	4	3	2	1
10. Organisational capacity building	5	4	3	2	1
11. Shared corporate social responsibility	5	4	3	2	1

Section 4: Key Stakeholders of D&C and O&M Supply Chains

Please rate to what extent you believe the following stakeholders are important for deriving **'better value'** by mobilising/ exploiting **'synergies'** between D&C and O&M supply chains.	Design & Construction (D&C)					Operations & Maintenance (O&M)				
	Very Important	Important	Neutral	Not so Important	Not Important at all	Very Important	Important	Neutral	Not so Important	Not Important at all
1. Clients	5	4	3	2	1	5	4	3	2	1
2. Main Contractors	5	4	3	2	1	5	4	3	2	1
3. Sub-Contractors	5	4	3	2	1	5	4	3	2	1
4. Designers and main consultants	5	4	3	2	1	5	4	3	2	1
5. Other (Specialist / Sub-) Consultants	5	4	3	2	1	5	4	3	2	1
6. Suppliers	5	4	3	2	1	5	4	3	2	1
7. Users	5	4	3	2	1	5	4	3	2	1
8. General Public	5	4	3	2	1	5	4	3	2	1
9. Relevant non-governmental organisations	5	4	3	2	1	5	4	3	2	1
10. Relevant Statutory bodies	5	4	3	2	1	5	4	3	2	1
11. Other relevant Government	5	4	3	2	1	5	4	3	2	1

organisations										
12. Project financiers	5	4	3	2	1	5	4	3	2	1

Section 5: Demographic Characteristics

1. Organisation type that you are currently employed in:
□ Client □ Consultant PM □ Consultant FM
□ Contractor □ Sub-contractor □ Supplier

2. Type of work you are predominantly experienced in:
□ Design & Construction □ Operations & Maintenance □ Others

3. Your supply chain size: □ 1 to 2 layers □ 3 layers □ > 3 layers

4. Your experience in the industry (no. of years): ____________ years.

5. Your designation/job title: _____________________

Table 1 Characteristics of the respondents

Description	Frequency	%
Years of experience		
< 10 years	21	65.6
10 – 20 years	7	21.9
> 20 years	4	12.5
Designation of respondents		
Top management	7	21.9
Mid management	10	31.2
Executive and professionals	15	46.9
Type of firm		
Client	12	37.5
Consultant	11	34.4
Contractor	9	28.1
Nature of work		
Design and construction	24	75
Operations and maintenance	8	25
Layers in supply chain		
1 or 2	18	56.3
3	8	25
> 3	6	18.7

Table 2 Statistical results of common goals to achieve better value

Degree of importance of the following **goals in achieving better value**	Overall			Clients			Consultants			Contractors		
	Mean	t	Sig.	Mean	t	Sig.	Mean	t	Sig.	Mean	t	Sig.
Cost, quality, time, safety	4.78	23.990	.000	4.92	25.000	.000	4.67	11.726	.000	4.71	9.295	.000
Effective and efficient information sharing	4.53	17.085	.000	4.54	10.690	.000	4.58	10.652	.000	4.43	7.071	.000
Lifecycle oriented project drivers, including overall sustainability concerns	3.88	8.941	.000	3.85	5.500	.000	4.08	7.288	.000	3.57	2.828	.030
Lifecycle oriented project outcomes, including life cycle benefit-cost profiles	4.00	8.418	.000	3.85	4.430	.001	4.25	6.966	.000	3.86	3.286	.017
Efficient resource utilization & management	4.41	14.207	.000	4.31	9.815	.000	4.25	6.966	.000	4.86	13.000	.000
Expanded business opportunities	3.66	5.298	.000	3.46	2.144	**.053***	3.67	3.546	.005	4.00	4.583	.004
Long-term network building	3.91	7.440	.000	3.69	3.959	.002	3.83	4.022	.002	4.43	7.071	.000
Relationship building and management	3.94	7.411	.000	3.77	3.825	.002	4.17	5.631	.000	3.86	3.286	.017
Dispute minimization, management & resolution	4.16	7.726	.000	4.15	5.196	.000	3.92	3.188	.009	4.57	7.778	.000
Organizational capacity building	3.66	5.298	.000	3.69	3.323	.006	3.67	3.546	.005	3.57	1.922	**.103***
Shared corporate social responsibility	3.59	4.443	.000	3.38	1.594	**.137***	3.75	3.447	.005	3.71	3.873	.008

Notes: * Not significant. Means derived from 5-point scale rating: 1= Extremely not important; 2= not important; 3= neutral; 4= important; 5= very important.

