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Making sense of team integration practice through the “lived experience” of alliance project teams

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Abstract

Purpose – Team integration is a concept that has been widely fostered in alliances as a way of improving collaborative relationships between diverse organisations. However, deeper insights into the practice of high levels of team integration remain elusive. The purpose of this paper is to develop a deeper understanding of team integration through the “lived experience” of practitioners in an alliance.

Design/methodology/approach – This study employed a qualitative research methodology. Using a phenomenological examination, via the lived experiences of 24 alliance practitioners, the practice of alliance team integration has been investigated based on the key indicators that foster alliance team integration: team leadership, trust and respect, single team focus on project objectives and key results areas, collective understanding, commitment from project alliance board, single and co-located alliance team, and free flow communication.

Findings – The findings highlight that alliancing gives the project teams’ flexibility to change and adapt, to advance the collaborative environment and that successful integration of multi-disciplinary project teams requires commitment to the identified indicators. These findings have led to the development of a framework of leadership for successful alliance integrated practices. It is proposed that to influence the leadership for the purpose of achieving successful integration practice, a team-centric approach is required which includes four elements: task and relationship-oriented behaviours; collaborative learning environments; cultivating cross-boundary networks; and collaborative governance.

Practical implications – As team integration is the central tenet of alliance projects, greater understanding regarding the leadership of integration practice is of value in leveraging the benefits of outstanding performance. Also, the results of the study are expected to be informative and provide insight for alliance teams to help them proactively recognise how the context of integrated teams is influenced by specific indicators, impacting on the extent of integration practice.

Originality/value – This study contributes to the current body of knowledge concerning the insights from the “lived experience” of alliance teams towards achieving a greater understanding of what contributes to the leadership of successful integration practices.

Keywords New Zealand, Team integration, Construction, Alliance, Lived experience

Paper type Research paper

Introduction

For centuries, the architecture, engineering and construction industry has been a highly fragmented industry, with multi-disciplinary teams from different types of organisations, with different characteristics, different cultures and organisational practices forming a temporary organisation working in an adversarial and traditional transactional
environment (Baiden *et al.*, 2006; Lahdenperä, 2012; Ibrahim *et al.*, 2013). This is especially the case in major and complex projects where broad and increasing expertise, as well as commitments across many national borders, is required. Cross-cultural issues in particular are complex and, hence, further contribute to the difficulty to embrace an integrated environment (Fellows and Liu, 2012).

Previous research (e.g. Ibrahim *et al.*, 2013; Alashwal and Fong, 2015) and government reports (Egan, 2002) highlighted the negative influence of the traditional approach on the achievement of project outcomes. The main impacts highlighted in these studies include project delay, cost and budget overrun, litigation and disputes, lack of integration and adversarial relationships. In fact, the features of the bilateral contract in the traditional approach are believed to inhibit effective integration (Walker *et al.*, 2002; Aapaoja *et al.*, 2013), resulting in an inability for diverse teams to embrace the collaborative culture as expected to deliver complex projects effectively (Evbuomwan and Anumba, 1998; Egan, 2002).

There is considerable debate in the literature over the rationale for the promotion of innovative delivery approaches as a potential panacea for fostering collaborative efforts in the construction industry and, hence, overcoming the frustration and fragmentation of the transactional approach (Lahdenperä, 2012). The project alliance, also known as a relationship-based procurement (RBP) approach, is one approach that was introduced to function and operate efficiently through the fostering of high-level integration practice in delivering complex infrastructure projects (Mills *et al.*, 2012; Walker, 2015). There has been a significant increase in the use of project alliancing in the construction industry, in particular in Finland, the Netherlands, UK and USA, with Australia and New Zealand arguably leading the world in this regard (Walker, 2015). It is argued that the collaborative nature of alliances enhances the opportunity to practice integration attributes compared to the other forms of procurement (Walker *et al.*, 2015). However, there is a common belief (Baiden *et al.*, 2006; Che Ibrahim *et al.*, 2013) that if continuous improvement in alliance projects is to be achieved through the use of integrated teams, then a greater understanding of what makes alliance teams integrate successfully is needed.

Although prior research on team integration has almost exclusively focussed on various types of procurement approaches, little has been undertaken on examining the extent of team integration practice specifically in alliance projects. In particular, Che Ibrahim *et al.* (2013) attempted to understand what makes alliance teams integrate better by quantitatively identifying the most significant key indicators (KIs) of alliance team integration. However, the identification of the indicators is mainly based on quantitative analysis rather than an in-depth discussion of the extent of these indicators being exercised qualitatively. More fine-grained knowledge of the indicators is needed based on the experiences of alliance practitioners. Using Che Ibrahim *et al*.’s (2013) indicators as a basis, the central research question posed is:

**RQ1.** What can we learn from the “lived experiences” of alliance practitioners that can help contribute to leadership that results in successful alliance integration practices?

With this in mind, this study aims to examine the lived experiences of alliance team integration, based on a conceptual framework developed by Che Ibrahim *et al.* (2013), in order to facilitate our understanding of how team integration is achieved in alliance projects. Team integration in this paper should be viewed, based on the definition suggested by Baiden *et al.* (2006), as the introduction of working practices, methods, attributes and behaviours that create a culture of efficient and effective collaboration by project teams in achieving the project objectives. Within the context of this research, the term project teams refers to teams comprised of multi-organisational (i.e. owner and non-owner) participants that come together to form one organisational entity.
This paper provides an overview of the challenges of integration in project alliancing, followed by a presentation of the existing literature on team integration in construction projects. Then, the conceptual framework of alliance team integration adopted in this study is discussed. Next, the research method is explained, followed by an analysis of the "lived experience" of alliance teams. Finally, a discussion on how this contributes to integration practice is presented in detailed before conclusions are drawn.

The challenges of integration in project alliancing

Project alliancing is a collaborative way of working on complex projects and involves the joint management of project challenges. Alliances are an agreement between two or more partners who undertake to work collaboratively on the basis of a behavioural set of contract conditions and collective shared risk and reward, for the purpose of delivering a complex project based on best-for-project criterion (Walker and Jacobsson, 2014; Jefferies et al., 2014). It provides a different approach, ranging from decision-making processes to the working arrangements, compared to the more traditional forms of contracting, and allows the owner to have closer, and a higher degree of, integration with project participants (Walker and Lloyd-Walker, 2014). Integration is vital for alliance teams as it promotes a collaborative culture and the continuity of equitable relationships to improve project performance (Che Ibrahim et al., 2013). Walker and Lloyd-Walker (2014) suggested that the success of a project alliance is built upon project teams that consciously integrate in an atmosphere that is open and non-competitive. In addition, the collaborative environment embraced by the project alliance approach will ensure the team is committed to channelling all talent and energy for the best possible project outcome (MacDonald et al., 2013). However, it should be noted that although team members in alliances build an understanding of the underlying alliance principles designed to create an integrated environment, the ability to commit to and sustain such an environment is essential in achieving the breakthrough outcomes (Ross, 2009). Furthermore, there is no guarantee that the desired behaviour and integrated culture will be continuously maintained, as some individuals display a tendency to revert back to their old mentality when things go wrong, due to a lack of insight and experience into the benefits of alliances (Rooney, 2009; Laan, Voordijk and Dewulf, 2011; Laan, Noorderhaven, Voordijk and Dewulf, 2011; Walker et al., 2015). Teams and individuals possessing substantial diversity in skills, knowledge and expertise, but who may not have previously worked together, make integration more difficult to achieve within the construction period (Baiden et al., 2006). In addition, according to Fellows and Liu (2012), given that the multiplicity of expertise comes from a range of organisations, and from several diverse countries, but form a separate entity, there are significant differences in professional values and commitments which are difficult to integrate.

A study by Laan, Voordijk and Dewulf (2011) and Laan, Noorderhaven, Voordijk and Dewulf (2011) found that team members who are versed in more traditional types of contracts may not be able to adopt an attitude of cooperative relationship automatically in order to ensure the success of the project alliance. Another study by Walker et al. (2015) found that individuals who are designated at higher management levels also tend to revert back to traditional practice due to self-interest and a lack of a collaborative mentality. Some individuals may experience culture shock in the new environment, and coping within a new challenging project environment may contribute to the difficulty to integrate proactively, move away from the traditional adversarial approach, and work collaboratively (Reed and Loosemore, 2012). This statement was supported by Lloyd-Walker et al. (2014), where they argued that project participants on traditionally procured projects tend to be risk averse due to their reluctance to engage in open and collaborative problem solving, leading towards self-protecting actions. This phenomenon potentially occurs because the principle and concept of the alliance model is yet to mature for some
industrial players (Yeung et al., 2007) due to the isolation in environments where adversarial cultures and attitudes still exist (Rooney, 2009; Laan, Noorderhaven, Voordijk and Dewulf, 2011) and the need for alliance team members to possess different attributes (i.e. alliance culture) than those involved in business-as-usual (BAU) in order to strengthen the sources of integrated practice (Che Ibrahim et al., 2013). Walker et al. (2015) suggest that insufficient commitment towards alliance principles could lead to the deficiency of attitudes and leadership skills in achieving a high-performing team. As emphasised by Lendrum (2011), alliancing relationships are about fundamental change in attitude, mindset, behaviour, practice and performance.

Against this background, the need for understanding the extent of team integration practice in alliance projects assumes a special significance, given that the key to alliance success is the relationship, and extent of integration, between owner and non-owner participants (NOPs). The need to find a way of integrating with a multiplicity of parties, especially in an alliance environment, is vital to support the shared desire of delivering a high-performing alliance (Lloyd-Walker and Walker, 2011). By considering team integration in this way, the performance of the integration activities can be managed at an earlier stage (Baiden et al., 2006). Moreover, the recognition of performance among project teams is vital to sustain the continuity of the team’s commitment and cooperation towards project objectives (Fellows and Liu, 2012).

**Team integration literature in construction research**

The subject of project team integration has received widespread attention in construction management research due to the fragmented relationships and adversarial nature of traditional procurement approaches (Zhang et al., 2013). Several scholars highlighted the increasing research interest in understanding the concept, features and elements of team integration practices in construction projects as a way to embrace collaborative environments. Consequently, a number of studies are reported here to provide insight into the extent of team integration research that has been undertaken. A summary of these studies is presented in Table I.

Particular attention has been given to Baiden et al. (2006), who made one of the first attempts to assess the extent of team integration in design-build (DB) and construction management procurement approaches. Ten dimensions of integration are used for the assessment, as follows: single team focus and objectives, seamless operations, mutually beneficial outcomes, increased time and cost predictability, sharing information, team flexibility, single co-located team, no blame culture, equal opportunity for inputs, equitable relationship and respect. The findings indicated that the level of integration among project teams could differ due to the characteristics of the procurement model. They concluded that either an integrated team is necessary, or the industry must overcome the existing adversarial culture, for project performance to be improved.

In another study, Mollaoglu-Korkmaz et al. (2013) focussed on measuring the level of integration in affecting sustainability goals in the DB procurement approach. They measure the level of integration in terms of attributes, such as early collaboration of the project’s participants, method and timing of communication and the chemistry among participants. They also found that some other delivery attributes such as owner commitment and team characteristics influence the level of integration achieved. Mollaoglu-Korkmaz et al. (2014), in another study, examined the dimensions of inter-organisational project teams in integrated project delivery (IPD) that could influence the effective implementation of IPD as an innovation. By using a qualitative approach (e.g. observations and interviews), they found that several mechanisms that are fundamental to successful joint collaboration (e.g. communication, information sharing, trust and commitment) can lead to innovation implementation success in IPD.
<table>
<thead>
<tr>
<th>Authors</th>
<th>Country</th>
<th>Procurement</th>
<th>Focus of the study</th>
<th>Outcome/contribution of the study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baiden et al. (2006)</td>
<td>UK</td>
<td>Design-build, cons. management</td>
<td>Determining the extent of project team integration practice</td>
<td>The level of integration is affected by the team practices adopted, set within the procurement approach</td>
</tr>
<tr>
<td>Mollaoglu-Korkmaz et al. (2013)</td>
<td>USA</td>
<td>Design-build, Design-bid-build, cons. management</td>
<td>Examining the influence of project delivery methods on integration and project outcomes</td>
<td>The level of integration in the delivery process affects final project outcomes, particularly sustainability goals</td>
</tr>
<tr>
<td>Mollaoglu-Korkmaz et al. (2014)</td>
<td>USA</td>
<td>IPD</td>
<td>Examining the key dimensions of inter-organisational teams in IPD influencing the innovation success</td>
<td></td>
</tr>
<tr>
<td>Ibrahim et al. (2013)</td>
<td>New Zealand</td>
<td>Project Alliance</td>
<td>Developing a model to assess the team integration performance</td>
<td>An index for measuring alliance team integration performance</td>
</tr>
<tr>
<td>Aapaoja et al. (2013)</td>
<td>USA</td>
<td>IPD</td>
<td>Analysing the level and challenges of team integration</td>
<td>Characteristics of an integrated project team and cornerstones for cohesive stakeholder integration.</td>
</tr>
<tr>
<td>Zhang et al. (2013)</td>
<td>China</td>
<td>IPD</td>
<td>Examining the flexibility of the integrated project team and exploring its antecedents</td>
<td>Linkage model from tacit knowledge sharing to integrated project team flexibility</td>
</tr>
<tr>
<td>Mohamad et al. (2014)</td>
<td>Malaysia</td>
<td>Various types of procurement</td>
<td>Evaluating the current status of the collaborative working environment</td>
<td>New matrix measurement guidelines</td>
</tr>
<tr>
<td>Senaratne and Hewamanage (2015)</td>
<td>Sri Lanka</td>
<td>Traditional</td>
<td>Exploring the role of team leadership in achieving LEED certification in a green building project</td>
<td>Framework for effective team integration and leadership in green building projects</td>
</tr>
<tr>
<td>Che Ibrahim et al. (2015)</td>
<td>New Zealand</td>
<td>Various types of procurement</td>
<td>Identifying the most significant KIs and providing suggestions on how to influence team integration</td>
<td>Framework for key relationship indicators of team integration</td>
</tr>
<tr>
<td>Cheng (2015)</td>
<td>USA</td>
<td>Design-Build</td>
<td>Highlight the collaborative best practices to advance the development of high-performing buildings</td>
<td>Commercial strategies, leadership strategies, logistical and process tools to influence team performance</td>
</tr>
<tr>
<td>Ujene and Edike (2015)</td>
<td>Nigeria</td>
<td>Various types of procurement</td>
<td>Evaluating the types and level of relationships, as well as factors that influence working relationships among the internal stakeholders in construction projects</td>
<td>Establishment of factors with significant influence on good relationships</td>
</tr>
</tbody>
</table>
Che Ibrahim et al. (2013) conducted a study to identify the most significant KIs of team integration in alliance projects. Their findings proposed team leadership; trust and respect; a single team focus on project objectives and key results areas (KRAs); collective understanding; commitment from project alliance board (PAB); creation of single and co-located alliance team; and free flow communication as the KIs for assessing alliance team integration. Their findings indicate that alliance team members must possess different attributes from those involved in BAU in order to strengthen the sources of integrated practice.

Others (Aapaoja et al., 2013), by contrast, examined the level of team integration practice in building projects procured by the IPD method. By using characteristics almost identical to Baiden et al. (2006) with one additional dimension, namely, results and innovations, they emphasised that due to the integrated nature embedded in the IPD method, projects can be successful although some of the integration characteristics are not fully achieved.

Zhang et al. (2013) focussed on assessing team flexibility as one of the important elements of team integration practice. They were measuring two main aspects of team flexibility: response extensiveness to attended/unattended dynamics and response efficiency to attended/unattended dynamics on a case study of an IPD project. The findings indicated that, in responding to the changing environment of construction projects, team flexibility is of greater importance for the integrated team and it intrinsically depends on tacit knowledge sharing at the early stage of construction projects.

On the other hand, based on a study by Baiden et al. (2006), Mohamad et al. (2014) conducted a questionnaire survey and interviews to develop new matrix measurement guidelines (MMG) for assessing collaborative teamwork environments in the Malaysian construction industry. The MMG was characterised by six elements: cross-functional factors, autonomy, contractual approach, communication, collocation and information sharing. They concluded that MMG is able to demonstrate the gradual process of achieving a collaborative teamwork environment based on six levels of interval scale.

In a study of two green building projects, Senaratne and Hewamanage (2015) found that team integration practice and team leadership for both projects was at a higher level compare to typical building projects based on examination of four key elements: common project objectives; collective implementation; teamwork for win-win; and continuous learning and knowledge sharing. They also emphasised that not only team integration, but also shared team leadership, is required for achieving LEED certification in a green building project, specifically in Sri Lanka.

Che Ibrahim et al. (2015) conducted a study to identify KIs influencing the management of team integration, based on the opinion of an established construction peer group in New Zealand. Based on an initial study by Che Ibrahim et al. (2013), they summarise that there are a total of 17 indicators influencing the management of team integration in construction projects. Their findings also indicated that there are five key relationship-oriented indicators: single team focus on goals and objectives; trust and respect; commitment from top management; free flow communication; and no blame culture have a strong influence towards successful team integration. A framework for influencing these relationship indicators was proposed based on four elements: team formation, contractual model, teamwork principle and operational monitoring.

Cheng (2015) documented three case studies to highlight collaborative strategies, processes and tools used by teams to develop high-performing buildings. From the comparative case studies, using a qualitative approach, the findings indicated that team performance could be influenced by three categories: commercial strategies, leadership strategies, and logistical and process tools.

Finally, Ujene and Edike (2015) completed a recent study on assessing relationship-oriented indicators of team integration in construction projects in Nigeria. Their study proposed 20 relationship-oriented indicators of team integration among four groups of stakeholders.
Although their research shows that significant variations exist in the priority placed on relationship-oriented indicators among the four groups of stakeholders, they did find that two highly significant indicators, communication and trust and respect, affected the four groups of stakeholders.

The above studies, summarised in Table I, all focus on the subject of team integration, or more specifically on the elements of team integration in a construction context. It is worth highlighting that the findings from these studies indicate that regardless of the geographical location of the study, there is a collective understanding among scholars that human relationships and a collaborative culture are critical to break down fragmented and adversarial barriers between the different players in the industry, hence improving the integration practice. In countries such as the USA and New Zealand, the focus of the studies is more towards highly ordered collaborative procurement (i.e. alliance and IPD), where the performance of the team would be significantly higher due to collective harnessing of all project participants’ talents and insights towards more collaboration. In developing countries such as Nigeria and Sri Lanka, the level of uptake of collaborative procurement remains to be seen, although the industrial players seem to be positive on the importance of integration practice in the industry.

Apart from similarities in terms of their methodology (i.e. using quantitative analysis), the above studies also emphasised the need for more qualitative research to be conducted in order to gain a greater understanding of the elements of team integration being practiced in real projects. While studies such as Mollaoglu-Korkmaz et al. (2014) and Cheng (2015) used a quantitative approach to investigate the integration practice, their focus was limited to certain aspects, and on different types, of procurement approaches. In addition, although numerous sets of elements, indicators or factors have been derived in the literature to cover most aspects of team integration practice, a detailed examination of these indicators in terms of the “lived experience” of alliance practitioners, remains elusive. Current perceptions of team integration practice are largely built around individuals, peer relationships, collaborative environments and skill-based practice. By its very nature, team integration is characterised by tangible and intangible elements. Nevertheless, due to the subjective nature of team integration practice, it is difficult to develop, assess and quantify. The need for increasingly collaborative environments in construction projects necessitates an understanding on the extent of team integration practice in RBP, especially in alliancing. Although there have been attempts to understand team integration in alliance projects (see Che Ibrahim et al., 2013), the focus is mainly on identifying quantitatively the indicators rather than examining the “lived experience” of alliance practitioners to help understand how these indicators are being practiced. Therefore, this study is focussed on examining the KIs of alliance team integration derived by Che Ibrahim et al. (2013), in order to gain a better understanding of how these indicators are being practiced based on the “lived experience” of alliance practitioners.

**Conceptual framework of successful alliance integrated project teams**

A conceptual framework, based on Che Ibrahim et al.’s (2013) KIs of team integration in alliance projects, has been adopted in an effort to better understand what makes alliance teams integrate. The current study is an extension of Ibrahim et al.’s (2013) research on KIs which were developed specifically for alliances. They also went through several rounds of validation and testing (see Che Ibrahim et al., 2016). According to Che Ibrahim et al.’s (2013) findings, which are based on the experience of an expert panel used in four rounds of Delphi questionnaire survey, it can be concluded that the best practices of alliance team integration are characterised by seven ranked KIs (see Figure 1): team leadership; trust and respect; single team focus on project objectives and KRAs; collective understanding; commitment from PAB; creation of single and co-located alliance team; and free flow communication. A brief definition of these indicators is included in Table II.
The findings from their study show that team leadership is ranked as the most significant KI of alliance team integration. This shows the importance of project participants engaging in authentic leadership across the hierarchy of the alliance team, especially in complex projects (Walker et al., 2015). The development of team leadership enriches collaborative culture (Love et al., 2010) and could be key to successful high performance relationship management (Lendrum, 2011). Trust and respect is ranked the second most significant KI for successful alliance team integration. Trust is recognised as a key element of alliancing (Yeung et al., 2007) in terms of empowering the team to take responsibility and to be accountable for their tasks and to generate commitment and constructive discussion for better integration (Walker et al., 2002). It is also argued by many scholars (Mills et al., 2012) that one of the most fundamental differences between the relationship-based and traditional contracting is the precondition that requires team member to develop trust and mutual
respect among them. Single team focusses on project objectives and KRAs, then collective understanding are ranked third and fourth, respectively. Shared commitment to common goals and objectives of a project could lead the alliance team to move towards more consistent integration in delivering high performance outcomes (Walker et al., 2002). The establishment of objectives that all parties could clearly understand and adhere to is important for continual progress of integration in achieving “best for project” outcomes (Love et al., 2010). One of the main principles of an alliance is collaboration through collective problem framing and solving (Walker et al., 2015). It is essential to ensure that as one integrated team, all participants adopt a collective approach to resolving problems caused by mistakes and negligence (Rooney, 2009). Joint problem solving, decision making and learning are greatly improved in an integrated environment, which enables a greater proclivity for innovation (Love et al., 2010).

Next, commitment from PAB and the creation of single and co-located alliance team are ranked fifth and sixth, respectively. A high degree of commitment leadership from the alliance board and management is required in order to inspire the development of a collaborative and participative culture as well as influence the intensity of the integration process towards best for project (McCormick, 2010; Mills et al., 2012). Forming an integrated office is critical for project teams to enhance and improve their interaction and collaboration in real time (Jefferies et al., 2014). Finally, in relation to free flow communication, several scholars (e.g. Mills et al., 2012; Jefferies et al., 2014) emphasised that the intense integration of alliance partners through the effective collaborative process requires excellence in interaction and communication between alliance participants. Alliance participants must communicate consistently at a variety of levels of management and move forward in agreement to improve relationships towards a collaborative environment (Lloyd-Walker and Walker, 2011). For a detailed discussion and evaluation of these indicators, the reader is referred to Che Ibrahim et al. (2013).

**Research method**

This study adopted a phenomenological research method in which the purpose is to describe the meaning for several individuals of their lived experiences of a concept or a phenomenon (Creswell, 2013). In particular for this study, it attempts to understand alliance practitioner’s perceptions, perspectives and understanding of successful alliance team integration practice based on an existing framework. According to Merleau-Ponty (2013), phenomenology studies the structure of various types of experience ranging from perception, action, thought and memory in our “life-world”. As Van Manen (1990) described, the aim of phenomenology is to reduce individual experiences with a phenomenon to a pure description of the universal essence.

Following the phenomenographic approach, the main data were collected by in-depth interviews. The interview questions were as open-ended as possible to give freedom to the participants choose the perspectives of the question. In line with the objective of this study, the qualitative interview was adopted, as the method has a direct interaction and in-depth discussion with the interviewees (Meng, 2012). Due to the nature of the information solicited, requiring in-depth knowledge and wide-ranging experience about the seven KIs of team integration, a purposive approach to sampling was adopted to select the group of interviewees. Three predefined criteria were used in identifying suitable candidates for this study including: having broad working experience in alliancing projects in New Zealand; having recent/ongoing and direct involvement on a PAB/alliance management team (AMT)/wider alliance team (WAT); and having sound knowledge and understanding of team integration concepts. Accordingly, the views of different stakeholders, including owner and each NOP’s representative, were sought. The interviewees were selected from different types of alliance partners and projects.
Initially, 34 individuals were contacted, based upon recommendations made by the researchers’ established contacts within the industry (snowballing method). All the recommended individuals met the selection criteria to determine whether they would be suitable to participate in this study. However, their availability to participate in such an exercise was limited by their work commitments and from these, a panel of 24 recognised practitioners confirmed that they would be available to participate in this survey. The selected alliance participants are not individually identified in this study, for confidentiality reasons, although the nature of their designation is described together with their respective portfolio, as shown in Table III. The responses indicated 8 of the practitioners (33 per cent) were owner representatives, 16 practitioners (67 per cent) were from NOPs in which 11 were from contractors and the remaining 5 were from consultants. The majority of the practitioners held AMT positions in their respective alliance projects. Given that the first alliance project in New Zealand started 15 years ago, in 2001, and currently about six projects are still ongoing, it was assumed that having an average of eight years of experience, as well having been involved in more than one alliance project, reflects the fact that the candidates have sufficient experience to be selected as interviewees. In addition, having a broad mix of designation and relevant organisations provides a balanced view and helps ensure the validity of this study.

The interview session with each interviewee was conducted at the project site office and lasted for about one to two hours. Throughout the interview process, participants were emphasised to describe and explain their experience as fully as possible. The interviews

<table>
<thead>
<tr>
<th>Organisation Type</th>
<th>Percentage</th>
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</thead>
<tbody>
<tr>
<td>Owner</td>
<td>33</td>
</tr>
<tr>
<td>Non-owner participant</td>
<td>46</td>
</tr>
<tr>
<td>Consultant</td>
<td>21</td>
</tr>
<tr>
<td>Designation</td>
<td></td>
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<tr>
<td>Alliance Manager 1</td>
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<tr>
<td>Deputy Alliance Manager</td>
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<tr>
<td>Key Relationship Manager</td>
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<tr>
<td>Construction Manager</td>
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<tr>
<td>Senior Project Engineer</td>
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<tr>
<td>Alliance Manager 2</td>
<td></td>
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<tr>
<td>Risk Manager</td>
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<tr>
<td>Senior Project Manager</td>
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<td>Project Service Manager</td>
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<td>Design Manager</td>
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<tr>
<td>Construction Manager</td>
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<td>Design Delivery Manager</td>
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<tr>
<td>PAB Board Member</td>
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<td>Pavement Manager</td>
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<tr>
<td>Senior Manager</td>
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<td>Alliance Culture Manager</td>
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<td>Urban Roads Manager</td>
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<td>Project Director</td>
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<td>Communication Manager</td>
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<td>Quality Assurance and Systems Manager</td>
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<tr>
<td>Sub Alliance Manager</td>
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<td>Consents Assurance and Key Results Manager</td>
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<tr>
<td>Project Controls Manager</td>
<td></td>
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<tr>
<td>Owner Interface Manager</td>
<td></td>
</tr>
<tr>
<td>Average years of experience in alliances</td>
<td>8 years</td>
</tr>
</tbody>
</table>

Table III. Profile of alliance practitioners
were conducted in-person, recorded digitally with the verbal consent of each participant, and transcribed. The research study was approved by the University of Auckland Human Participants Ethics Committee (No. 2011/255).

In addition to the interviews, secondary sources of evidence were examined. The alliance provided relevant documents including the project’s summary (i.e. the Alliance agreement), in-house guidelines for implementing the alliance approach and relevant project reports. The documents were examined before, during and following the interviews. Secondary sources of evidence were used to support the primary source and minimise bias in data collection during interviews.

**Evaluation of interviews on the KIs**

The phenomenological method involves a rigorous analysis of life descriptions. Based on guidelines from Ekstedt and Fagerberg (2005), some important steps were adopted: careful reading in order to comprehend a sense of the whole; perception of meaning indicators within the chosen perspective, focussing on the phenomenon under study; every indicator was reflected on with free imaginative variation and transformed into a statement that can provide better understanding, the participants’ lived experience of the phenomenon (Table IV); when all meaning had been transformed, reflecting on the variations of meanings the analysis brought out an essence of the phenomenon, the insights reached were synthesised and integrated into a descriptive structure comprising seven most significant team integration indicators.

**Team leadership**

There is widespread acceptance among interviewees of the importance of team leadership in influencing the success of alliance team integration practice. Building upon the basic principle of collaborative culture, the very existence of team leadership attributes can be responsible for setting a strong foundation for all indicators to be successful. The concept of multi-disciplinary team leadership remains a critical role for construction professionals to be successful in collaboration (Koutsikouri *et al.*, 2008).

Specific comments from practitioners that reinforced the above include:

Leadership is three times more important than the sum of everything else. Where the team fails, generally it comes from lack of leadership and when I say leadership, in that sense of the word, I mean across the hierarchy of the alliance teams. (Design Manager)

Although normally leadership is associated with higher levels of management, often we know, particularly in the implementation phase, we rely heavily on leadership at all levels. You need leaders across the organisation and if you can get it right, that trumps all of those (other indicators). (Alliance Manager 1)

<table>
<thead>
<tr>
<th>Interview excerpt</th>
<th>Imagination variation</th>
<th>Integration perspective</th>
</tr>
</thead>
<tbody>
<tr>
<td>…setting an example, an example that people will follow, I try to make myself perfect and expect people to follow the lead, you can’t do that by having a big ego, need to be humble person, need to know what you’re talking about, treat all people equally, no favouritism, be consistent, reliable in decision making…</td>
<td>Describes how he has experienced being a leader in a diverse project team and his humanistic engagement, how positive relationships could influence the decision making</td>
<td>Team leadership emerges through a relationship-driven environment and individuals who can stimulate collaborative culture within the workplace</td>
</tr>
</tbody>
</table>

Table IV.
Example of overview analysis
It is worth highlighting that although the alliance model embraces the function of high-level management from every NOP, it is not sufficient to ensure positive decision-making outcomes. Rather, it is the integration and collaboration among networks of multi-tiers of management that is important. Some interviewees expressed their view that the success of the collective leadership depends not on the PAB and AMT, but rather on the level of wider team participation in aligning the values and visions of the alliance. The following statements from practitioners support the above arguments:

Vision and direction is obviously defined by the PAB, implemented by the management and the whole team but they also need ownership and leadership at each level to ease the integration practice. (Senior Manager)

Leadership can be exhibited by the wider alliance members, be they AMT, or Alliance board members. The key to success is that you’ve got leadership all the way down the chain. (Senior Project Manager)

While not all individuals have the attributes to work in the alliance environment, the commercial environment in an alliance provides the platform to use advanced leadership practices to help teams to nurture their full potential. Interviewees who advocated such an environment indicated that an alliance is able to provide an opportunity for teams to show their leadership through creating innovations; for example, a general manager stated that “Leadership is about doing something differently tomorrow than you did it yesterday. If there is a lot of innovation, or changes are being identified, then the project is developing a leadership culture where they are looking for ways to do things better”. This was also reiterated by an urban road manager who made the following comment: “The design team, probably for them that’s been harder because they’re not used to having leadership skills because they just usually sit down and do the job and hand it in. While here (in an alliance), all employees work as a team, and at one point in time. Because we got all different kinds of jobs, sitting under one roof and in an integrated environment, everyone has to take the lead.”

It is clear that the ability to think differently and adapt to certain situations is a crucial leadership skill, as it could help the dynamics of the team. In addition to that, continuous learning from the alliance coaching sessions, close interactions across the governance structure and top management being visibly engaged with the WAT are some of the processes that could help alliance teams adopt the required leadership skills.

Single team focus on project objectives and KRAs
One of the important elements of alliance team integration is the single team focus on project objectives and KRAs. The alliance practitioners indicated that overall project success lies with the team’s ability to focus and integrate together towards common objectives and agreed KRAs within an alliance governance system; for example, a construction manager made the following comment: “The objectives and the mission statement on the big picture target needs to be as clear as it could be and easier for the team to buy into, so that it could help the performance of the team”. On the topic of having KRAs, the Alliance Manager 2 and Design Delivery Manager provided the following comments:

The whole point of having KRAs is to show that this is what’s important to us, and if it is important, we are going to measure it and we are going to get results that allow us to take some action to respond to whatever the measure is telling us. This will help us to monitor the performance and how integrated the team is in focusing on the project objectives. (Alliance Manager 2)

The purpose of having a KRAs score is the client organization want to incentivise the project team to continue to focus on the kind of behaviours that give a good outcome towards project objectives. (Design Delivery Manager)
The commercial framework in the alliance model strongly incentivised the team in the context of aligning the team around the core objectives and helping to progressively focus the team not only on the standard “iron triangle” measures, but also on the triple bottom line measures. In that sense, the focus of the individual alliance participants within different functional groups (e.g. designers and stakeholder team) could certainly be improved towards achieving the same alliance objectives. Nevertheless, although the nature of alliances, as well as having KRAs, play a vital role in aligning the team around the objectives, interviewees indicated that the ability of each member to behave as part of a multiparty organisation is vital to ensure the consistency of the practice. Specific comments from practitioners that reinforce the above include:

If everybody keeps their home boundaries alive, then the focus will be directed to their parent company instead of for the best for project and it will affect the objectives and even the KRAs of the project. (Construction Manager)

We started by not calling ourselves one organization. When we talked about the design team early on, it was easy to say Company A, and when we talked about the construction team, we talked about Company B. We stopped that straight away, you are part of the construction team, design team or management team, so we took out all the calling people by their home organization, so removing the boundaries itself helps everyone realize they’re part of one integrated team focusing on the same objectives and visions. (Pavement Manager)

Forming an alliance team takes time and, often, the team needed to go through several stages as they changed from being outsiders to an integrated team with common goals and objectives. From the interviews, it can be seen that as teams work to fulfil project objectives, their focus could shift from accomplishing the project’s objectives to completing their parent organisation’s tasks. Reminding them of the value and importance of the project’s objectives over time, coupled with frequent discussions on the benefits of the alliance, encouraged them to commit. In addition, although the Alliance Manager and AMT members were appointed as KRA champions to actively promote outstanding cost and non-cost outcomes, ensuring discussions about KRA performance extend beyond ALT and AMT meetings is vital to enhance the WAT’s desire to work on the project.

Trust and respect

Successful alliances build upon sharing resources and experiences as well as nurturing human relationships. It must therefore be based on trust and respect, maintaining honesty at all times. Throughout the interviews, it was clear that generally such trust and respect existed among the alliance teams due to previous experience in working in such collaborative environments, as well as understanding that the building of successful team integration practice requires mutual trust and respect.

Development of trust in teams is essential but challenging in the context of cross-functional project teams and prior ties can have an influence on the team’s ability to create trust (Buvik and Rolfsen, 2015). The following statements from practitioners support the above arguments:

Trust and respect is a fundamental building block for any alliance team. It is very challenging to create, but if you’ve got trust, you can move mountains and you can achieve great things. (Deputy Alliance Manager)

Trust and respect is about how well people are working together, and doing what they said they’ll do, not withholding information, building mutual long-term relationships and making an effort to understand and integrate with each other, and all of that is part of the integration process. (Risk Manager)

A basis for stimulating trust and respect in alliances is provided by continuously embracing the collaborative principles between the teams rather than within the specific teams.
Teams from different parent organisations must be encouraged to value their experience working in a collaborative environment as learning and personal growth, rather than solely as the means to a career goal. They are responsible for rendering an atmosphere of trust among themselves by consistently performing as a high-performing team. For example, an alliance manager suggested that “Most arguments, debates and unhappiness in the teams comes from when somebody doesn’t trust another person and doesn’t respect them. Trust and respect have to be earned. We can’t just ask everybody to trust and respect each other”. Many scholars described that one of the most fundamental differences between the collaborative and traditional approach is the requirement to trust other team members and recognise that they are trying to achieve the very best results of which they are capable. This was also reiterated by a key relationship manager who stated “Lack of trust is one of the five features of a dysfunctional team. If you haven’t trust in the first place, you’ll never move past that consensual agreement that you need for proper integration”. The combination of interaction of project teams and organisational culture to support relationships over time can help develop trust within the team.

Commitment from PAB
The governance arrangement of an alliance, where the team is being led by the top management from all alliance participants, requires transparent decision making and leadership. This was seen by the experts as absolutely essential for alliance success, but also critical in influencing team integration practice. As one PAB member described:

The PAB is a project management board made up of directors from every alliance parent company and sets up the governance of the alliance. What’s its doing is its setting directions, making sure the vision, the principles are up and clear and defined to the integrated team.

Whilst collective responsibility from the PAB to oversee the whole governance structure is inevitable, a number of experts believed that the degree of commitment and support from the PAB over time is critical to take decisions that integrate the alliance but, at the same time, the decisions must be unanimous. The ability of the board to put the time and effort into building relationships with the project team members and acknowledging their synergies is essential. The interviewees also emphasised that the board ensured ongoing development and application of innovative alliance management practices to ensure their continued visibility. Specific comments from the practitioners that reinforce the above include:

If you look at the team, we are a self-contained team; we have got all the skills we need here to perform and integrate, all the drive, engine and enthusiasm to build this job. If we can get consistent support from the PAB, it definitely will make our job easier. (Alliance Manager)

Interaction with the team is vital, they (PAB) come in the morning, go for a site tour and sit in the meeting room for most of the day. You will get some of the PAB members walking around and interacting with the team and some that won’t. It’s important for them to show their commitment and belief to the teams as we’re in it as one integrated team and as an alliance. (Senior Project Engineer)

When the environment around you is changing due to political, social and economic pressures, the role of the PAB, to keep you (the team) on track and keep you focused on what’s important, is essential. (Senior Project Manager)

The issue of consistent commitment is of central importance to integration, as construction projects involve complex organisational and technically challenging design/construction systems. Having a PAB who are continuously challenging the team’s decisions, to ensure that they best meet the vision and objectives of the project, is vital to ensure that project teams can bring tangible benefits (e.g. saving cost, stakeholder satisfaction, etc.) to the project environment. A high degree of leadership from the PAB is needed in order to
enhance the integration process and determination of transparent and mutually beneficial processes for all team members in the supply chain (Dainty et al., 2001). As McCormick (2010) stated, board members need effective leadership attributes to inspire the development of the collaborative and participative culture at the heart of the alliance. This is important to ensure effective and consistent corporate commitment in initiating, leading and direction of the alliance in achieving its objectives.

Free flow communication

Experts acknowledged that free flow communication is one of the core indicators that affect the practice of alliance team integration. It was suggested by experts that the collaborative philosophy, in terms of generating consistent energy and engagement, that involves communication between project teams can contribute to effective integration; for example, an urban road manager made the following comment: “Here we have a team meeting every Friday for the whole team, a pre start meeting every morning on site with teams, alliance management team, weekly programme meeting, weekly integration meeting with all the different areas on site, so we do communicate very well, we communicate directly, by emails, we’ve got a big office that helps teams integrate with each other by open communication because everyone is talking to everybody all the time”. In an alliance, many platforms were introduced to ensure the flow of communication between teams, for example through “world café” communication where the team was trained to participated in small group conversation and idea generation. In the case of having continuous and consistent interactions between teams, a senior manager and communication manager provided the following comment:

In the project alliance, you’ve got some formal interactions set up. Not just the PAB meeting, you’ve got AMT meeting, work bench meeting, tool box meeting and there’s a lot of flow of information that happens that can assist the team integration over time. (Senior Manager)

One of the successful features of an integrated team is ability to communicate quickly and effectively to get the message across, especially when there’s been changes, why the changes are necessary and how they can be managed. (Communication Manager)

Communication levels within alliance teams were not static. It is worth highlighting that integrated information and communication technology systems, such as “Project Link” and “Darzin”, were introduced in some of the alliance projects in order to enhance the digitalization of information and, hence, improve the flow of information within the alliance. In addition, virtual means of communication (e.g. video and teleconferencing) were engaged to facilitate remote communication between organisations.

Apart from having enablers to assist the communication, encouraging the project team to have valuable face-to-face relationships and interaction is indeed critical to ensure the free flow of communication. The following statements from practitioners support the above argument:

I share everything that I know with other people, there are no secrets. Most information can be shared, you have to remember to share it, if you forget to share it then everybody assumes that you’re holding onto it. (Senior Project Manager)

As we get more mature over the course of the project, we can easily foster our communication pattern as part of learning and growth of the relationships. (Project Director)

Changing and switching team members and reorganizing office space could help the team to improve their communication. (Owner Interface Manager)

The extent of communications in the alliance was seen as a two-way dialogue, in both upward and downward directions, ensuring that the alliance team (from PAB to WAT)
were kept informed of any project developments. The openness of the alliance environment (e.g., proximity of each participant organisation) encouraged teams to communicate openly and freely, which facilitated communication flows in the project alliance.