Table 3 Statistical results of key stakeholders of DC and OM supply chains

Degree of importance of stakeholders in integrating DC and OM	Design and Construction				Operations and Maintenance			
	Rank	Mean	t	Sig.	Rank	Mean	t	Sig.
Clients	1	4.63	16.605	.000	1	4.53	12.069	.000
Main contractors	2	4.66	17.181	.000	2	4.44	12.155	.000
Sub-Contractors	4	4.13	7.642	.000	6	3.84	5.910	.000
Designers and main consultants	3	4.53	13.940	.000	3	4.31	9.515	.000
Other specialist / sub-consultants	5	4.06	8.984	.000	4	4.03	9.807	.000
Suppliers	9	3.63	4.061	.000	7	3.72	4.776	.000
Users	8	3.78	4.533	.000	5	4.00	6.177	.000
General public	12	2.84	-1.044	.305*	12	3.31	1.621	.115*
Relevant non-governmental organizations	11	3.53	2.871	.007	11	3.44	2.521	.017
Relevant statutory bodies	6	3.91	4.844	.000	7	3.72	3.973	.000
Other relevant government organizations	9	3.63	3.401	.002	10	3.47	2.611	.014
Project financiers	6	3.91	5.522	.000	9	3.66	3.483	.002

Notes: * Not significant at $p= 0.05$. Means derived from 5-point scale rating: 1= Extremely not important; 2= not important; 3= neutral; 4= important; 5= very important.

Table 4 Activities to achieve better value

Code	Degree of agreement that the activities lead to better integration of DC and OM supply chains	Mean			T test		Anova	
		Overall	DC	OM	t	Sig.	F	Sig
X1	Sharing relevant information between DC and OM teams	4.41	4.50	4.00	10.522	.000	1.995	.169*
X2	Addressing sustainability jointly between DC and OM teams	4.13	4.13	3.80	8.470	.000	.765	.389*
X3	Having similar procurement protocols in DC and OM supply chains	3.69	3.67	3.80	6.035	.000	.164	.689*
X4	Integrating life cycle optimization options and opportunities in DC and OM supply chains	4.34	4.46	4.00	10.849	.000	1963	.173*
X5	Overlapping DC and OM supply chain networks	3.69	3.75	3.60	5.271	.000	.160	.692*
X6	Arranging for some common/ linked resource pools and requirements between DC and OM supply chains	3.94	3.92	4.00	7.411	.000	.056	.815*
X7	Providing expanded long-term business opportunities for DC and OM teams	3.84	3.79	4.00	6.599	.000	.347	.560*
X8	Integrating team building activities between DC and OM teams	3.78	3.75	4.00	7.266	.000	.665	.422*
X9	Using joint ICT tools between DC and OM teams	3.72	3.79	3.40	5.268	.000	.999	.326*
X10	Integrating business continuity management practices between DC and OM teams	3.69	3.71	3.60	7.268	.000	.161	.692*

Notes: * Not significant at p= 0.05. Means derived from 5-point scale rating: 1= Strongly disagree; 2= disagree; 3= neutral; 4= agree; 5= strongly agree.

Table 5 Factor analysis of activities to achieve better integration

Code	Degree of agreement that the activities lead to integration of DC and OM	h^2	Factor Loading	Strategies (Eigenvalue/ % of variance)
X1	Sharing relevant information between DC and OM teams	.695	.790	Factor 1: Integrate functions (2.458/24.6%)
X2	Addressing sustainability jointly between DC and OM teams	.660	.719	
X3	Having similar procurement protocols in DC and OM supply chains	.624	.592	
X5	Overlapping DC and OM supply chain networks	.791	.687	
X6	Arranging for some common/ linked resource pools and requirements between DC and OM supply chains	.771	.752	Factor 2: Integrate relationships (1.928/19.3%)
X7	Providing expanded long-term business opportunities for DC and OM teams	.759	.677	
X8	Integrating team building activities between DC and OM teams	.616	.592	
X10	Integrating business continuity management practices between DC and OM teams	.533	.577	
X9	Using joint ICT tools between DC and OM teams	.756	.826	Factor 3: Integrate IT tools (1.634/16.3%)
X4	Integrating life cycle optimization options and opportunities in DC and OM supply chains	.866	.619	Factor 4: Integrate life cycle options (1.051/10.5%)