Creating a single and co-located alliance team
It is widely acknowledged by experts that in order to overcome the complexity of an integrated alliance team, the team members need to be forced to work in close physical proximity. Often, the challenging tasks in a complex project require rapid integration of individuals from diverse engineering backgrounds. Normally the alliance team was completely self-contained and located on site, which assisted with dissemination of knowledge resulting in positive insights and innovations. Specific comments from practitioners that support the above include:

It’s a key driver because it generates the subsequent ones. We know that co-located teams work and integrate significantly better than when you don’t have a co-located team. So, when you’re trying to do works simultaneously at different offices, the separation and distance can get in the way. (Risk Manager)

Generally, it’s an essential part of an alliance. Because of the intensity of work and specialist jobs, especially in an infrastructure mega project, in principal you want your core team, leadership and management team to be co-located to get them towards more consistent integration in delivering high performance outcomes. (Alliance Manager)

It is evident that co-located teams have multiple means of initiating the integration and coordination required, since direct interaction opportunities are readily available under one roof. In addition, alliance team members have more visible means of monitoring and assessing the others and they use these direct cues to help establish the relationship of other team members. Although having a single co-located office is now standard practice in every alliance project, maintaining parent company boundaries in a co-located environment could create cross-fertilisation that sparks high integration activities and establish direct dialogue without sparing feelings, that lead to decisions that are best for project; for example, a construction manager stated that: “Engineers from different organisations are sitting in different places in the office but more defined by disciplines and roles rather than which company they belong to, which is quite good. The way you see how integration actually works is not when things went very well but when you’ve got a problem and people from different organisations as well as the client solves the problem together for the best for project”. The deputy alliance manager added: “If you fail to take into account the environment in which you’re working, you will not realise how important integration practice is in affecting performance”. Having the entire project team in the same location provides an opportunity to unify teams from different organisations and to promote team practices and behaviours. It also reinforces the collaborative culture and provides an opportunity for all to interact and provide support, meet new staff (who regularly join the team) and provide communication and management skills that could improve organisational productivity.

Collective understanding
The creation of a highly integrated team is important to the success of an alliance, and it could be achieved by having a collective development of a common understanding among the teams. Bringing the team into the norming stage is essential as individuals could start to resolve their differences as well as respect and appreciate partners’ decisions. Specific comments from the practitioners that reinforce the above include:

This is also part of getting to know the people relationship. We tried to involve those who are important to our decisions, for example, design issues, resourcing issues. We also are trying to bring people into sharing the solution and spirit of understanding. (Quality Assurance and Systems Manager)

It is about joint decision making, i.e. making a decision with consulting other key members of the project team, and ensuring there’s buy-in into the solution or decision. (Sub Alliance Manager)
Providing a platform for teams to interact and socialise could strengthen their relationship and develop a stronger commitment to the project goals. Ensuring that collective understanding and transparent decision making is achieved from the perspective of the client, users and other stakeholders directly involved with the project is clearly important, as this can contribute to project success (Jørgensen and Emmitt, 2009). As described by Love et al. (1998), the formulation of, and collective agreement on, project goals within a multi-disciplinary team environment at an early stage can develop a creative, innovative and functional team. Forgues and Koskela (2009) added that in achieving collective decision making, it is expected that all team members have their “voice” heard and that all ideas are open to discussion. For example, the alliance manager made the following comment: “We had a series of workshops when we first set the team up, had professional facilitators, went through a process of understanding what is important to everybody in terms of quality of work, effort required, communication standard, environmental management where everybody has their own opinion, discussed everyone’s opinion together, and then if there is a difference, we sit and discuss during the workshop and set the standard to accept”. This was also reiterated by a senior project manager who stated: “It’s always a challenge in any alliance team arriving at a consensual decision with enough debate and discussion but then still at the end arriving to the decision that everyone at least feels they played a part in, as one integrated team. One of the reasons was because of the collaborative culture that has been developed and emphasised at an earlier stage”.

Project alliances involve a variability of decision-making process in which various owner and NOP teams contribute relevant information during the project delivery process. Thus, the ability to have individuals with the collaborative culture and philosophy will ease the process of achieving the collective understanding. For example, the alliance manager emphasised that: “You need people who are suitable to an alliance environment, you need people who can get their head around and understand what an alliance means. Some people are much better for rough and tumble type of contracts. In an alliance, you, as one integrated team, need to have a very good understanding of trying to deliver high performance, not contract obligations. You don’t have to build a road to a certain standard. You have to build the best road you can”.

From an organisational culture perspective, collective understanding in an alliance is framed in such a way that it serves as a platform for enhancing organisational learning. Every team builds a collective understanding of project goals in order to collectively commit to achieving them. As pointed out by Culmsee and Awati (2012), alliance procurement can foster a holding environment where it provides individuals the support they need to understand (lead to a similarity of understanding) and tackle challenging issues that confront them. The interviewees also highlighted that having collective understanding would enable different teams engaged in explorative or exploitative learning to collaborate across functions.

**Framework of leadership for successful alliance integrated practices**

Integrated organisations underpinned by integrated teams, such as in alliances, are about maximising the potential of leadership to influence team integration practices. The key to successful alliance integrated practice is the process of developing a vision, guiding and securing alliance team engagement. Drawing from the “lived experience” analysis based on the seven indicators, it is proposed that a team-centric approach is necessary to ensure that leadership results in successful alliance team integration practice (see Figure 2); these include task- and relationship-oriented behaviours; collaborative learning environments; and cultivating cross-boundary networks and collaborative governance. The main purpose of this section is to describe the distinctive nature of the leadership elements influencing successful alliance integrated practices. The way each KI formed a structure of leadership for alliance integrated practice is shown in Table V.
Task and relationship-oriented behaviour

The importance of leadership behaviour towards the integration practice cannot be overstated, as it will help shape the culture of diverse practitioners to the team’s needs. The reconfiguration of alliance team behaviour over time, especially in the context of task and relationship behaviour, is vital to ensure the team is in pursuit of the common purpose. The findings revealed that alliances invest in relationship-based practices; they make a visible investment by encouraging collaborative behaviour as well as ensuring the integration activities needed to support the collaborative culture are undertaken. As emphasised by Fellows and Liu (2012), construction industry has a tradition of individualism and opportunistic behaviour and, hence, requires consistent integration and collaboration in order to be successful.

Specifically, compared to other types of procurement approaches, alliance teams are focussed more on understanding the goal, clarification of their responsibility and commitments, together with building enduring relationships and leadership among team members, consistently over time. A very positive aspect found is this study is that the teams sense leadership that is both integrative and synergistic. The ability to create an environment where team leadership emerges through the distribution and collective expertise from the PAB to WAT could initiate active leadership, active listening and acceptance of different views (due to mutual trust) and, hence, produce a perfect solution for encountered problems (Nurmi, 1996). It is acknowledged that alliance teams must possess an authentic leadership skill set to facilitate collective learning and capability building for integrated practice to flourish. Buvik and Tvedt (2016) further suggested that trust has both direct and indirect impacts on cross-functional project team performance through alleviating conflicts and easing the way for integration in the form of risk and knowledge sharing, as well as collective decision making.

Performance obligations in an alliance are collective where teams, wearing the hat of the alliance, commit to work together in good faith on a best for project basis. A set of clearly defined alliance team objectives and KRAs provide a means to help the teams focus beyond the task framework, thereby enabling them to commit to developing better inter-organisational relationships. The sense of ownership in goal setting was communicated early in the projects, and throughout the project lifecycle, in order to ensure its flow on effects to the alliances in facing the challenges of technical- and human-related interface issues and also uncertainty about unknowns and ambiguous conditions (Walker, 2015).

Collaborative learning environment

It is well acknowledged that the success of a project alliance is built upon project teams that consciously integrate in an atmosphere that is collaborative (MacDonald et al., 2013;
<table>
<thead>
<tr>
<th>Team-centred elements</th>
<th>Description</th>
<th>Team leadership</th>
<th>Trust and respect</th>
<th>Collective understanding</th>
<th>Commitment from project alliance board</th>
<th>Single and co-located alliance team</th>
<th>Free flow communication</th>
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</thead>
<tbody>
<tr>
<td>Task and relationship-oriented behaviour</td>
<td>Direct influence on the relationship between project teams</td>
<td>Alliance teams have the sense of integrative and synergistic teamwork of leadership</td>
<td>Mutual trust and respect are prerequisites to fulfilling the complex relationships in diverse organisations</td>
<td>The sense of ownership in task and goal setting</td>
<td>Unanimous decision making is vital, as collective effort commits all teams in one direction</td>
<td>Create a platform for a sense of community (i.e. working intensively together)</td>
<td>Constant direct and indirect communication able to increase efficiency and reduce conflicts</td>
</tr>
<tr>
<td>Collaborative learning environment</td>
<td>Platform to actively promote desired collaboration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cultivating cross-boundaries network</td>
<td>Embracing the seamless operation with no organisational boundaries</td>
<td>Promote trustful relationships by cross-boundary information sharing about values, goals and expectations</td>
<td>Integration of expertise that cross-fertilisation towards collective decision</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Collaborative governance</td>
<td>Concept that engaged in joint effort to orchestrate the collective action towards common goals</td>
<td>Ensuring the flow of leadership responsibilities into the team</td>
<td>Shared understanding and collective effort that commits all teams in one direction</td>
<td>Create ways of working and share learning to enhance decision making</td>
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Table V. The way each key indicator formed a structure of alliance leadership alliance integrated practice

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Walker and Lloyd-Walker, 2014). The collaborative environment is crucial for some teams, particularly where they had the right culture but were not skilled in the practice of integration in a diverse environment (i.e. less experienced in collaborative procurement). One of the ways of working towards achieving the collaborative learning environment is by establishing an integrated alliance office. This initiative is essential as it helps to create a platform for a sense of community in the context of working intensively together right from the inception phase. Further, creating a learning environment that draws on the experience of teams (capitalising on pre-existing relationships) will maximise the potential for innovation in the project. Walker (2015) emphasised that substantial co-location is a platform for foundational facilities for any form of collaboration. Individuals from diverse organisations are able to stay in close physical proximity, and this sharing of identity enhances the learning within the social system and, hence, moderates the effect of interpersonal and task conflict. It is important to note that it is easy for team members to feel isolated and to lose their sense of identity and belonging due to an inability to have regular contact with individuals from other organisations. By having a co-located team, frequent communication and interaction among a network of individual’s (from AMT to WAT) could greatly accelerate and improve the collaborative learning, as well as raising the reliability of the relationships and, hence, cultivate their shared commitment to the project.

The value of relationships and knowledge sharing are generally seen as necessary ingredients for achieving high levels of communication. The adaptation to a multi-disciplinary environment and visualisation in the sense of being co-located certainly improves the patterns of communication, i.e. the flow of communication becomes more fluid and dynamic to allow unrestrained and continuous interaction. Practical tools and processes were introduced in the form of specific communication techniques (e.g. small group conversations, morning teas, etc.) to enhance relationships in preparation for everyday tasks. Constant direct and indirect communication (via vertical and horizontal channels of communication) are key means to increase efficiency, clear decision making and reduce conflicts in facilitating organisational communication (Mollaoglu-Korkmaz et al., 2013; Cheng, 2015).

Cultivating cross-boundary networks

Most of the alliance teams need to be able to operate seamlessly due to the ability to work within their boundaries of organisational identity and within an agreed set of alliance principles. The teams need to willingly suppress their organisational or individual agendas in support of the best for project. Buying early into the understanding of role clarity and task ambiguity early on will contribute to a compelling direction for the team and, hence, increase the cooperation and reaching, or indeed stretching, the targets. In an alliance, they take measures to cultivate networks that cross boundaries while maintaining the professional identity through one common platform, so that teams can switch in and out without disrupting collaboration. In such complex projects, the integration of expertise that crosses organisations and functional boundaries are crucial to cross-fertilisation that sparks insight and innovation. Bringing together the frontline workers will empower the team to take ownership of the project, be more engaged with the vision, as well as drive alliance peak performance by connecting with the interests of the stakeholders over time.

Cross-boundary networks can be nurtured by promoting trustful relationships through cross-boundary information sharing about values, goals and expectations. The findings indicated that alliance teams recognise that being in a diverse organisation is an advantage to encourage discovery and creativity. When the trust is present, both respect for individuals and respect for team values could increase the level of cooperation, relationships and co-ordination of the activities (Rahman and Kumaraswamy, 2008).
Collaborative governance

The essence of collaborative governance in integration practice is about the engagement of alliances that orchestrate a more collective action towards common goals. Developing a much wider base of people with leadership skills to operate effectively across the governance structure is crucial to provide higher visibility of professionalism to the project (engineering, stakeholder management, community relations, etc.) and enable teams to innovate, take risks, create ways of working and share learning to enhance practices. Owner and NOPs need to be capable of developing and exercising the necessary levels of behaviour and collaboration, and to work within a rigorous governance framework to enhance the leadership in an alliance (Walker and Lloyd-Walker, 2016).

The governance arrangement of an alliance is a coalition of senior management members from parent organisations. In the spirit of collaboration, the board (known as PAB) commits to providing leadership and direction to ensure that the alliance achieves or exceeds its mutual objectives (McCormick, 2010). They also lead through driving cultural changes to enable maximum performance from the collective actions of the alliance. The board members must be able to develop both task and relationship-oriented attributes with the project teams. They need to be accessible to affirm their interest in, and the importance of, the team’s work. Focussing on task at the outset of a project and shifting towards a relationship orientation among the teams at a later stage will lead to complacency over time. As Lloyd-Walker et al. (2014) described, apart from behavioural factors, having governance such as PAB and AMT structures formalise norms and practices of team leadership. Every individual within the team may serve as a leader in both formal and informal capacities, and the flowing of leadership responsibilities into the team is essential as it could produce innovative and collective decisions on a best for project basis.

In alliances, compelling targets inspire and challenge the team and give a sense of urgency. They also have a levelling effect, requiring members to focus on the collective effort rather than individuals (Katzenbach and Smith, 2013). The requirement for unanimous decision making in an alliance is inevitable, as collective effort commits all teams in one direction. Among other things, sense making in a group decision is a highly collaborative process. Individuals will engage in a process to share their understandings with the purpose of accomplishing a task, synthesising perspectives in an evolving subject and through such integration. capture decision rationale (Culmse and Awati, 2012). Lloyd-Walker et al. (2014) further emphasised that such an environment greatly distributes the team interaction in shaping decisions and taking action for problem resolution.

Conclusions

Team integration is a concept that has been widely fostered in alliances as a way of improving collaborative relationships between diverse organisations. However, deeper insights into the leadership practice of high levels of team integration remain elusive. Furthermore, understanding the team integration practice, which is a collaborative process in project-based organisations, is clearly difficult. The research presented in this paper attempts to develop a deeper understanding on fostering team integration through the “lived experience” in an alliance environment based on a framework of successful alliance team integration by Che Ibrahim et al. (2013). Based on the lived experiences of 24 alliance practitioners, who are currently working in a number of alliance road infrastructure projects in New Zealand, it has shown that team integration is a relationship practice which emerges from the specific circumstances of activities. The identified indicators of alliance team integration were found to have an explicit and implicit influence in the development of the team towards leadership of successful integration practice. The findings highlight that alliancing gives the project teams flexibility to change and adapt, to advance the collaborative environment and that integration of multi-disciplinary project teams requires the additional attributes of behaviours and
orientation of ability and motivation to be committed to collaborate. The findings also indicated that the existing underlying collaborative principles embedded in the alliance model enable project teams to stimulate the integrated environment and, hence, provide a game breaking performance to achieve outstanding outcomes. These findings have led to the development of a framework of leadership for successful alliance integrated practices. It is proposed that to influence the leadership for the purpose of achieving integration practice, four elements, namely, task and relationship-oriented behaviours; collaborative learning environments; cultivating cross-boundary networks; and collaborative governance, are required. The framework will be of use to help academics and industry organisations to respond to the needs and prepare a project team towards achieving successful integration practices especially in collaborative environments.

It is worth highlighting that the diversity of practitioners in this study displayed similarities in perceptions and understanding of the indicators; often, the formation of integration is greatly embraced due to matured relationships and principles embedded in the alliance model. Similarities between the participants’ experiences of the integration practices may be influenced by embedded collaborative culture within themselves (i.e. having experience in many relationship-based procurement approaches) and the fact that the scale of New Zealand’s alliance industry is small and individuals tend to be more cautious in building relationships and their reputation.

While the findings are valid in the New Zealand setting, similar studies are required internationally to determine if the team integration practices observed here hold elsewhere. That being said, if projects were being procured and governed similarly, it is hard to imagine that the results reported here would not hold. Further research is warranted to test this proposition. A limitation of the study is that it examined only the project alliance procurement approach; further research could also focus on the other variants of the alliance model (e.g. program alliance, design alliance, planning alliance) as these variants differ significantly.

References


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Project scheduling with time, cost and risk trade-off using adaptive multiple objective differential evolution

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Abstract

Purpose – As often in project scheduling, when the project duration is shortened to reduce total cost, the total float is lost resulting in more critical or nearly critical activities. This, in turn, results in reducing the probability of completing the project on time and increases the risk of schedule delays. The objective of project management is to complete the scope of work on time, within budget in a safe fashion of risk to maximize overall project success. The purpose of this paper is to present an effective algorithm, named as adaptive multiple objective differential evolution (DE) for project scheduling with time, cost and risk trade-off (AMODE-TCR).

Design/methodology/approach – In this paper, a multi-objective optimization model for project scheduling is developed using DE algorithm. The AMODE modifies a population-based search procedure by using adaptive mutation strategy to prevent the optimization process from becoming a purely random or a purely greedy search. An elite archiving scheme is adopted to store elite solutions and by aptly using members of the archive to direct further search.

Findings – A numerical construction project case study demonstrates the ability of AMODE in generating non-dominated solutions to assist project managers to select an appropriate plan to optimize TCR problem, which is an operation that is typically difficult and time-consuming. Comparisons between the AMODE and currently widely used multi-objective algorithms verify the efficiency and effectiveness of the developed algorithm. The proposed model is expected to help project managers and decision makers in successfully completing the project on time and reduced risk by utilizing the available information and resources.

Originality/value – The paper presented a novel model that has three main contributions: First, this paper presents an effective and efficient adaptive multiple objective algorithms named as AMODE for producing optimized schedules considering time, cost and risk simultaneously. Second, the study introduces the effect of total float loss and resource control in order to enhance the schedule flexibility and reduce the risk of project delays. Third, the proposed model is capable of operating automatically without any human intervention.

Keywords Optimization, Scheduling, Risk management, Project management, Construction planning

Paper type Research paper

Introduction

The development of an appropriate resource scheduling approach is one of the most important tasks of project manager to reduce unnecessary expenditures and produce higher profits. Typically, there is a trade-off between time and cost. Project managers are frequently required to make time–cost trade-offs (TCTs) since it is an important element of project (Haj and El-Sayegh, 2015; Zahraie and Tavakolan, 2009). Researchers have established numerous models and applied many methods to optimize the TCT problem in the construction industry. Of these methods, evolutionary algorithms (EAs) have proven relatively more efficient at avoiding local optimization (Feng et al., 1997; Geem, 2010; Hegazy, 1999; Xiong and Kuang, 2008; Yang, 2007). The costs of resources and technologies used in a project are typically associated with work productivity and, thus, project duration.
Conversely, higher resource and technology costs are typically associated with shorter project durations. However, shorter project durations and/or costs may lead to project threatening risk enhancement and project quality, resulting in earlier-than-projected aging/deterioration and higher-than-anticipated maintenance and rehabilitation costs, such as highways, bridges and tunnels projects (Zhang and Xing, 2010).

Construction projects are risky and many uncertainties exist due to weather conditions, labor skills, site conditions, materials, equipment and management (Sakka and El-Sayegh, 2007). Because of the dynamics and uncertainties of construction projects, unexpected delays often occur and adversely affect the planned schedule. Delays to activities that are not on critical paths may not affect the total duration of the project; however, unplanned consumption of the float reduces the ability to absorb schedule changes and can result in extra costs. In the TCT problems, each activity of project has several execution methods during the scheduling phrase. In some case as the project duration is shortened, the total float is lost resulting in more critical or nearly critical activities. Furthermore, the fluctuations of resource are troublesome for the contractors. These, in turn, results in reducing the probability of completing the project on time and increases the risk of schedule delays. However, in some case the project duration increasing could lead to the float loss increasing due to cost reduction. Consequently, the project risks could be increased (Al-Gahtani, 2009; Haj and El-Sayegh, 2015; Mohammadipour and Sadjadi, 2016). Hence, there is a need to incorporate that extra risk into the TCT problem. This will result in a more reliable project schedule because of incorporating the resource fluctuations and the total float-loss variations (Cheng et al., 2017; Haj and El-Sayegh, 2015).

The TCT is one of the more frequently investigated topics in the literature since the 1960s with the aim of developing several methods that can optimize the project cost and duration (Adam et al., 2017; Mohammadipour and Sadjadi, 2016). Initially, several researchers adopted mathematical techniques to solve the TCT optimization problem since they can provide optimal solutions at hand (Cusack, 1985; Fulkerson, 1961; Klánšek and Psunder, 2012; Liu et al., 1995). However, these methods become impractical when the size of project network reaches a considerably large number. Hence, mathematical methods are not computationally tractable for real-life projects. Due to the limitations of mathematical methods, the application of EAs for the TCT problem has attracted more attention over past decade (Chen and Tsai, 2011; Sonmez and Bettemir, 2012; Srivastava et al., 2010; Zhang and Li, 2010). EAs are characterized by iterative progresses used to guide the randomly initiated population to the final optimal solution. Using EAs for increasing the efficiency and reducing the computational time involved when finding the optimum solution for the TCT (Zhou et al., 2011).

Recently, numerous researchers included additional parameters to the TCT problem. Quality is a crucial factor that correlates highly with time and cost factors (Hu and He, 2014). Scholars have established various models and methods that attempt to optimize the time–cost–quality trade-off (Babu and Suresh, 1996; El-Rayes and Kandil, 2005; Khang and Myint, 1999; Zhang and Xing, 2010). The trade-off problems are not limited to time–cost or time–cost–quality. Xu et al. (2012) proposed multiple modes under fuzzy uncertainty to deal with a discrete time–cost–environment trade-off problem for large-scale construction systems. The objective functions are to minimize the total project cost, project duration, crashing cost and environmental impact (Cheng and Tran, 2014; Elbeltagi et al., 2016; Ozcan-Deniz et al., 2012). Other researchers proposed various trade-off model in the field of project management, such as the trade-offs among time, cost and resource (Ghoddousi et al., 2013; Nabipoor et al., 2013); time, cost and reliability (Raziyeh et al., 2005). Nevertheless, there is a few reported research that focus on the effect of total float loss, resource fluctuation resulting from schedule compression and activities’ start time (ST). Haj and El-Sayegh (2015), first, introduced the concept of total float-loss impact into the trade-off
analysis using non-linear programming solved by Microsoft Excel. Therefore, this study aims to build a new optimization model for time–cost–risk trade-off that can provide an optimum time–cost value for a project taking into consideration the effect of total float loss and resource control in order to enhance the schedule flexibility and reduce the risk of project delays.

Differential evolution (DE) is currently one of the most popular EAs. DE may be used in a wide variety of highly non-linear and complex optimization problems. This algorithm is simply structured and easy to use, while demonstrating great robustness and fast convergence in solving single-objective global optimization problems (Storn and Price, 1997). The ability of DE to provide efficient solutions for complex problems with relatively simple operations has encouraged many researchers to develop MODE-based techniques (Das and Suganthan, 2011; Zhou et al., 2011). Despite many reported impressive performances of DE on benchmark functions and practice applications, this algorithm has yet to be applied to solving the TCRT problem. Therefore, this paper applies the adaptive MODE algorithm in a model designed to solve the TCRT problem.

Based on the above, this study develops the novel, adaptive MODE algorithm to deal with TCRT analysis. On the basis of classical DE, this proposed algorithm adopts an external elitist archive to store non-dominated solutions found during the evolutionary process. In order to maintain the exploration and exploitation capabilities of the proposed model, an adaptive mutation operation is introduced. The objective is to demonstrate that the proposed algorithm attains fast convergence without losing solution diversity on the Pareto front. The remainder of this paper is organized as described here. The following section describes mathematical formulation of the TCRT problem. The third section elaborates the proposed optimization model for the TCRT problem. The forth section demonstrates the performance of the newly developed model via a numerical case study. Concluding remarks and suggested directions for future work are presented in the final section.

**Problem formulation for project scheduling with time, cost and risk trade-off**

In the TCRT problem, a project is represented by the diagram $G = (A)$, which is an activity-on-node network with $N$ activities. These activities are numbered from 0 to $N+1$ in the project network, where activities 0 and $N+1$ are “dummy” activities denoting, respectively, the start and finish of the project. $P$ is the set of all paths in the activity-on-node network, starting from activity (0) and ending at activity (N+1). $P_i$ is the set of activities contained in path $l \in P$. Each activity $i \in A$ is associated with several execution methods. Each method has its time $D_i$, cost $C_i$, and resource $R_i$. The TCRT problem concentrates mainly on selecting an optimal combination of execution methods for all activities and the ST value for non-critical activity in order to arrive at an optimal compromise among time, cost and risk for the project. The project time, cost and risk are quantified as follows.

**Calculating overall time in project**

The first objective, minimization of total project duration, may be expressed as follows:

$$\text{Minimize project time } T_p = \max_{i=1,...,N} (FT_i) = \max_{i=1,...,N} (ST_i + D_i),$$

(1)

where $ST_i$, $FT_i$ are the start time and finish time of activity ($i$), $ST_i$ ($i = 1,...,N$) are decision variables in the proposed method. In general, project duration is calculated based on precedence constraints and activity duration. The project information determines the precedence constraints and the selection alternatives determine activity duration.
Calculating overall cost

The total cost of a project includes direct costs (DCs), indirect costs (ICs) and tardiness cost (TC). The DC of the project is the sum of the DCs of all its activities. ICs are costs proportional to the duration of the project as a whole. In accordance with contract requirements, contractors are often subject to TC because of delays in project completion.

The second objective, minimization of total project cost, may be calculated as follows:

\[
\text{Minimize project cost} = \sum_{i=1}^{N} \left( DC_{i}^{S} + IC_{i}^{S} + TC_{i}^{S} \right),
\]

where \( DC_{i}^{S}, IC_{i}^{S} \) and \( TC_{i}^{S} \) is the direct, indirect and TC of activity \( i \), respectively, for a specific option of execution methods \( S_{n} \) and \( N \) is the total number of activities. Indirect cost \( C_{i} = C_{0} + b \cdot T_{P} \) where \( T_{P} \) is the project duration, and it is determined by Equation (1), \( b \) is the indirect cost per day (e.g. daily expenditures). \( C_{0} \) is the initial cost (e.g. mobilization cost, temporary facilities, etc...). \( DC_{D} = \sum_{i=1}^{N} C_{i} \), where \( C_{i} \) is the DC to complete activity \( i \).

The TC is a payment of a delay in executing certain schedule.

Calculating project risk

A “risk value” is defined as a function that integrates the two elements: first, the total float of project; second, the resource fluctuation. Total float is defined as the amount of time that an activity can be delayed without delaying the whole project. A safe float range can be used by project parties so as to minimize risks associated with delays in non-critical activity based on a time-disturbance analysis over the project schedule (Al-Gahtani, 2009; Garza et al., 2007; Gong and Rowings, 1995). In project, construction schedules generated by network scheduling techniques often bring about undesirable resource fluctuations that are impractical, inefficient, costly and high risk for the contractors to implement. Thus, construction managers mandatorily need to perform schedule-adjusting process to reduce unnecessary fluctuations in resource utilization during the project execution. The float on non-critical activities can lead to efficient resource utilization.

The third objective, minimization of total project risk, may be calculated as follows:

\[
\text{Minimize project risk} = w_{1} \times \left( 1 - \frac{TF_{\text{current}}}{TF_{\text{max}}} + 1 \right) + w_{2} \frac{\sum_{t=1}^{Pd} (R_{t} - \bar{R})^{2}}{Pd \times (\bar{R})^{2}},
\]

where \( TF_{\text{current}} \) is total float of project as current scheduling; \( TF_{\text{max}} \) is total float of project as the most flexible scheduling which all activities’ STs are set as earliest start times. \( \bar{R} \) is resource required on day \( t \); \( \bar{R} \) is uniform resource level; \( w_{i} \) is the weights for the importance of each indicator. In the first element of Equation (3), if \( TF_{\text{current}} \) increases then \( (1 - (TF_{\text{current}} + 1)/TF_{\text{max}} + 1)) \) deceases. As the total float is large resulting in more reserved time for activities. This, in turn, results in increasing the probability of completing the project on time and decreases the risk of schedule delay. In the second element of Equation (3), when the daily usage resource \( R_{t} \) is close to uniform resource level \( \bar{R} \), the resource profile is smooth out and nearly ideal. Consequently, the fluctuation of resource usage decreases, the project risk reduces.

Since a project comprises various resources, such as materials, machines, labor, the overall. The scope of this study is limited to a deterministic environment in which decisions are made with deterministic input data from the case study. The assumptions of the case study are that all the objective functions are quantified data and the mean values of the resources are used.
Adaptive multiple objective DE for the time–cost–risk trade-off problem (AMODE-TCR)
This section describes the adaptive multiple objective differential evolution (AMODE) for solving the TCR problem by optimizing project time, cost and risk simultaneously. The model was developed in this study based on version of the original DE algorithm (Storn and Price, 1997). The AMODE modifies a population-based search procedure by using adaptive mutation strategy to prevent the optimization process from becoming a purely random or a purely greedy search. An elite archiving scheme is adopted to store elite solutions and by aptly using members of the archive to direct further search. Figure 1 shows the overall operational architecture of the proposed algorithm. The following subsections provide further details on the flowchart.

Population initialization
This study considers the TCRT problem, in which project cost, project duration and project risk are optimized simultaneously. The model requires project information inputs including activity relationship, activity duration ($D_i$), activity cost ($C_i$), activity resource use ($R_i$) and execution methods ($S_n$) for each activity. In addition, the user also must provide parameter settings for the search engine (AMODE), such as the value of population size $NP$, number of decision variables $D$, number of objective functions $M$, value of “limit,” value of the mutant constant $F$, value of the crossover probability constant $CR$, maximum number of generations $G_{max}$, the lower bound ($LB$) and the upper bound ($UB$) of decision variables. With these inputs, the optimizer conducts calculations to obtain an optimal set of execution methods for all construction project activities. With all the necessary information provided, the model is capable of operating automatically without any human intervention.

Population initialization is the first and the primary task in any EA. The population in the AMODE may be guided toward more promising areas if the initial population is spread as much as possible over the objective function surface. Hence, the $NP$ individuals of the population may be easily generated as follows:

$$X_{ij} = LB_i + rand[0, 1] \times (UB_i - LB_i); \quad (i = 1, ..., D; j = 1, ..., NP),$$  

(4)
where $LB_i$ and $UB_i$ indicate the lower and upper bound of the $i$th decision variable; $\text{rand}[0, 1]$ denotes a uniformly distributed random number between 0 and 1; and $X_{i,j}$ is the $j$th individual in the initial population.

**Decision variables and constraints**

A candidate solution to the TCRT problems may be represented as a vector of these decision variables: first, execution method used for each activity; second, the ST value of each activity ($N$) as follows:

$$X = \left[ x_{1,j}, \ldots, x_{n,j}, \ldots, x_{N,j}, x_{N+1,j}, \ldots, x_{t,j}, \ldots, x_{2N,j} \right]; \quad n = 1; \ldots; N; \quad t = N+1; 2N; \quad (5)$$

where $2N$ is the number of decision variables in the problem at hand. It is obvious that $N$ is also the number of activities in the project network. Index $j$ denotes the $j$th individual in the population.

**Execution option.** Execution-option ($S_n$) represents the feasible execution options for activity $j$. Every option has specific combinations of duration, cost and resource use that lead to different total project duration, cost and risk. Sub-vector $x_{n,j} \in S_n$ represents one execution method for activity $n$. Execution method $s_{n,j}$ is an integer number in the range $[1, S_n] \ (n = 1 \text{ to } N)$, meaning one position from $S_n$ execution methods. Because the original DE operates with real-value variables, a function is employed to convert the execution methods of those activities from real values to integer values within the feasible domain:

$$s_{n,j} = \text{Ceil} \left( x_{n,j} \times S_n \right); \quad (n = 1, \ldots, N) \quad (6)$$

Ceil is a function to round a real number to the nearest integer greater than or equal to it.

**ST variable.** ST variable ($x_{t,j}$) represents the preference value for each activity to determine actual start time $ST_t$. The following equation shows the constraint for this variable:

$$0 \leq ST_t \leq 1; \quad t = 1, \ldots, N. \quad (7)$$

Together with execution constraints and the precedence relationships between activities, $S_t$ values help determine the project activities’ ST and calculate project risk value based the scheduling subsystem presented in the following subsection.

**Scheduling subsystem**

Once the AMODE individual is created, the project objectives are calculated through scheduling subsystem. The execution-option ($S_n$) values define the execution mode of each activity and then determine the corresponding durations and resource information including cost, resource of all activities. The values ($ST_t$) carry out the ST of all activities. Figure 2 demonstrates how the scheduling subsystem generates all project objectives, where $ST_i$ represents the ST of activity $i$ in the project at the individual $j$th. $LB(i)$ and $UB(i)$ are the earliest ST and latest ST for activity $i$. In scheduling module, two constraint conditions limit the actual ST of all activities: first, actual ST must be between the earliest and latest STs and, second, actual ST is restricted by the actual ST of its predecessor activities. The first constraint is easy to handle because boundaries are fixed prior to calculation. However, the boundaries of the second constraint is unknown prior to calculation and thus more difficult
to find. Each dimension of the decision variables is determined in turn. When calculating the actual ST of one activity, actual STs of all activities in its predecessor set \( ST_{pset} \) have been computed, the max \( \max_{k} (ES_k + D_k); i = 1, N \) has been confirmed simultaneously.

The search engine (AMODE) takes into account the results obtained from the scheduling module and the search for an optimal combination of execution methods for each activity. This research used three contradicting objectives. Second section describes the formulae for each objective function.

**Adaptive DE operators**

Once initialized, the DE crossover-mutation operators mutate the population to produce a set of mutant vectors. For each target vector \( X_i \), a mutant vector \( V_i^{G+1} \) is determined using the following equation:

\[
V_i^{G+1} = X_i^G + F(X_i^G - X_j^G),
\]

where, \( r_1, r_2, r_3 \in \{1, 2, \ldots , NP\} \) are randomly selected such that \( r_1 \neq r_2 \neq r_3 \neq i \), and \( F \) is a scaling factor such that \( F \in [0, 1] \).

In the original DE (Price et al., 2005) three mutant vectors are selected arbitrarily and the base vector is chosen randomly among 3 vectors (DE/rand/1/bin). This has a good exploratory but it slows down the convergence of DE. In DE/best/1/bin the base vector is always selected as one having the best fitness value. The strategy may provide a fast convergence but it may lead to loss of diversity.

To help AMODE in maintaining the exploration and exploitation capabilities, this research proposed three selection mechanisms that are operated based on itself parameter call \( ms = 1/3 \) (mutant selection) and maximum of generation \( G_{\text{max}} \).
Phase 1: \( g \leq ms \times G_{\text{max}} \) (call random selection).

In Equation (8), \( X_{r1}, X_{r2} \) and \( X_{r3} \) are randomly chosen in the population set of \( NP \). At the beginning of the evolutionary process, all the vectors for mutation are randomly selected and the best point of the population may or may not be included in them. Because of its random nature, this strategy helps algorithm in preserving the diversity.

Phase 2: \( ms \times G_{\text{max}} < g \leq 2 \times ms \times G_{\text{max}} \).

\( X_{r} \) is the base vector is selected from external elitist archive. \( X_{r2} \) and \( X_{r3} \) are arbitrarily chosen in the population set of \( NP \). In this strategy, the base vector is always selected as the one have the best fitness function value and the other vectors are chosen randomly among population. This technique makes algorithm neither purely greedy nor purely random in nature. It balances between diversity and convergence.

Phase 3: \( g > 2 \times ms \times G_{\text{max}} \) (call elitist selection).

In the last phase of optimization process, the algorithm needs to accelerate the convergence. All the vectors \( X_{r1}, X_{r2} \) and \( X_{r3} \) for mutation are the best points which taken in the external elitist archive.

Following the mutation step, the crossover operator is applied to increase the diversity. For each mutant vector \( U_{G}^{i+1} \), a trial vector \( U_{G}^{i+1} = (u_{G_{1}, i}^{i+1}, u_{G_{2}, i}^{i+1}, \ldots, u_{G_{D}, i}^{i+1}) \) is generated using the following scheme:

\[
U_{G_{j}, i}^{i+1} = \begin{cases} 
    u_{G_{j}, i}^{i+1}, & \text{if } \text{rand}_{j}[0, 1] \leq CR \text{ or } i = i_{\text{rand}} \\
    x_{G_{j}, i}, & \text{otherwise}
\end{cases}, \quad i = 1, 2, \ldots, D. \tag{9}
\]

\( CR \in [0, 1] \) is a user-defined crossover constant; \( i_{\text{rand}} \) is a randomly chosen index from \( \{1, 2, \ldots, D\} \) that ensures trail vector \( U_{G}^{i+1} \) differs from its target \( X_{G}^{i} \) by at least one parameter.

The most important task of multi-objective optimization is the modification of the selection mechanism. The selection operation is based on the concept of Pareto dominance. In this operation, first evaluate trial vector \( U_{G}^{i+1} \) then compare with target vector \( X_{G}^{i} \). There may be at most three dominance possibilities between \( U_{G}^{i+1} \) and \( X_{G}^{i} \):

- If \( X_{G}^{i} \) dominates \( U_{G}^{i+1} \), \( U_{G}^{i+1} \) is discarded.
- If \( U_{G}^{i+1} \) dominates \( X_{G}^{i} \) and \( X_{G}^{i+1} = U_{G}^{i+1} \), and update external archive with update rule.
- If \( U_{G}^{i+1} \) and \( X_{G}^{i} \) are non-dominated each other, Crowding entropy is used to select individual to next target vector (the less crowded the better).

**Update elitist archive**

The vector which is chosen in selection operation process is called selected vector. If the selected vector is dominated by a member(s) of archive, the selected vector is rejected. If the selected vector dominates some member(s) of the archive, then the dominated members are deleted and selected vector is accepted. If the selected vector is non-dominated with each member in archive, it will enter archive.

The Update rule is illustrated in Figure 3, in which three non-dominated solutions, shown as bold dots, are stored in the archive: A1, A2 and A3. At the current iteration, three
archive candidate solutions are found to be \( C_1 \) through \( C_3 \), shown as hollow squares. Since archive member \( A_1 \) is dominated by \( C_1 \), \( A_1 \) is deleted. \( C_2 \) is dominated by some archive members, so \( C_2 \) is rejected. \( C_3 \) is non-dominated with each member in archive, it will become archive member.

When the external archive population reaches its maximum capacity \( N_{\text{max}} \), the crowding entropy to select \( N_{\text{max}} \) individuals with less crowded.

**Stopping conditions**

The optimization process terminates when the stopping conditions are met. The user sets the type of these conditions. Maximum generation \( G_{\text{max}} \) or maximum number of functions evaluations may be used as the stopping criterion. This study used the maximum number of generation as stopping condition for the proposed algorithm. When the optimization process terminates, the final set of optimal solutions, called the Pareto front, is presented to the user. Obtaining the entire Pareto front is of great importance because it assists decision makers to evaluate the pros and cons of each potential solution based on qualitative and experience-driven considerations.

**Case study**

This study analyzed a numerical construction project to demonstrate the effectiveness of the proposed AMODE in application to the TCRT problem. The obtained results were compared to three approaches used previously in the literature to handle the TCRT problem, including NSGA-II, MOPSO and MODE. The project comprised ten construction activities, each of which has a number of possible execution methods. Table I shows the precedence relationships, the time, cost and resource usage associated with each execution method (mode). Each possible combination has a unique impact on project performance, which means that decision makers must search a large number of potential solutions to find those that establish an optimal trade-off/balance among construction project duration, cost and risk. We used the newly developed multi-objective optimization model to search the many potential solutions.

**Optimization result of AMODE-TCRT**

Table II shows parameter settings for the proposed AMODE-TCRT (Ali et al., 2012; Li et al., 2013; Storn and Price, 1997; Wu et al., 2010). In total, 30 independent optimization runs were conducted to avoid randomness. Based on the importance of each factor contributed to project risk, the weights for each resource are set approximately as: \( w_1 = 0.6 \), \( w_2 = 0.4 \). Consequently, the project total risk objective function for the case study is figured out. Table III lists the first-eight non-dominated solutions in descending order of time, cost, risk and compromised.

<table>
<thead>
<tr>
<th>Act.</th>
<th>Predecessor</th>
<th>( D ) (days)</th>
<th>Option 1</th>
<th>( C ) ($)</th>
<th>( R ) (worker)</th>
<th>Option 2</th>
<th>( D )</th>
<th>( C )</th>
<th>( R )</th>
<th>Option 3</th>
<th>( C )</th>
<th>( R )</th>
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<td>–</td>
<td>9</td>
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<td>5</td>
<td>7</td>
<td>6,000</td>
<td>7</td>
<td>5</td>
<td>10,000</td>
<td>8</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>8</td>
<td>2,900</td>
<td>7</td>
<td>7</td>
<td>3,500</td>
<td>9</td>
<td>5</td>
<td>4,400</td>
<td>12</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>12</td>
<td>1,700</td>
<td>2</td>
<td>10</td>
<td>3,500</td>
<td>4</td>
<td>9</td>
<td>4,700</td>
<td>7</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>5</td>
<td>3, 4</td>
<td>4</td>
<td>1,300</td>
<td>3</td>
<td>3</td>
<td>2,000</td>
<td>4</td>
<td>2</td>
<td>2,800</td>
<td>6</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>9</td>
<td>3,200</td>
<td>4</td>
<td>7</td>
<td>5,800</td>
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<td>5</td>
<td>6,200</td>
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<td>4,000</td>
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<td>6</td>
<td>7,400</td>
<td>4</td>
<td>–</td>
<td>–</td>
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</tr>
<tr>
<td>9</td>
<td>6, 7</td>
<td>6</td>
<td>4,200</td>
<td>3</td>
<td>5</td>
<td>5,000</td>
<td>5</td>
<td>4</td>
<td>6,200</td>
<td>6</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>10</td>
<td>8, 9</td>
<td>10</td>
<td>6,400</td>
<td>3</td>
<td>6</td>
<td>8,400</td>
<td>4</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Table I. Project data
respectively, along with optimal execution method combinations. Solutions 1, 2 generated the smallest project duration value, solution 3 generated the smallest values for cost, solution 5 generated the smallest values for project risk and the other solutions struck a balance among the three objectives. Project managers may select the optimal solution for a specific project scenario based on experience, preferences and specific situation conditions. For instance, if a manager prioritizes time, then solutions 1, 2 are optimal. If a manager prioritizes budget, then solution 3 is optimal. Solution 5 is optimal if a manager prioritizes project risk. However, if a manager wants to strike a measured balance between the three objectives, then solution 7, for example, provides a centrist solution marked by acceptable project duration (33 days), moderate cost (US$45100) and moderate project risk (6.27). Figure 4 shows the typical Pareto optimal fronts obtained using the AMODE for this case study. These fronts show clearly the relationships among project duration, cost and risk. This three-dimensional visualization of the trade-offs may help decision makers evaluate the impact on project performance of the various potential resource-utilization plans. Figure 4 also shows the relationship between time and cost, cost and risk and time and risk, respectively. As shown in the time–cost curve example, the lower project funding we spend on project correlates with the longer project duration we need to complete project and vice versa. Figure 4 might not be good representatives of the entire trade-off surface in the three-dimensional space. In fact, the three-dimensional trade-off surface, when projected from three to two dimensions, might lose some non-dominated points because there is a hidden dimension that makes these points non-dominated. For illustration purpose, schedules (ST, shift option of each activity and allocated resource of each shift) of three selected non-dominated solutions (1, 3, 5) and their corresponding time, cost and total risk for case study are presented in Figure 5.

Statistical comparison and analysis

We compared AMODE performance against NSGA-II (Deb et al., 2002), MOPSO (Yang, 2007) and MODE (Ali et al., 2012) to assess comparative effectiveness. For comparison purposes, all four algorithms used an equal number of function evaluations had a

<table>
<thead>
<tr>
<th>Input parameters</th>
<th>Notation</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of decision variables</td>
<td>$D$</td>
<td>20</td>
</tr>
<tr>
<td>Population size</td>
<td>$NP$</td>
<td>100</td>
</tr>
<tr>
<td>Crossover probability</td>
<td>$CR$</td>
<td>0.5 ~ 0.9</td>
</tr>
<tr>
<td>Scaling factor</td>
<td>$F$</td>
<td>0.5</td>
</tr>
<tr>
<td>Mutant selection</td>
<td>$ms$</td>
<td>1/3</td>
</tr>
<tr>
<td>Maximum size of Archive</td>
<td>$N_{max}$</td>
<td>100</td>
</tr>
<tr>
<td>Maximum generation</td>
<td>$G_{max}$</td>
<td>300</td>
</tr>
</tbody>
</table>

Table II. AMODE-TCRT parameter settings

<table>
<thead>
<tr>
<th>No.</th>
<th>Partial set</th>
<th>[Execution mode; activity start time]</th>
<th>Time (days)</th>
<th>Cost ($)</th>
<th>Risk (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sorted by time</td>
<td>$[1.3.2.3.3.2.2.1.2; 0.0.7.5.14.5.10.16.16.22]$</td>
<td>28</td>
<td>53,100</td>
<td>12.27</td>
</tr>
<tr>
<td>2</td>
<td>$[2.3.1.3.2.2.2.2.2; 0.0.3.5.14.5.12.16.16.22]$</td>
<td>28</td>
<td>58,700</td>
<td>9.72</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Sorted by cost</td>
<td>$[1.1.1.1.1.1.1.1.1.1; 0.0.7.9.21.9.18.25.25.35]$</td>
<td>45</td>
<td>34,600</td>
<td>14.30</td>
</tr>
<tr>
<td>4</td>
<td>$[1.1.1.1.1.1.1.1.1.1; 0.0.7.9.21.9.18.25.25.35]$</td>
<td>45</td>
<td>35,400</td>
<td>13.76</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Sorted by risk</td>
<td>$[1.2.1.2.1.3.2.2.2.2; 0.0.3.9.19.9.18.22.22.28]$</td>
<td>34</td>
<td>49,100</td>
<td>5.17</td>
</tr>
<tr>
<td>6</td>
<td>$[1.2.1.2.1.3.2.2.2.2; 0.0.3.9.19.9.18.22.22.28]$</td>
<td>34</td>
<td>48,300</td>
<td>5.38</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Compromised</td>
<td>$[1.2.1.1.3.1.3.2.2.2.2; 0.0.7.7.19.7.18.22.20.27]$</td>
<td>33</td>
<td>45,100</td>
<td>6.27</td>
</tr>
<tr>
<td>8</td>
<td>$[1.1.1.1.2.1.2.2.2.2; 0.0.7.9.21.9.18.24.24.30]$</td>
<td>36</td>
<td>41,500</td>
<td>6.07</td>
<td></td>
</tr>
</tbody>
</table>

Table III. Best non-dominated solutions obtained by AMODE-TCRT
population size of 100 and a maximum of 300 generations. In NSGA-II, the constant mutant and crossover probability factors were set at 0.5 and 0.9, respectively. In MOPSO, the two learning factors $c_1, c_2$ were both chosen at 2, and the inertia factor $w$ is set in range of 0.3 to 0.7. MODE and AMODE control parameters remained the same, as stated previously in Table II. In total, 30 independent runs were carried out for all experiments.
Multi-objective optimization problem performance measures are more complex than those of single-objective optimization problems. Three issues are normally taken into consideration: first, convergence to the Pareto optimal set; second, maintenance of diversity in solutions of the Pareto optimal set; and third, the maximal distribution bound of the Pareto optimal set (Wu et al., 2010). In the literature, the researchers have suggested numerous risk indicators (Coello Coello, 2006; Deb et al., 2002; Fonseca and Fleming, 1995; Zitzler et al., 2003). These indicators may be classified into three categories based on whether they evaluate: (1) closeness to the Pareto front; (2) the diversity in obtained solutions; or (3) both (1) and (2) (Zitzler et al., 2003). The following describes the three risk indicators used in this research to evaluate, respectively, each of the three issues.

**C-metric (C)**

C-metric is often used to assess the risk of the true Pareto front of optimized problems (Zitzler and Thiele, 1999). Let $S_1, S_2 \subseteq \mathbb{R}$ be two sets of decision solutions.

\[
C(S_1, S_2) = \frac{\{a_2 \in S_2: \exists a_1 \in S_1 : a_1 \preceq a_2\}}{|S_2|}.
\]  

The numerator in Equation (10) denotes that the number of solutions in $S_2$ is dominated by at least one solution in $S_1$, and the denominator equals the total solutions in $S_2$. Provided that $C(S_1, S_2) = 1$, all solutions in $S_2$ are dominated by or equal to solutions in $S_1$. If $C(S_1, S_2) = 0$, then $S_1$ covers none of the solutions in $S_2$. Both $C(S_1, S_2)$ and $C(S_2, S_1)$ should be checked in the comparison because the C-metric is not symmetrical in its arguments (Wang and Singh, 2009).

Table IV illustrates the comparative results among five algorithms in terms of the C-metric, where $A_1, A_2, A_3$ and $A_4$ indicate AMODE, MODE, MOPSO and NSGA-II, respectively. Results show that AMODE dominates more than 15.4 percent of the MODE solutions, 67.5 percent of the MOPSO solutions and 72.1 percent of the NSGA-II solutions on average.

**Spread (SP)**

This indicator (Wang et al., 2010) measures the extent of spread achieved among the non-dominated solutions. The mathematical definition of SP may be given as:

\[
SP = \frac{\sum_{i=1}^{k} d(E_i, \Omega) + \sum_{X \in \Omega} |d(X, \Omega) - \bar{d}|}{\sum_{i=1}^{k} d(E_i, \Omega) + (|\Omega| - k)\bar{d}},
\]  

where $\Omega$ is a set of solutions, $(E_1, ..., E_k)$ are $k$ extreme solutions in the set of true Pareto-front $PF$, $k$ is the number of objectives and $d(X, \Omega) = \min_{Y \in \Omega, Y \neq X} \|F(X) - F(Y)\|$ is the minimum Euclidean distance between solution $X$ and its neighboring solutions in the obtained non-dominated $\Omega$ set; $\bar{d} = (1/|\Omega|) \sum_{X \in \Omega} d(X, \Omega)$ is the mean value of all $d(X, \Omega)$; $|\Omega|$ is the total solutions in $\Omega$ set. A value of zero for this metric indicates that all members of the Pareto optimal set are spaced equidistantly. A smaller value of $SP$ indicates a better distribution and diversity of non-dominated solutions. Table V shows a comparison of the spread metric for

<table>
<thead>
<tr>
<th>Algorithm combination</th>
<th>Best</th>
<th>Worst</th>
<th>Average</th>
<th>Std.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_1, A_2$</td>
<td>0.2670</td>
<td>0.0520</td>
<td>0.1540</td>
<td>0.0618</td>
</tr>
<tr>
<td>$A_2, A_1$</td>
<td>0.1981</td>
<td>0.0000</td>
<td>0.0952</td>
<td>0.0515</td>
</tr>
<tr>
<td>$A_1, A_3$</td>
<td>0.8810</td>
<td>0.0000</td>
<td>0.6750</td>
<td>0.1938</td>
</tr>
<tr>
<td>$A_3, A_1$</td>
<td>0.1522</td>
<td>0.0500</td>
<td>0.0324</td>
<td>0.1406</td>
</tr>
<tr>
<td>$A_1, A_4$</td>
<td>0.9600</td>
<td>0.0909</td>
<td>0.7207</td>
<td>0.2876</td>
</tr>
<tr>
<td>$A_4, A_1$</td>
<td>0.2680</td>
<td>0.0500</td>
<td>0.1510</td>
<td>0.1148</td>
</tr>
</tbody>
</table>
different algorithms. This supports that the average performance of the AMODE is superior to that of the four other algorithms.

Hyper-volume (HV). This indicator calculates the volume (in the objective space) covered by members of a non-dominated set of solutions $\Omega$ for a problem that works to minimize all objectives (Wu et al., 2010; Zitzler et al., 2003). A hyper-cube $v_i$ is constructed for each solution $X_i \in \Omega$, with reference point $W$ and the solution $X_i$ as the diagonal corners of the hyper-cube. The reference point may be found simply by constructing a vector of worst objective function values. Thereafter, a union of all hyper-cubes is found, with the HV of this union calculated as:

$$HV = \bigcup_{i=1}^{\Omega} v_i.$$

(12)

Algorithms with larger HV values are desirable. The HV value of a set of solutions is normalized using a reference set of Pareto optimal solutions with the same reference point. After normalization, the HV values are confined to range $[0, 1]$. Table VI lists the results for each of the four compared algorithms in terms of HV. From Table VI, we see that the proposed model obtains the largest HV values, which means that the AMODE has better convergence and diversity performance than the other four algorithms.

Conclusions and further study
The proposed model introduces the concept of risk as an integrated function of total float and resource fluctuation into the project scheduling. Time, cost and risk are important and interdependent variables in construction projects. Integrating all goals into the optimization process and pursuing the trade-offs among these goals represent one approach to improving the overall efficiency and effectiveness of construction projects. This research makes three important contributions: first, this paper presents an effective and efficient adaptive multiple objective algorithms named as AMODE for solving the TCRT problem. Second, the study introduces the effect of total float loss and resource control in order to enhance the schedule flexibility and reduce the risk of project delays. Third, the proposed model is capable of operating automatically without any human intervention.

The Pareto front generated by AMODE provides an efficient solution to the time–cost–risk trade-off problem while maintaining a flexible schedule that meets the project needs. Results show that the proposed model AMODE generates a better Pareto

<table>
<thead>
<tr>
<th>AMODE</th>
<th>MODE</th>
<th>MOPSO</th>
<th>NSGA-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best</td>
<td>0.7062</td>
<td>0.8036</td>
<td>1.0356</td>
</tr>
<tr>
<td>Worst</td>
<td>1.0346</td>
<td>1.3149</td>
<td>1.0825</td>
</tr>
<tr>
<td>Average</td>
<td>0.8215</td>
<td>0.9808</td>
<td>1.0682</td>
</tr>
<tr>
<td>Std.</td>
<td>0.2110</td>
<td>0.0803</td>
<td>0.0138</td>
</tr>
</tbody>
</table>

Table V. Comparison of SP-metric for different algorithms

<table>
<thead>
<tr>
<th>AMODE</th>
<th>MODE</th>
<th>MOPSO</th>
<th>NSGA-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best</td>
<td>0.6187</td>
<td>0.2165</td>
<td>0.3107</td>
</tr>
<tr>
<td>Worst</td>
<td>0.8726</td>
<td>0.3105</td>
<td>0.3994</td>
</tr>
<tr>
<td>Average</td>
<td>0.7121</td>
<td>0.2618</td>
<td>0.3478</td>
</tr>
<tr>
<td>Std.</td>
<td>0.2712</td>
<td>0.0358</td>
<td>0.0122</td>
</tr>
</tbody>
</table>

Table VI. Comparison of HV-metric for different algorithms
front than widely used approaches in terms of diversity of characteristics, compromise solutions and degree of satisfaction.

The model has practical implications since it does not impose any limitation on the number of objectives and may be extended to include additional objectives. Further, minor modifications of the proposed AMODE algorithm hold interesting potential to resolve other multi-objective optimization problems in the field of construction management such as the trade-offs among performance, cost and reliability in engineering design work and resource constrained and resource leveling in project scheduling activities.

The case study only considered deterministic and static input data. However, in practice, experts, contractors, engineers and managers often evaluate performance particularly, risk using linguistic and other imprecise terms due to uncertainties in the environment and subjectivity. Hence, further study is required to build an optimization model to stochastic data. Integrating the current model with other techniques such as fuzzy and stochastic simulation are interesting directions for future research.

References


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Resource levelling optimization model considering float loss impact

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Abstract

Purpose – The purpose of this paper is to propose a Non-Linear Integer Programming (NLIP) model that solves the resource leveling problem while reducing the negative effect of the total float loss on risk.

Design/methodology/approach – An NLIP model is formulated to solve the resource leveling optimization problem incorporating float loss cost (FLC). The proposed model is implemented using “What’s Best solver” for Excel. The FLC is calculated using the float commodity approach. An example is solved using the proposed model in order to illustrate its applicability. Sensitivity analysis is also performed.

Findings – The results confirmed that resource leveling reduces the available float of non-critical activities; decreases schedule flexibility and reduces the probability of project completion. The probability of timely completion dropped from 50 percent (for the normal schedule with 32 resource fluctuations) to 13.5 percent for leveled resources with zero fluctuations. Using the proposed method, the number of resource fluctuations is 8 but the probability of completing the project on time improved to 20 percent.

Practical implications – The proposed model allows project managers to exercise new trade-offs between resource leveling and schedule flexibility which will ultimately improve the chances of successful project delivery.

Originality/value – Resource leveling techniques result in reducing the available total float for the non-critical activities. Existing methods focus on moving noncritical activities within their available float and ignore the impact of the resulting float loss. This reduces the schedule flexibility and increase the risk of project delays. The proposed model incorporates the FLC into the resource leveling optimization problem resulting in more efficient schedules with improved resource utilization while keeping some schedule flexibility.

Keywords Construction management, Project management, Scheduling

Paper type Research paper

Introduction

Successful delivery of construction projects requires the efficient utilization of the numerous resources. Efficient resource utilization includes reducing the number of required resources and minimizing the idle time of the available resources. Resource management is linked to the construction schedule as the schedule dictates the number of required resources at different periods of time. It is important to consider the availability of resources before finalizing the construction schedule. Scheduling without considering resource constraints gives unreliable schedules (Kastor and Sirakoulis, 2009). It is difficult to manage a project when the resource demands are erratic (Gray and Larson, 2008). Having a schedule that respects the time only may be inappropriate from other views such as the resources used (Elbeltagi et al., 2016).

The critical path method (CPM) is the most commonly used method for scheduling and managing construction projects. The initial CPM schedule is usually prepared based on logic (Hariga and El-Sayegh, 2011) and with little regards to the availability of resources. Once the initial schedule is prepared, resource management techniques are used to ensure the efficient utilization of resources. Resource management includes two main techniques: resource allocation and resource leveling. Resource allocation is concerned with scheduling the project activities based on the availability of the limited resources. If the required resources are not available, the corresponding activity/activities are delayed (Hinze, 2012). If the delay is in critical activities, the project duration is extended. Resource leveling is concerned with the efficient utilization of resources when the project duration is fixed (Hinze, 2012).
It involves moving non-critical activities, within their float, in an effort to reduce the peak resource demands and minimize the resource fluctuations. Leu and Hung (2002) added that the main objective of resource leveling is to reduce peak resource requirements and smooth out period to period assignment within the required project duration.

The resource leveling topic has been investigated since the 1960s. However, existing methods ignored the effect of total float loss resulting from resource leveling. Resource leveling techniques result in reducing the available total float for noncritical activities. This float loss reduces the schedule flexibility and increases the risk of project delays. Therefore, there is a need for a new resource leveling model that can provide an optimum schedule taking into consideration the effect of total float loss. The research described in this paper is aimed at developing a new model to solve the resource leveling problem taking into account the total float loss impact.

**Resource leveling techniques**

Resource leveling techniques can be generally categorized into three groups: heuristic, analytic and meta-heuristic methods (Alsayegh and Hariga, 2012). Heuristic methods rely on general rules to move activities within their floats to achieve an acceptable (but not necessarily the optimum) solution. Harris (1978) developed the Minimum Moment Algorithm (MMA) for resource leveling by making use of the available free float. The activities are moved based on their highest improvement factors. Later, Harris (1990) developed the packing method (PACK) for resource leveling using different heuristics. Hiyassat (2000) proposed a modification to the heuristics used in the MMA. The heuristic methods do not guarantee the optimum solution. Therefore, several researchers adopted analytic techniques to solve the optimization problem. Talbot and Patterson (1978), Karaa and Nasr (1986) and Easa (1989) used integer linear optimization to achieve the optimum resource leveling for construction projects. Mingozzi et al. (1998) and Rieck et al. (2012) used mixed integer programming. Mattila and Abraham (1998) and Hyari and El-Rayes (2006) developed optimization models for linear schedules. Recently, meta-heuristic techniques were used to solve the resource leveling problem to reduce the calculation times. Meta-heuristic techniques are used to find the optimum or near optimum solutions. These methods include: neural networks (Savin et al., 1996), genetic algorithms (Hegazy, 1999; Leu and Yang, 1999; Ponz-Tienda et al., 2013), simulated annealing (Son and Skibniewski, 1999), harmony search (Ponz-Tienda et al., 2017) and particle swarm optimization (Alsayegh and Hariga, 2012). Bettemir and Sonmez (2015) developed a hybrid genetic algorithm with simulated annealing for resource constrained scheduling. Other researchers included additional parameters to the resource leveling problem. Typically, splitting activities are not permitted in resource leveling. Nevertheless, some authors developed resource leveling models that allow activity splitting using mixed binary-integer programming such as the models developed by Son and Mattila (2004), Hariga and El-Sayegh (2011) and Alsayegh and Hariga (2012).

The previously mentioned resource leveling methods focus on moving noncritical activities within their available float and ignore the impact of the resulting float loss.

**Float loss impact**

The total float is defined as the number of days an activity can be delayed without extending the project duration. Those activities that have zero float are referred to as critical activities. Those that have float are referred to as noncritical activities. Total float is shared amongst activities in the same path. The total float is an attribute of a network path and does not belong to any specific activity along that path (Prateapsanond, 2003). The availability of float for construction activities is important as it provides some flexibility for contractors and clients. Contractors may use the float for resource
management purposes while clients and designers may use the float to introduce changes without extending the project duration. The total float is an asset for both owners and contractors (De La Garza et al., 2007). The amount of float is essential for resource management purposes (Ammar, 2003; Al-Gahtani and Mohan, 2005). The schedule flexibility is measured by the total float (PMBOK5, 2013). Gong (1997) stated that floats are used for resource allocations without causing negative impact on project duration. The inclusion of accurate float ensures schedules are realistic, and contractors have the opportunity to undertake resource scheduling and resource leveling (Ling and Ang, 2013).

Consuming the float may have a negative impact on the project. Several researchers discussed the value of float and the effects of its loss. Gong and Rowings (1995) introduced the method of time-disturbance analysis for the project network by examining the effect of float use of noncritical activities on the expected time of a given merge event. They suggested that there is a safe float range that can be used to delay noncritical activities without major impacts on project duration. Raz and Marshall (1996) proposed new float definitions considering the effect of resource availability on the schedule. De La Garza et al. (1991) proposed that the float is traded as a commodity between contractors and owners. Sakka and El-Sayegh (2007) introduced a method to calculate the float consumption impact on the cost and schedule using the multiple simulation analysis technique developed by Isidore and Back (2002). Sakka and El-Sayegh (2007) showed that the cost of the float consumed by shifting the noncritical activities have a negative impact on the overall cost of a project.

Due to the importance of float to both contractors and clients, researchers suggested several methods for float allocation in construction contracts. Ponce de Leon (1986) introduced the bar approach based on the concept that no one has the right to use the float. Householder and Rutland (1990) suggested that the float should be distributed among parties based on their responsibilities toward project’s risks. Pasiphol and Popescu (1995) recommended that the total float, for each noncritical path, can be distributed based on the duration of the activities in that path and that activities must be completed within the original duration and the allocated float. De La Garza et al. (2007) suggested that float can be allocated between project parties based on a pre-agreed ratio. Al-Gahtani (2009) suggested that the total float has to be allocated to the parties based on the amount of risk they encounter in the project. The subject of float ownership has been debated for a long time. Owners claim that they should own the float as they need it to incorporate some changes without delaying the project. On the other hand, contractors claim float ownership as they need the float for resource management purposes and to have some flexibility in their schedules. The proposed model allows contractors to use the float to improve their resource utilization and at the same time maintain some level of flexibility.

In this paper, the float commodity approach, suggested by De La Garza et al. (1991), is used to quantify the float loss cost (FLC). The FLC is then incorporated into the proposed resource leveling optimization model. De La Garza et al. (1991) suggested that there is an early finish cost (EFC) and a late finish cost (LFC) for each noncritical activity. The EFC represents the normal conditions (executing the activities at their earliest times) while the LFC represents the abnormal conditions (the activities are delayed and executed at the latest times). The float cost per day is then calculated by dividing the difference between the LFC and EFC by the total float. The following equation (De La Garza et al., 1991) is used to calculate the float cost per day:

$$\text{Total float cost per day} = \frac{\text{LFC} - \text{EFC}}{\text{TF}},$$

where EFC is the early finish cost; LFC the late finish cost; TF the total float.
Proposed resource leveling optimization model

A Non-Linear Integer Programming (NLIP) model is developed to solve the resource leveling optimization problem considering the total FLC. The NLIP model is formulated under the following assumptions:

- a uniform float cost distribution per day throughout the available float days;
- activities’ durations are constant;
- activity resource usage is constant throughout the duration of the activity; and
- once an activity starts, it cannot be interrupted.

Problem parameters

$I =$ a set of $n$ project activities, where project activities are denoted by the symbol $i \in I$, and $i = 1, 2, 3, \ldots, n$; $P =$ a set of $nc$ critical activities, where critical activities are denoted by the symbol $p \in P$, and $p = 1, 2, 3, \ldots, nc$; $Q =$ a set of $nn$ noncritical activities, where noncritical activities are denoted by the symbol $q \in Q$, and $q = 1, 2, 3, \ldots, nn$; $d_i =$ original duration of activity $i$; $DT =$ project duration; $ES_i =$ Early Start time of activity $i$; $EF_i =$ Early Finish time of activity $i$; $LS_i =$ Late Start time of activity $i$; $LF_i =$ Late Finish time of activity $i$; $OF_q =$ original total float of noncritical activity $q$; $CF_q =$ current total float of noncritical activity $q$; $FUC_q =$ total float unit cost of noncritical activity $q$; $LFC_q =$ late finish cost of noncritical activity $q$; $EFC_q =$ early finish cost of noncritical activity $q$; $R =$ resource quantity; $RCR =$ resource fluctuation cost rate; $NF =$ number of resource fluctuations; $RFC =$ resource fluctuation cost; $FLC =$ float loss cost; $TC =$ total cost (resource fluctuation cost (RFC) and FLC).

Problem decision variables

$S_q =$ Scheduled start time of noncritical activity $q$; $F_q =$ Scheduled finish time of noncritical activity $q$.

Problem constraints

The decision variables should satisfy two types of constraints: the activities logic constraints and the project duration constraint. Klansek and Psunder (2012) developed generalized precedence equations and used binary coefficients to indicate whether a relationship exists or not. Al Haj and El-Sayegh (2015) extended the formulations to include those related to the backward pass. This model extends the formulations to resource leveling considering float loss impact. There are four relationship types that are used in project scheduling. These are: finish to start (FS), start to start (SS), finish to finish (FF) and start to finish (SF). Binary coefficients are introduced to indicate whether the relationship exists or not. These coefficients are $FS_{ij}$, $SS_{ij}$, $FF_{ij}$ and $SF_{ij}$ where $i$ is the predecessor and $j$ is the successor. $L_{ij}$ represents the lag between two activities. The CPM calculations include two passes: the forward pass and the backward pass. The objective of the forward pass is to calculate the early start (ES) and early finish (EF) of all activities in the network and determine the project duration. A dummy start activity needs to be included to provide the starting point of the network. Similarly, a dummy finish activity is added at the end of the network. The early start ($ES_0$) of the first activity is set to 0 as per the following equation:

$$ES_0 = 0.$$  \hspace{1cm} (2)

The early start ($ES_j$) of the successor activity $j$ is calculated as the maximum early start value based on the constraints in the following equations corresponding to the four relationship types:

$$ES_j \geq EF_i + L_{ij}; \forall (i,j); FS_{ij} = 1,$$

$$ES_j \geq EF_i + L_{ij}; \forall (i,j); SS_{ij} = 1,$$

$$ES_j \geq EF_i; \forall (i,j); FF_{ij} = 1,$$

$$ES_j \leq EF_i + L_{ij}; \forall (i,j); SF_{ij} = 1.$$  \hspace{1cm} (3)

The early start ($ES_j$) of the successor activity $j$ is calculated as the maximum early start value based on the constraints in the following equations corresponding to the four relationship types:
The early finish (EF) is calculated using the following equation:

\[ EF_i = ES_i + d_i. \]  

(7)

The project duration is calculated as the EF of the last activity as per the following equation. At the same time, the late finish (LF) of the last activity is set as its EF:

\[ DT = LF_{END} = EF_{END}. \]  

(8)

The objective of the backward pass is to calculate the LF and the late start (LS) and of all activities. The late finish (LF) of activity \( i \) is calculated as the minimum LF value of its successors based on the constraints in the following equations corresponding to the four relationship types:

\[ LF_i \leq LS_j - L_{ij} \quad (i,j) \forall SS_{ij} = 1, \]  

(9)

\[ LF_i \leq LS_j - L_{ij} + d_j \quad (i,j) \forall SS_{ij} = 1, \]  

(10)

\[ LF_i \leq LF_j + d_j - L_{ij} \quad (i,j) \forall SF_{ij} = 1, \]  

(11)

\[ LF_i \leq LF_j - L_{ij} \quad (i,j) \forall FF_{ij} = 1. \]  

(12)

The LS is then calculated using the following equation:

\[ LS_i = LF_i - d_i. \]  

(13)

For resource leveling, the project duration should be fixed as only the non-critical activities are allowed to move within their float:

\[ EF_{END} = DT. \]  

(14)

**Objective function**

The objective of the optimization model is to minimize the total cost. The total cost includes the RFC and the FLC in noncritical activities. In order to calculate the number of fluctuations (NF), there is a need to introduce another binary variable \( b \) to indicate whether the activity is active in certain days. The total number of required resources is added for each time period \( t \). The period to period fluctuation is calculated as the absolute value of the difference between two successive periods. The total number of fluctuations is calculated by adding all period to period fluctuations as illustrated in the following equation:

\[ NF = \sum_{t=1}^{T-1} (ABS(TR_t - TR_{t+1}), \]  

(15)
where NF is the number of resource fluctuations; T the total number of time periods; TR\textsubscript{t} the total number of resources in period \( t \).

The following equation is used to calculate the RFC:

\[
RFC = RCR \times NF,
\]

where RFC is the resource fluctuation cost; \( RCR \) the resource fluctuation cost rate; NF the number of resource fluctuations.

The Float Unit Cost (FUC) for each noncritical activity is calculated using the following equation:

\[
FUC_q = \frac{LFC_q - EFC_q}{OF_q},
\]

where \( FUC_q \) is the float unit cost of noncritical activity \( q \); \( LFC_q \) the late finish cost of noncritical activity \( q \); \( EFC_q \) the early finish cost of noncritical activity \( q \); \( OF_q \) the original total float of noncritical activity \( q \).

The following equation is used to calculate the current total float of the noncritical activities:

\[
Cf_q = LF_q - F_q,
\]

where \( Cf_q \) is the current total float of noncritical activity \( q \); \( LF_q \) the late finish time of noncritical activity \( q \); \( F_q \) the scheduled finish time of noncritical activity \( q \).

The following equation is then used to calculate the extra cost due to FLC:

\[
FLC = \sum_{q=1}^{mn} FUC_q \times (OF_q - Cf_q)
\]

where \( FLC \) is the float loss cost; \( FUC_q \) the float unit cost of noncritical activity \( q \); \( OF_q \) the original total float of noncritical activity \( q \); \( Cf_q \) the current total float of noncritical activity \( q \); \( mn \) the number of noncritical activities.

The objective function (Equation (20)) can now be written through combining Equations (16) and (19) which results in a general equation for the total cost.

Minimize \( TC \):

\[
TC = (RCR \times NF) + \sum_{q=1}^{mn} FUC_q \times (OF_q - Cf_q)
\]

Model application example

The above formulation, for the resource leveling optimization problem considering float cost, can be solved by any available optimization packages. In this paper, “What's Best Solver 14.0” for Excel is used. An application example is developed. Table I shows the project information, along with the early and LFCs and total FUCs. In this example, the LFC and EFC are assumed for each activity in the project. The minimum, most likely and maximum duration for each activity will be used to validate the model and show the effect of float loss on project risk. Figure 1 shows the network diagram for the example project. The project duration is calculated to be 24 days. The critical path includes activities A, C, F, I and K. Activities B, D, E, G, H, J, L and M are noncritical activities. The FUC, in Table I, is calculated using Equation (17). For example, the FUC for activity “D” is calculated as follows:

\[
FUC_D = (\$4,500 - \$4,000) / 5 = \$100 \text{/day}
\]
The network was developed in Excel along with the constraints, decision variables and objective function. Figure 1 shows the initial schedule. For the forward pass, the ES and LF dates are calculated using Equations (2)–(8). For activity D, for example, the duration is four days and it has two predecessors (A and B) with FS relationships. Applying the precedence constraint for the FS relation based on Equation (3):

\[ ES_D \geq EF_A + L_{AD} \text{ and } ES_D \geq EF_B + L_{BD} \]

\[ ES_D \geq 5 + 0 \text{ and } ES_D \geq 3 + 0. \]

Therefore, \( ES_D = 5 \).

The early finish (\( EF_D \)) of activity D is then calculated using Equation (7):

\[ EF_D = ES_D + D_A, \]

\[ EF_D = 8 + 4 = 12. \]

The project duration is set to equal the EF of the last activity and is equal to 24 days. The LF of activity K is 24. For the backward pass calculations, Equations (8)-(13) are used. Activity B,
for example, has two successors (D and E) with FS relationships. Applying the precedence constraint for the FS relation based on Equation (9):

\[ LF_B \leq LS_D - L_{BD} \text{ and } LF_B \leq LS_E - L_{BE} \]
\[ LF_B \leq 10 - 0 \text{ and } LF_B \leq 12 - 0. \]

Therefore, \( LF_B = 10 \).

The late start (\( LS_B \)) of activity B is then calculated using Equation (13):

\[ LS_B = 10 - 3 = 7 \]

Figure 2 shows the resource histograms based on the initial schedule, leveled schedule using the traditional resource leveling method and the leveled histogram using the proposed method. For the initial schedule, the histogram shows that the maximum resource demand is 23 resources on days 9 through 11. The total number of period to period fluctuation is added to be 32 fluctuations. This is not the ideal scenario as these fluctuations are costly. The schedule was then leveled to minimize the fluctuations. The number of fluctuations dropped from 32 to 0 and the peak resource demand dropped from 23 to 14. This presents a significant improvement over the initial schedule. However, this resulted in moving all the noncritical activities within their float. The schedule was then optimized using the proposed method and considering the float loss impact. The number of fluctuations is 8.

Figure 3 shows the final schedule after leveling.

The activities’ start date (\( S_a \)), for the noncritical activities, are set to be adjustable parameters and linked to the network. As the network changes, activities’ start dates change and the calculations are done accordingly via the model. Table II shows the FLC calculations.
The original float values are fixed while the current float ($CF_q$) values vary according to the model calculations at each run. The values in the FUC column are calculated using Equation (17). The values in the “Current Float” and the “FLC” columns are calculated using Equations (18) and (19), respectively. For example, the current float for activity G is calculated using Equation (18) to be 0 days as compared to the original float of 5 days. This corresponds to a float loss of 5 days. The FLC of activity G is calculated by multiplying the float loss by the FUC to be $2,000. The total FLC is then added for all activities using Equation (19). The FLC is $5,600. The objective function is then set to minimize the total cost. The total cost consists of the resource fluctuations cost and the FLC. The RFC rate ($R_{C_R}$) is assumed to be $500 per fluctuation. The number of fluctuations is calculated, using Equation (15), to be 8. Therefore, the RFC is $4,000 (using Equation (16)). The total cost is $9,600 (using Equation (20)).

After developing the model and running it using What’s Best, the optimum schedule; without considering the total FLC, resulted in the minimum number of fluctuations of 0 (Figure 2). Therefore, the fluctuation cost is $0. However, this optimum solution resulted in the reduction of the available float of the noncritical activities. The FLC is calculated to be $10,900. This means that the optimum solution, focusing on minimizing fluctuations, resulted in a cost of $10,900. Using the proposed model, the total cost is $9,600.

In order to highlight the significance of incorporating the FLC into the resource leveling optimization problem, a comparison is performed between the results of the
traditional method and the proposed NLIP model in terms of schedule flexibility and the probability of timely project completion. Table III shows a comparison between the remaining float values for all project activities for the normal, traditional leveling and proposed method. Using the traditional resource leveling method, without considering FLC, most of the available float is lost, with only 3 non-critical activities (B, E and H). Using the proposed model, some floats are preserved. The proposed model offers better solution in terms of schedule flexibility as the non-critical activities have higher float values and there are more non-critical activities (B, E, H, L and M). The solution, using the proposed method, has fewer critical activities and paths. This means that the proposed method offers a more flexible schedule.

Monte Carlo Simulation was then used to calculate the Probability of Finishing (POF) the project on time using three scenarios: normal schedule, traditional resource leveling method and the proposed resource leveling method. Activity durations were assumed to follow triangular distribution with the minimum, most likely and maximum values presented in Table I. In total, 100,000 iterations were used to find the POF for each scenario. For the normal schedule, the mean duration was calculated to be 24 days with a standard deviation of 2.01 days. Therefore, the POF the project within 24 days was calculated to be 0.5. Using the traditional resource leveling method, the mean project duration was calculated to be 25.4 days with a standard deviation of 1.29 days. The POF the project within 24 days was calculated to be 0.135. Using the proposed resource leveling model, the mean project duration was calculated to be 25.12 days with a standard deviation of 1.33 days. Therefore, the POF the project within 24 days was calculated to be 0.202. This shows that the proposed model reduces the risk of project delays compared to the traditional resource leveling method.

Discussion of the results
The optimization model depends on two multipliers for the cost of resource fluctuations ($R_{C_d}$) and the FLC. To study the sensitivity of the objective function toward these parameters, sensitivity analysis is needed. The RFC rate is one value for the whole project. However, the FLC is different for each non-critical activity. Sensitivity analysis is performed by varying each of the two parameters between $-20$ and $+20$ percent with an increment of 10 percent. Figure 4 shows the sensitivity of the objective function to the variations in these two parameters. The RFC rate was varied between $-20$ ($400$) and $+20$ percent ($600$) while keeping the original float cost values. As shown in Figure 4, the corresponding variation in the objective function (total cost) varied between $-14.6$ and $+8.3$ percent. The FLC was

<table>
<thead>
<tr>
<th>Activity</th>
<th>Total float (initial case)</th>
<th>Total float (traditional method)</th>
<th>Total float (NLIP model)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>7</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>E</td>
<td>9</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>F</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>G</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>H</td>
<td>9</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>I</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>J</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>K</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>L</td>
<td>10</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>M</td>
<td>10</td>
<td>0</td>
<td>6</td>
</tr>
</tbody>
</table>

Table III.
Comparison of TF between the traditional method and the NLIP model.
varied between −20 and +20 percent for all noncritical activities while keeping the original RFC rate at $500. As shown in Figure 4, the corresponding variation in the objective function (total cost) varied between −11.7 and +5.8 percent. The objective function is more sensitive to the RFC than FLC.

Through experimentation with the model using different values for the cost of resource fluctuation and keeping the float costs at their original values, it is observed that this optimal project schedule will remain optimal when the RFC is between $488 and $662. For example, when the RFC is larger than $662, most of the float will be consumed to minimize the fluctuations to zero. In other words, the model reverts to the traditional resource leveling method. On the other hand, when the RFC drops below $488, the FLC becomes more significant and the optimum solution is reached with 16 fluctuations. Similarly, when the RFC drops below $172, the FLC becomes even more significant and the optimum solution is reached with 28 fluctuations. This same solution will be reached until the RFC drops below $94, in which case, resource leveling will not be recommended and the original schedule will be the optimum schedule. Table IV shows the results using different values of RFC.

The loss of float decreases schedule flexibility and increases the risks as it reduces the probability of timely project completion. The decision is dependent on the risk tolerance of the project manager. Some project managers may choose to have a completely leveled schedule regardless of the float loss. In that case, they may put a higher value for the RFC and the model reverts to the traditional resource leveling. In the example, that value should be greater than $662. In that case, the probability of timely project completion drops to 0.135. Other project managers may have less risk tolerance, yet they want to level the resources. In that case, the optimum schedule is reached with only eight fluctuations and the corresponding probability of timely completion is 0.202. Others may want to reduce the risk further. That can be accomplished by either increasing the FLC or decreasing the RFC.
If the project manager reduces the RFC to $400, the optimum solution is reached with 16 fluctuations and the corresponding probability of timely project completion increases to 0.261 (see Table IV).

**Summary and conclusions**

Leveling project resources is important for the successful delivery of construction projects as it reduces the costly fluctuations in resource demands and decreases their peak demands. Resource leveling is accomplished through moving the noncritical activities within their available float. This results in considerable float loss and decreases the schedule flexibility. Float is important to all project participants. The proposed resource leveling optimization model incorporates the extra cost resulting from float loss. This provides a more practical solution for project managers who desire an improvement to the resource profile while maintaining some schedule flexibility in the form of activity float. The resulting schedule will have fewer fluctuations than the original normal schedule. The schedule may have more fluctuations than those leveled using traditional methods. However, it will have higher float values. This preserves some flexibility in the construction schedule and reduces the schedule risks. The proposed model provides a solution that has a higher probability of timely project completion compared to the existing methods.

The proposed model provides project managers with a better tool to solve the resource leveling optimization problem in terms of schedule flexibility and risk. Construction projects are risky and there is a need to incorporate risk in scheduling decisions such as the resource leveling decision. This proposed model offers project managers a trade-off between a completely leveled schedule with minimum float and flexibility and a new solution with more float and flexibility. If resource fluctuations are more important, costly, than float loss, the project manager may put a higher RFC value in the model. The model then, works as the traditional methods and provides a solution that has the minimum fluctuations. However, if the float cost is higher, then the model will provide a better solution that minimizes the total cost of resource fluctuations and FLC.

The FLC was quantified using the float commodity equation. Future research may focus on finding other way to calculate the FLC. The proposed model was developed using NLIP which provides the optimum solution. As with all optimization models, the computational time increases as the problem scale increases. In real projects, with a large number of activities, the computational time will increase sharply. Future research may look into using metaheuristic techniques (such as Particle Swarm Optimization or Ant Colony Optimization) to provide a quicker solution. These metaheuristic techniques may not guarantee the optimum solution but will reduce the computational time.

<table>
<thead>
<tr>
<th>Resource fluctuation cost rate, $</th>
<th>Number of resource fluctuations</th>
<th>Resource fluctuation cost, $</th>
<th>Float loss cost, $</th>
<th>Objective function (total cost), $</th>
<th>Probability of timely project completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>32</td>
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</tr>
<tr>
<td>100</td>
<td>28</td>
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<td>3,000</td>
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<td>200</td>
<td>16</td>
<td>3,200</td>
<td>1,800</td>
<td>5,000</td>
<td>0.261</td>
</tr>
<tr>
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<td>16</td>
<td>4,800</td>
<td>1,800</td>
<td>6,600</td>
<td>0.261</td>
</tr>
<tr>
<td>400</td>
<td>16</td>
<td>6,400</td>
<td>1,800</td>
<td>8,200</td>
<td>0.261</td>
</tr>
<tr>
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<td>8</td>
<td>4,000</td>
<td>5,600</td>
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<td>10,900</td>
<td>10,900</td>
<td>0.135</td>
</tr>
</tbody>
</table>

Table IV. Effect of varying resource fluctuation cost
References


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Human resource management practices to improve project managers’ job satisfaction

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Abstract
Purpose – More attention should be paid to project managers’ (PMs) job satisfaction as they play an important role in ensuring projects are completed successfully. The purpose of this paper is to identify human resource management (HRM) policies and practices that lead to higher PMs’ job satisfaction.

Design/methodology/approach – A questionnaire survey was conducted on PMs who are working in construction firms and project management consultancy firms. Data were collected via random, convenience and snowball sampling. The data collected were analysed using partial least square-structural equation modelling, independent samples t-test and Pearson’s correlation.

Findings – The findings show that PMs who are satisfied with their firms’ HRM practices and job rewards also have higher job satisfaction. Several HRM strategies that give rise to higher job satisfaction are identified, e.g. a system to recognise and develop talent, and taking active steps to identify and develop backups in case of emergency. Unfortunately, some practices are not implemented to a significant extent, and these include: systematically recruiting and retaining talented PMs, encouraging PMs to plan for their careers, offering performance and development coaching, and appraising employees.

Research limitations/implications – The limitations include the low response rate and the relatively small sample size of 81. The profile of respondents is largely from construction companies with more than 150 staff, and, therefore, the findings are more applicable to medium- to large-sized construction firms.

Practical implications – The study identified many HRM practices and policies that are significantly associated with PMs’ job satisfaction, yet many of these are not implemented to a significant extent by the employers. The practical implication is that employers of PMs should systematically implement these in order that their PMs have higher job satisfaction which is important for a project’s success.

Originality/value – The originality of this research is that the HRM practices and policies that are associated with job satisfaction of PMs are uncovered. Its value is in showing that PMs derive greater job satisfaction when HRM policies encompass talent development, career coaching and a personalised management style. Among these important practices, those that have been neglected were also identified. The study offers recommendations on the HRM practices that firms should be put in place for their PMs to experience higher job satisfaction.

Keywords Human resource management, Talent development, Job satisfaction, Project managers, Job rewards, Career coaching

Paper type Research paper

1. Introduction
The construction industry is known to be labour-intensive (Jamshidi et al., 2012), relying largely on its human capital to meet project deliverables. Human capital is one of the most difficult resources for organisations to manage due to the individuality of each contributing
member (Loosemore and Dainty, 2003). Yet, effective human resource management (HRM) can ensure that employees are effectively used, company risk is reduced and the return on investment maximised.

Project managers (PMs) play a critical role in ensuring project success as they are responsible for a multitude of tasks that include the management of project scope, time, cost, quality and integration (Saladis and Kerzner, 2009).

Hence, the right HRM practices should be in place to retain construction industry professionals (Loosemore and Dainty, 2003) such as PMs, in order to attract and retain them (Chan and Dainty, 2007). A high turnover rate can lead to poor project performance and low competitiveness (Du et al., 2006). It has also been found that adopting the right HRM practices help to increase job satisfaction (Phua, 2012), and thereby reduce voluntary turnover. Generally, effective HRM can bring about significant benefits such as risk elimination, increased productivity and improved performance (Loosemore, 2000; Qureshi et al., 2009).

However, there are few studies on PMs’ perspectives on their firms’ HRM practices. It is not known if an organisation’s HRM practices would affect the job satisfaction of PMs. If they do, specific HRM practices that give rise to higher job satisfaction need to be identified to inform PMs’ employers.

The aim of this research is to investigate the association between HRM practices and PMs’ job satisfaction. The specific objectives are to: identify HRM practices that PMs are satisfied and dissatisfied with, examine HRM practices that give rise to higher job satisfaction and recommend HRM practices that firms could adopt to enable PMs to have higher job satisfaction.

This paper focuses on HRM practices that PMs in architectural, engineering or construction (A/E/C) firms in Singapore are subject to. Singapore is an open market economy and a developed country, and therefore the findings may be applicable to countries that operate on a similar system.

This paper is structured as follows. After the introduction, a literature review of job satisfaction and HRM is presented. This is followed by a description of the research method. The next section covers results and discussion. Finally, recommendations and conclusions are made.

2. Literature review

2.1 Job satisfaction

Job satisfaction is an overall measure of the degree to which the employee is satisfied and happy with the job (Hackman and Oldham, 1980). Job satisfaction and dissatisfaction are a function of the perceived relationship between what one wants from one’s job, and what one perceives it as offering or entailing (Locke, 1969). Hulin and Judge (2003) defined job satisfaction as psychological responses to one’s job, including cognitive (evaluative), affective (or emotional) and behavioural components.

Satisfaction with job rewards is one of the components of job satisfaction as it measures whether the job rewards can meet employee’s expectation (Balzer et al., 1997). Satisfaction with HRM practices measures the appeal of HRM practices (incentives, benefits, training, support from managers, employee engagement, etc.) (Alfes et al., 2013; Tran et al., 2013) to employees. Employees’ satisfaction with HRM practices is linked to their behaviour and intention to stay (Alfes et al., 2013; Kehoe and Wright, 2013).

It is important for PMs who work in the construction industry to have job satisfaction because improving job satisfaction helps in retaining valuable employees who can help sustain the company and decrease the turnover rate (Lee and Way, 2010). In a project team, when job satisfaction is met, team members feel internally connected with the project and are willing to work hard to make the project successful (Rezvani et al., 2016; Schmid and Adams, 2008).
2.2 Human resource management

HRM refers to policies and practices that influence an employee’s behaviour, attitudes and performance (Noe et al., 2012). HRM policies are the principles and guidelines while HRM practices are the specific methods to express the policies. How the policies are implemented and the effects perceived by employees might be different from the intention of the policies (Kinnie et al., 2005; Kooij et al., 2010). The five basic constructs of HRM that support high-performance work systems are staffing, work design, training, compensation and performance management.

2.2.1 Staffing. HRM starts with the staffing process. Some avenues whereby job opportunities are made known and filled include advertising in print media (Noe et al., 2012), headhunting, word-of-mouth recommendation (Raidén et al., 2009) and choosing those who are related to existing staff (Hutchings and Weir, 2006).

Selection methods vary across different companies and industries. Interviews are commonly used but can be unreliable and biased when not properly handled (Posthuma et al., 2002). Noe et al. (2012) also suggested a variety of tests such as physical ability, psychometric and technical skill tests to pick potential candidates. It is not known which types of selection method are effective in the recruitment and selection of PMs.

2.2.2 Work design. Noe et al. (2012) proposed that work design should include the following features: participation in planning changes, work being organised in teams, job rotation to develop skills, use of a variety of skills, opportunity for decision making and access to information. Among these, it is not known if PMs prefer HRM practices that give them opportunities to make decisions and access to information.

2.2.3 Training. The next element of HRM is training. Bratton and Gold (2003) stressed the importance of maintaining and developing employees’ existing capabilities. Training can help employees feel more valued (Sisson and Storey, 2000), which increases their motivation and loyalty to the company. Fraser (2000) discovered that employees who have attended some training are likely to be more effective in their work, but it is hitherto not known if this is useful for PMs.

2.2.4 Compensation. HRM involves setting up a system to reward and retain contributing employees, motivating them to strive for the best while attracting suitable candidates for the job (Tan and Torrington, 2004). A reward system can be classified broadly as monetary and non-monetary. For a reward system to be effective, it has to be adequate, equitable, balanced, cost-effective, incentive-providing and accepted by employees (Patton, 1997).

2.2.5 Performance management. Performance management has a dual functionality to focus on maximising individual, team and organisational performance while facilitating employees’ career development (Raidén et al., 2009). Seeking employee feedback allows the management to identify the areas that they are doing right and those that need improvement, and helps to foster an environment of trust and respect (DeVoe, 1999).

Another aspect of performance management is the performance appraisal. It is a sensitive process as it involves measuring an employee’s contribution towards company objectives with the purpose of deciding rewards and penalties (Loosemore and Dainty, 2003). Performance appraisal should be employee centric to help them improve their performance (Mullins, 1999). However, in construction industry, the assessors, usually the PM’s supervisors, are unable to assess the individual’s day-to-day performance as there is disparate locale problem (Druker and White, 1995).

2.3 HRM and project managers

HRM practices need to be carefully crafted for project-based employees such as PMs. Companies need to assign an optimal number of projects to such employees in order for...
them to meet their career aspirations but not overload them as this causes burnout or work-life imbalance (Turner et al., 2008). Companies also need to craft their HRM practices carefully to ensure employees working in a rapidly changing project-based environment are treated well and ethically (Huemann, Keegan and Turner, 2007; Huemann, Turner and Keegan, 2004).

2.4 HRM practices and job satisfaction
Organisational behaviour theory proposes that appropriate use of people improves organisational effectiveness, and when mediated by effective HRM, these employees have lower intention to leave and better job satisfaction (Koys, 2001). Studies have found that HRM practices have significant positive association to job satisfaction (Kaya et al., 2010; Mudor and Toossoon, 2011; Majumder, 2012). Kinnie et al. (2005) found that satisfaction with some HRM practices is linked to commitment to job, which is also related to job satisfaction. These studies did not focus on PMs in the construction industry. For example, Kaya et al. (2010) and Majumder (2012) investigated the banking sector while Parvin and Kabir (2011) studied pharmaceutical sector.

2.5 Knowledge gap
Lim and Ling (2012) investigated the HRM practices adopted by construction firms that give rise to job satisfaction of their professional staff. Their sample comprised largely engineers and quantity surveyors, with little emphasis on PMs. Phua (2012) found that the job satisfaction of construction professionals is higher when their HRM preference matches the practices adopted in their organisations. The study did not investigate the specific HRM practices that give rise to job satisfaction. While some studies covered HRM in construction projects (e.g. Loosemore and Dainty, 2003), hitherto, no comparison has been made between the satisfactory and the unsatisfactory HRM practices of construction firms. It is also not known if PMs are satisfied with the HRM practices adopted by construction firms. There are also few studies on PMs’ perspectives on their company’s HRM practices. The fieldwork was, therefore, undertaken to fill the knowledge gap.

3. Research method
Using the survey research design, a questionnaire with three sections was drawn up based primarily on Noe et al. (2012). The first section gathered general information on the PM respondents and their firms. The second section sought information on the HRM practices of respondents’ firms gleaned from the literature review. The final section asked respondents for their perspectives on their firms’ HRM practices. A pilot test of the questionnaire was conducted with three PMs and minor changes were made.

The population was PMs who worked in Singapore’s construction industry. The sampling frame comprised PMs from construction firms that are registered under the General Building and Civil Engineering workheads of the Singapore Building and Construction Authority. The samples were randomly selected and augmented with convenience and snowball sampling to increase the sample size.

The data collected were analysed using the SPSS software. Besides descriptive statistics, t-test of the mean, independent samples t-test and correlation analysis were conducted.

4. Characteristics of the sample
A total of 430 questionnaires were sent out via e-mail and postal mail to construction firms. In total, 81 completed questionnaires were collected, giving a response rate of 19 per cent, which is usual for surveys of this nature. Among the returned questionnaires, 65, 19 and 16 per cent were based on convenience sampling, random sampling and snowball sampling, respectively.
All the respondents were from different companies. In total, 73 per cent of them work as PMs in construction firms while the other 27 per cent were PMs for project management consultancy firms. The projects that they were involved in have clear start and end dates, and typically do not last more than three years.

The profiles of the respondents and their firms are presented in Table I. The respondents were all PMs, with the majority having more than ten years of experience in the construction industry. The firms are well distributed in terms of number of employees. In total, 89 per cent of the respondents’ firms have an HR department, which suggests that most firms recognise the need for an HR department to maximise the potential of their employees. Respondents were asked to indicate their level of satisfaction with the HRM practices implemented by their firms on a seven-point scale, where 1 = extremely not satisfied, 4 = neutral and 7 = extremely satisfied. The responses were classified into three categories (dissatisfied = ratings of 1, 2 and 3; neutral = rating 4; and satisfied = ratings of 5, 6 and 7). Table I shows that 25 per cent of the PMs are dissatisfied with their firms’ HRM practices, 34 per cent are neutral and 41 per cent are satisfied with the practices.

The relationships between satisfaction with different types of rewards, HRM practices and job satisfaction were explored using the partial least square-structural equation modelling (PLS-SEM). PLS-SEM was chosen because it can estimate the complex cause-effect relationships between different practices and satisfaction categories. Four measured variables (i.e. satisfaction with salary (R1), promotion opportunities (R2), welfare package (R3) and total package (R4)) were labelled as satisfaction with job rewards (Y1). The PLS-SEM results show factor Y1 has adequate reliability and validity (see Table II). All loadings are greater than 0.50 with t-values greater than 2.58 (Hulland, 1999). This indicates acceptable indicator reliability. There is a high level of reliability of internal indicators within each factor as the values of composite reliability are over 0.7 (Baggozzi and Yi, 1988). A satisfactory level of convergent

<table>
<thead>
<tr>
<th>Description</th>
<th>Number</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Respondents’ experience in construction (years)</td>
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<tr>
<td>⩽5</td>
<td>13</td>
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</tr>
<tr>
<td>&gt; 5–10</td>
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<td>&gt; 15–20</td>
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<td>21.0</td>
</tr>
<tr>
<td>&gt; 20</td>
<td>11</td>
<td>13.6</td>
</tr>
<tr>
<td>Type of firm</td>
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<tr>
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</tr>
<tr>
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</tr>
<tr>
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<tr>
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<tr>
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</tr>
<tr>
<td>&gt; 450 staff</td>
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<tr>
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<td></td>
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</tr>
<tr>
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<td>11.1</td>
</tr>
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<td>Table I. Characteristics of respondents and their firms</td>
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<td></td>
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<tr>
<td>Satisfaction with firm’s HRM practices</td>
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<td>Dissatisfied</td>
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<tr>
<td>Neutral</td>
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</tr>
<tr>
<td>Satisfied</td>
<td>33</td>
<td>40.7</td>
</tr>
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</table>
validity of the factors was achieved by examining the values of the average variance extracted more than 0.5.

Figure 1 shows the two path coefficients of the PLS-SEM model are significant. The path coefficient between Y1 and Y2 (Satisfaction with HRM practices) is 0.794, while the path coefficient between Y1 and Y3 (Job satisfaction) is 0.718. The result indicates that a higher satisfaction with the job rewards offered (Y1) leads to higher job satisfaction (Y3). In addition, when PMs are more satisfied with their firms’ job rewards (Y1), they have higher satisfaction with the HRM practices of their firms (Y2). The results indicate that when PMs are more satisfied with their job rewards (measured by salary (R1), promotion opportunities (R2), welfare package (R3) and total compensation package (R4)), they also have higher job satisfaction (Y3) (see results in Table V).

The PLS-SEM test did not show a significant causal relationship between satisfaction with HRM practices (Y2) and job satisfaction (Y3). However, significant correlation between Y2 and Y3 is found in the Pearson’s correlation analysis (see Table V, r = 0.562, p = 0.000). This indicates a significant association between PM’s satisfaction with the HRM practices of their firms and their overall job satisfaction.

<table>
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<tr>
<th>Indicators</th>
<th>Loadings</th>
<th>t-value</th>
<th>Factors</th>
</tr>
</thead>
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<td>R1: satisfaction with salary</td>
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<td>27.98</td>
<td>Y1 Satisfaction with rewards</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Composite reliability = 0.880</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Average variance extracted = 0.648</td>
</tr>
<tr>
<td>R2: satisfaction with promotion opportunities</td>
<td>0.757</td>
<td>8.352</td>
<td>Y1 Satisfaction with rewards</td>
</tr>
<tr>
<td>R3: satisfaction with welfare package</td>
<td>0.716</td>
<td>7.943</td>
<td>Y1 Satisfaction with rewards</td>
</tr>
<tr>
<td>R4: satisfaction with total compensation package</td>
<td>0.879</td>
<td>29.040</td>
<td>Y1 Satisfaction with rewards</td>
</tr>
<tr>
<td>Y2: satisfaction with HRM practices</td>
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<td>–</td>
<td>Y2 Satisfaction with HRM practices</td>
</tr>
<tr>
<td>Y3: job satisfaction</td>
<td>1.000</td>
<td>–</td>
<td>Y3 Job satisfaction</td>
</tr>
</tbody>
</table>

Table II. Measurement model evaluation

Notes: Numbers linking Y1 and R1 to R4 are the factor loadings. ***p<0.001

Human resource management practices

Figure 1. Relationship between satisfaction with the job, rewards and HRM practices
5. Results and discussion of HRM practices

In the survey, respondents were asked to indicate the HRM practices adopted by their firms and their satisfaction with compensation and promotion. The results are shown in Tables III and IV, respectively. The responses were categorised according to how the PMs felt about their firms’ HRM practices: dissatisfied, neutral or satisfied.

5.1 Recruitment and selection

Table III shows that among the different recruitment methods, filling job vacancies through recommendation is the most frequently used method (42.0 per cent), and among PMs who are satisfied with their firms’ HRM, this is also the most often used method (n = 11). Hiring staff via recommendation or contacts can be a source of high-quality applicants, especially in the case of employee referrals since the referring employees have to vouch and put their reputation on the line for the person they are recommending into the company (Vijava, 2012). Recruiting through friends and recommendations has the downside of not leveraging on diversity and ending up with a socially homogenous group of employees (Marsden, 1994). The second most frequent recruitment method is through websites, but the relative low usage (19.8 per cent) suggests that companies are not leveraging on various internet platforms for recruitment purposes.

Table III shows that the majority (92.6 per cent) of the PMs were selected through interviews, followed by the technical skill selection test (21 per cent). Posthuma et al. (2002) have also found that the interview method is consistently used by most companies. Technical skill selection test allows employers to assess the competency of applicants as well as the claims they make in their resumes. A large proportion of PMs who are satisfied with their firms’ HRM practices were selected through interviews (n = 29).

5.2 Work design

Table III shows that most of the decision makers in projects are the team members (44.4 per cent) and PMs (42 per cent). The final authorities in decision making are: project directors (50.6 per cent), PMs (29.6 per cent) and project team (19.8 per cent). Among PMs who are dissatisfied with their firms’ HRM, a large number of them are the final authority in decision making (n = 9 out of 20). On the other hand, among PMs who are satisfied with their firms’ HRM, in majority of the cases, the project directors as the final decision-making authority (n = 20 out of 33).

The result indicates that most construction companies appoint someone in senior management to be held accountable, and this is also what PMs prefer. While Noe et al. (2012) found that decentralised decision-making results in high-performance work, this study found that PMs are more satisfied when their directors have the final authority in decision making. This could be attributed to the time-consuming and costly nature of the decisions in construction projects. A higher-ranking employee in the organisation is also likely to have more expertise and experience to make well-informed decisions to ensure the project deliverables are met, and this takes away much of the pressure from PMs.

Information sharing is another component of work design to produce high-performance employees. The questionnaire requested PMs to rate the level of accessibility of information in their firms, with 1 being highly inaccessible and 7 being highly accessible. Table IV shows that accessibility of information (B3) is significantly high (mean = 4.98; p = 0.000). Table IV also shows that there is significant difference in the ratings for this item between PMs who are satisfied with, neutral or dissatisfied with their firms’ HRM practices. Those who are satisfied with their firms’ HRM practices have significantly better access to information than those who are neutral or dissatisfied. This suggests that effective HRM requires companies to give PMs adequate access to information. Companies should adopt practices aimed at increasing the accessibility and retrieval of information by PMs.
### Human Resource Management Practices

#### Recruitment and Selection

<table>
<thead>
<tr>
<th>Description</th>
<th>PMs dissatisfied with firms' HRM (n = 20)</th>
<th>PMs neutral about firms' HRM (n = 28)</th>
<th>PMs satisfied with firms' HRM (n = 33)</th>
<th>Total responses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% out of Total No.</td>
<td>% out of Total No.</td>
<td>% out of Total No.</td>
<td>% out of 81 No.</td>
</tr>
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</tr>
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<tr>
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<td>Project manager</td>
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<td>26.5</td>
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<td>35.3</td>
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<td>22.2</td>
<td>14</td>
<td>38.9</td>
</tr>
<tr>
<td>Director</td>
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<td>31.3</td>
<td>4</td>
<td>25.0</td>
</tr>
<tr>
<td>Final authority in decision making</td>
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<td>Project manager</td>
<td>9</td>
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<td>Director</td>
<td>7</td>
<td>17.1</td>
<td>14</td>
<td>34.1</td>
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<td><strong>Training and development</strong></td>
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<td>Voluntary basis/express interest</td>
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<td>27.3</td>
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<td>Frequency of training</td>
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<td>18.8</td>
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Table III. Breakdown of HRM practices in PMs' firms (continued)
Measures include centralising the information database, converting archives of past projects to softcopy and uploading it to the company’s intranet. This will improve PMs’ accessibility to information that can assist them in making informed and timely decisions, thereby improving schedule performance.

5.3 Training and development
Table III shows that while the majority (61.7 per cent) indicated that supervisors determined who could be selected for training, and 54.3 per cent reported they were allowed to express their interest in being selected for training. However, what stands out for firms where PMs are satisfied with the HRM practices, as compared to those who are not satisfied, is that the selection for training is based on merit or performance (54.5 per cent satisfied).

In terms of frequency of training as stipulated in company HRM practices, the majority have at least one training annually, with some twice or four times a year. In firms where PMs are more satisfied with their HRM practices, the policy is to send PMs for training once every six months (50 per cent satisfied). The majority (88.9 per cent) of the respondents had attended at least one training programme in the last 24 months. Attending more training courses does not necessarily make PMs more satisfied because work piles up when they are...
away, and they may be required to catch up on work at night or put in extra hours when they return to work (Nilson, 1999). The type of trainers impacts the learning process of the individuals. The majority (66.7 per cent) had a mix of external and internal trainers (Table III). When firms adopt a mix of internal and external trainers, there is lower percentage of PMs who are unsatisfied (16.7 per cent unsatisfied). External trainers are usually trained personnel from external agencies with the necessary knowledge and presentation skills to deliver the desired material. In comparison, in-house trainers cost less and have more hands-on experience. A mix of trainers is recommended to leverage the advantages of both to provide a more comprehensive learning experience for the PM.

It is no surprise safety training is the most prevalent (82.7 per cent), followed by training in regulations (65.4 per cent) (see Table III). This is in part due to the need to be informed of fast changing workplace safety and health regulations and to comply with them. Companies know that if there are safety violations, their construction sites may be compulsorily shut down by the authorities through the issuance of stop work orders, and safety breaches have significant repercussions on a project’s progress.

### 5.4 Compensation

Besides the basic salary, the top three items in PMs’ compensation package are: medical benefits (93.8 per cent); transport allowance (80.2 per cent); and mobile phone allowance (80.2 per cent), and PMs who are satisfied with their firms’ HRM practices also receive these benefits (see Table III). The finding is consistent with Lim and Ling (2012) who found that employees with adequate medical insurance coverage also have higher job satisfaction.

Table IV shows that overall, PMs are significantly satisfied with their salary (R1), promotion opportunities (R2), welfare package (R3) and total compensation package (R4). When comparing across the three groups of respondents (dissatisfied, neutral and satisfied with HRM practices), the level of satisfaction with compensation and promotion in each group goes up when the group is more satisfied with the firms’ HRM practices. The implication is that firms need to pay close attention to HRM practices pertaining to compensation and promotion in order to retain their staff.

### 5.5 Performance management

Giving feedback to employees is as essential as receiving feedback from them to foster an environment of trust and respect (DeVoe, 1999). However, 18.5 per cent of the respondents reported there is no collection of feedback in their firm and many of the PMs in these firms are dissatisfied with the HRM (46.7 per cent) (Table III). This diminishes an avenue whereby employee commitment to the company can be developed as employees lack a channel to voice their concerns and suggest improvements (Donnelly, 2010). Firms that collect feedback do so through online system (35.8 per cent), oral response (32.1 per cent) and feedback boxes (22.2 per cent). PMs who are able to give feedback anonymously are more satisfied with their firms’ HRM practices (45.9 per cent). Feedback may require the condition of anonymity if it is sensitive or controversial (e.g. whistleblowing). In addition, while the collection of feedback is important, management must also act on the feedback received to foster a two-way trust and communication (DeVoe, 1999).

Table III shows that performance appraisal is usually conducted by the immediate supervisor (65.4 per cent), and/or senior management (60.5 per cent). A larger percentage of those who are satisfied with their firms’ HRM practices are appraised by senior management (46.9 per cent). Appraisal by peers and subordinates was virtually non-existent although it is a crucial component of the 360-degree appraisal system that is extensively encouraged by academics (Walker and Joines, 2004; O’Boyle, 2013). This may be because not many companies in Singapore see the benefits of investing resources in implementing the
360-degree appraisal system or they feel that peers may have conflict of interest when rating
their colleagues as they are seen as competitors.

Table III shows that the appraisal results were made known to the majority of the PMs (64.2 per cent), with significantly more of those (25 of 52 or 48.1 per cent) who are satisfied with their firms’ HRM practices enjoying this privilege. This way, PMs will have a better understanding of the areas they have done well in and those that need improvement, which will assist them in their career progression planning. For appraisals to be effective, discussions on career development and performance should be conducted separately as a performance discussion may contain criticisms that may distract attention from matters on career progression that require individuals to be constructive (Lawler et al., 2012).

6. Job satisfaction and HRM practices

Objectives 2 and 3 were to identify HRM practices that give rise to higher job satisfaction and recommend them for adoption, respectively. Based on Pearson’s correlation analysis, several HRM practices that are significantly correlated with a PM’s job satisfaction are identified (see Table V).

The first set of HRM practices that are significantly correlated with job satisfaction relate to talent development. Of these, companies need to recognise the need to develop talent (X1), be willing to develop talent (X2), be aware of the objectives of talent development (X4), and take active steps to identify and develop backups (X5) to ensure business continuity. To increase the job satisfaction of PMs, it is recommended that firms adopt more of the following HRM practices: assess individual potential (X6), and recruit (X7), develop (X10), and retain (X21) talented people as these practices are hitherto not adopted to a significant extent. It is further recommended that supervisors model development by developing themselves (X24). Talent development is important for attracting and retaining talented PMs, and also for their career development (Noe et al., 2012; Mehdiaabadi and Li, 2016).

The next set of HRM practices relate to coaching. All the HRM practices under coaching are significantly correlated with a PM’s job satisfaction, but none of these are adopted to a significant extent (Table V). Firms hiring PMs are recommended to encourage them to plan for their career (X11), and offer them career counselling (X12),
performance coaching (X13) and development coaching (X14) as these may give rise to higher job satisfaction. Career coaching gives PMs the satisfaction that there is supportive and developmental career management in their firms (Segers and Inceoglu, 2012). The results further show that appraising PMs (X15) is significantly correlated with job satisfaction, although this is not done to a significant extent. Appraisal is a form of performance evaluation that can improve the performance of both employees and organisations (Javidmehr and Ebrahimpour, 2015).

The final set of HRM practices that are significantly correlated with job satisfaction is the contextual management of PMs. Table V shows that when supervisors know how to get work out of PMs effectively (X3) and know how to work with a diverse group of PMs (X22), PMs tend to have higher job satisfaction. It is recommended that organisations be more effective in managing PMs who have high potential (X17) and are highly professional (X18), as doing so gives higher job satisfaction. When employees with high potential are well managed, they perceive that there is distributive justice (Gelens et al., 2014), and this may lead to higher job satisfaction.
From the literature review, 25 HRM practices are identified. Among these, 18 practices are found to be significantly correlated to job satisfaction. The other 7 (X8, X9, X16, X19, X20, X23 and X25) do not affect job satisfaction significantly (see Table V).

7. Limitations of the study
This study has several limitations. They include the low response rate and the relatively small sample size. A higher response rate will give a more holistic representation. Also, the profile of respondents is largely from construction companies with more than 150 staff. This suggests the findings are more applicable to PMs working for contractors in medium- to large-sized firms. It is recognised that the results of the correlation analysis between HRM practices and job satisfaction cannot be construed as causation. As such, the findings need to be interpreted carefully.

8. Conclusion
This study investigated the HRM practices adopted in PMs' firms and PMs' job satisfaction vis-à-vis their satisfaction with their firms' HRM practices and rewards. Data were collected via a questionnaire from 81 PMs, the majority of whom have more than ten years of experience. Using PSL-SEM, it is found that satisfaction with job rewards leads to job satisfaction.

The first objective was to compare and contrast the HRM practices of firms that PMs are satisfied with or dissatisfied with. Compared to those firms where PMs are dissatisfied with the HRM practices, the firms where PMs are satisfied adopted the following HRM practices: using more external consultants to recruit PMs; subjecting potential hires to cognitive tests; letting project directors be the final decision makers instead of loading this responsibility on PMs; selecting PMs for training based on merit; sending them for training at least twice a year; and having a mix of in-house and external trainers. PMs who are satisfied with their firms' HRM practices want to be able to give feedback anonymously, be appraised by senior management, and be told of their appraisal outcome. The findings add to knowledge as they inform firms on what they could do in crafting HRM practices to give rise to satisfaction.

The second and third objectives are to examine HRM practices that are significantly correlated with job satisfaction, and recommend HRM practices that firms could adopt to enable PMs to have higher job satisfaction, respectively. The correlation result shows that talent development is significantly correlated with job satisfaction, but is not always adopted to a significant extent. In addition, career coaching of PMs is not done enough, although this would give rise to higher job satisfaction. It is recommended that organisations invest time and effort in career coaching as this has been found to increase job satisfaction, and also the value offering of employees to the organisation. Finally, it is recommended that PMs be managed in a contingency or contextual style rather than with a one-size-fits-all approach.

The results in Table V show significant correlation between Y2 and Y3. This contributes to knowledge as it informs firms that they should set up their HRM practices carefully as these have deep implications for PMs' job satisfaction.

References


Nilson, C.D. (1999), How to Start A Training Program: Training is a Strategic Business Tool in Any Organization, American Society for Training & Development, Alexandria, VA.


Further reading


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Abstract

Purpose – The purpose of this paper is to develop and explain an empirically validated scale to measure service quality for architects in India.

Design/methodology/approach – This study applies a systematic procedure for development of a psychometric scale in three phases. Phase 1 includes item generation and selection through review of literature and expert opinion. Phase 2 comprises scale refinement using item analysis and exploratory factor analysis. Phase 3 applies confirmatory factor analysis (CFA) for establishing convergent, discriminant and nomological validity. This study has involved 15 expert participants in Phase 1 and sought participation from 250 respondents using an online questionnaire in two other independent phases.

Findings – The findings of the empirical study resulted in the development of a 22-item scale that measures the constructs such as design quality, project administration quality, communication quality, relationship quality and dependability quality.

Research limitations/implications – This study has developed a context-specific psychometric scale of service quality for architects in India using snowball sampling. Although this study identified five valid service quality factors, the classified information relating to the formation of expectations was not collected.

Practical implications – This reliable and valid scale would be helpful for architects to measure the level of service quality in enhancing business performance. This study has established that service quality for architects is achieved only when the perceived benefits are available from the aspects like design, project administration, communication, relationship and dependability.

Social implications – This study can facilitate an architect interested in opportunities relating to contracting, consulting and engineering to explore possibilities of higher fees from clients.

Originality/value – This study is an original attempt in developing a validated tool to measure service quality of architects in India.

Keywords Design, Architecture, Management, Integrated practice

1. Introduction

In architecture, uncertainty and turbulence in a business environment may bring progressive sophistication in design and construction. Such complexities arise principally because of changes within the construction sector and advances in numerous innovative technologies (Alharbi et al., 2015). Although the modern advances in architecture in India owe a great deal to the western architectural styles of the twentieth century since the Second World War (Colquhoun, 2002), these dynamics in changes and advances might reshape the character of service quality for architects. Service quality is being considered parallel to the increasing dominance of the services sector in an economy aspiring to meet growth needs (Forsythe, 2016).

Further, regardless of these complexities, architects typically make the initial decision on the construction type appropriate for a built project in India (Deobhakta, 1997). Several pieces of information are required to determine the type of construction needed. Many a times, the required information is not included in the content of building codes and regulations, as it is considered to be advisory (Baird, 2010). Often, the advisory solutions are
not documented in a way that allows their use as law (Wates, 2014). This results in challenges in planning and designing work for architects in India; a country which is a booming economy attracting productive investment flows in areas like construction, real estate, infrastructure and similar other projects. Yet the profession of architecture in globalized India is restricted to a handful of architects belonging to a specialized architectural wing of civil engineering, whose numbers are not more than 60,000 in a population of over 1.25 billion (Khan, 2016). This turns out to be only 48 architects for each million residents in India.

Given the magnitude coupled with the variety of buildings to be constructed in developing India, it is an exciting time to be an architect, only if opportunities and challenges are embraced with adequate service quality. The study on service quality for architects in India can be beneficial from two perspectives; first, it will contribute to realize the true potential of their discipline; second, it pre-empts faulty architectural planning (Day and Barksdale, 1994). Further, service quality can benefit architects in other ways as well like from promoting themselves to providing clients a positive experience (Baker and Lamb, 1994). However, an empirically validated scale to measure service quality of architects is not found in the extant literature. To fill this major research gap, this study attempts to develop and explain an empirically validated psychometric scale to measure service quality for architects in India based on responses from the users of architectural services like contractors, developers, consultants and owners of commercial and industrial real estate.

This paper is organized into four major sections. In the first section, a systematic review of literature on service quality has been presented. The second section discusses a standard scale development procedure for developing an empirically validated psychometric scale. The results of the study are discussed in the third section. The study concludes in the last section with research contributions, implications, limitations and directions for the future research.

2. Review of literature

Johnston (1999) defined service quality as “customers’ overall impression of an organization’s services in terms of relative superiority or inferiority.” Furthermore, literature on evaluation of service quality is overwhelmed with a wide variety of attributes. Grönroos (1982) with the Nordic way of thinking suggested two factors for service quality namely, “technical quality” and “functional quality.” Parasuraman et al. (1985) with the American way of thinking initially suggested ten dimensions to evaluate service quality, which were perhaps the most widely accepted dimensions. Later in 1988, Parasuraman et al. fine-tuned these ten into five dimensions in their SERVQUAL survey instrument namely “tangibility,” “reliability,” “responsiveness,” “assurance,” and “empathy.” Parasuraman et al. (1985, 1988) argued that the service delivery process can be broken down into specific stages to be measured according to the gaps in customer perceptions when benchmarked against customer expectations for measuring service quality. Despite critical debate about SERVQUAL (Babakus and Boller, 1992; Brown et al., 1993; Carman, 1990; Cronin and Taylor, 1992, 1994; Parasuraman et al., 1991, 1993, 1994a, b; Teas, 1993), it has retained its longevity and endurance due to its psychometric advantages to diagnose service quality in comparison to competing instruments like SERVPERF (Cronin and Taylor, 1994; Cronin et al., 2000; Jain and Gupta, 2004).

One of the earliest applications of service quality in the construction industry was seen in analyzing its behavioral determinants in the real estate brokerage industry (Johnson et al., 1988). In the past, only Baker and Lamb (1994) had attempted to determine what specifically constituted service quality in the context of commercial architectural design gathering data from in-depth interviews with just 11 subjects where participants were asked to expand
on what they meant by fine-tuned five dimensions of SERVQUAL. New practices are emerging in architecture, engineering and construction comprising real estate and infrastructure known as integrated practice. This practice facilitates architects, engineers, construction managers, and contractors to work together either as fully integrated firms or in multi-firm partnerships. Therefore, this study reviews service quality with reference to the integrated practice in the construction industry.


These notable studies have been assumed to be developed sequentially, providing a continuous updatation and learning from the findings of the predecessors to draw issues suitable for comparative evaluation. As the application of service quality to the integrated construction industry seems to be quite broad, the following 17 issues are considered suitable for comparative evaluation of these notable studies:

(1) involves architects;
(2) involves construction engineers and managers;
(3) involves contractors;
(4) involves customers;
(5) involves tenants;
(6) reviews prior literature;
(7) hierarchical representation to achieve original service quality measurement;
(8) hierarchical representation to use SERVQUAL-based dimensions;
(9) reports of exploratory factor analysis (EFA);
(10) reports of confirmatory factor analysis (CFA);
(11) empirical research involving anecdotal evidence/examples;
(12) empirical research involving descriptive reporting of overview;
(13) empirical research using case study;
(14) empirical research involving hypotheses testing;
(15) adequate theoretical foundations for postulated structural relations;
(16) develop a link for measurement of customer satisfaction; and
(17) develop a link for measurement of patronage intension.
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**Note:** The markings "✓" denote that the issues (in rows) are present in particular study’s model (in columns)
The findings of evaluation of service quality studies are presented in Table I. An extensive and interesting literature on the measurement of service quality has emerged since 1994. Some essential learning points are as follows:

- Several authors have suggested that service quality is a hierarchical construct. However, very few like Sunindijo et al. (2014) have attempted for original measurement for construct service quality.

- Almost all studies have made an attempt to review prior literature relating to service quality in the domain of integrated practice.

- Most of the empirical studies since 2008 have involved tenants and customers as respondents in applying hierarchical representation using SERVQUAL-based dimensions.

- Only Sunindijo et al. (2014) applied EFA in the domain of integrated construction industry.

- No study has been reported so far using CFA showcasing psychometric properties of the service quality scale.

- Although some studies have attempted to develop a link for measuring customer satisfaction and patronage intension, only recently adequate theoretical foundations have been seen postulated for structural relations among constructs relating to service quality (Sunindijo et al., 2014; Eldejany, 2016).

As most of these studies are tailored to suit the context of specific markets in construction industry such as building maintenance, engineering, building surveying, housing refurbishment and real estate, there is a need to do a study for service quality of architects. Just specific to service quality of architects, only the study by Baker and Lamb (1994) has been found to be of high relevance. Consequently, an emphasis has been placed on their adaption of SERVQUAL assured with adequate psychometric advantages.

3. Methodology

This study employs the scale development paradigm of Churchill (1979) which got augmented subsequently by Nunnally et al. (1994), and Patyal and Koilakuntla (2015). This study has divided the procedure of scale development into three independent phases. The procedure has been shown in Figure 1.

Phase 1 makes a qualitative inquiry that includes item generation and selection through a review of literature and expert opinion. Phase 2 deals with scale refinement using EFA and reliability analysis. For the pilot study involving EFA, a non-probabilistic snowball sampling method is adopted and a total of 250 respondents were approached, of which 115 useful responses were obtained, corresponding to a response rate of 46 percent. Phase 3 deals with scale validation that applies CFA for establishing convergent, discriminant and nomological validity. In phase 3, the snowball sampling method was adopted again to approach a total of 250 independent respondents, of which 160 useful responses were obtained, corresponding to a response rate of 64 percent. The target respondents in both phases were ensured to be users of architectural services like contractors, developers, consultants and owners of commercial and industrial real estate. Table II depicts the profile of these respondents in Phase 2 and Phase 3.

3.1 Phase 1: qualitative inquiry

3.1.1 Conceptual definitions. This is the first step in the development of an instrument of service quality for architects. The items of service quality for architects were adopted after a systematic review of the literature. In order to keep similar level of understanding about the
construct “service quality” for respondents, most of the measures were initially taken from Baker and Lamb (1994), which comprised 19 items of tangibles, 13 items of reliability, eight items of responsiveness, 16 items of assurance and 15 items of empathy as process or functional dimensions of service quality for architectural design firms. The study of Baker and Lamb (1994) also subjectively grouped 17 items as outcome or technical dimensions of service quality for architectural design firms comprising four categories: function (five items), appearance (six items), maintenance (two items), and other (four items). This classification of service quality comprising two dimensions, namely, process related and outcome related was motivated by Grönroos (1990, p. 37). However, aspects of process quality were seen to be motivated by Parasuraman et al. (1988). This was a crucial step in this research as it intends to develop or select a conceptual definition for service quality of architects. Accordingly, “service quality of architects” has been defined as the gap stemming from perceptions and expectations due to performance of an architectural service. This conceptual definition is intended to provide a theoretical base underlying the scale for service quality of architects.

3.1.2 Expert opinion. Initially, the study involved 85 items including 71 items of process dimension of service quality for architectural design firms in the study of Baker and Lamb (1994). The other 14 items have been included after an interaction with the key faculty at National Institute of Construction Management and Research in Pune. This designed scale was subjected to review by five experts to verify its content validity. The review by the panel of these five experts helped in shaping comprehensive and noteworthy items to study service quality for architects in the context of India. This review allowed 45 of the total 85 items to be noteworthy. Further, the remaining items to study service quality were pre-tested with a group of another ten expert participants. These ten experts included five academicians involved in the area of service operations management and who had been publishing research papers for over 15 years in journals of repute. They also held responsible positions like director, dean or head of department in their respective organizations. This panel was further enriched by five expert architects who had been registered with the Council of Architecture under the Architects Act 1972 for over 20 years having experience in the field of feasibility studies, architectural programming and project management. Each of these ten experts was asked to assess remaining 45 items to study
service quality for architects in support of readability, bias, understanding, ambiguity and appropriateness for relevance to architectural settings in India. Accordingly, their suggested and finalized 30 items were used for scale refinement in phase 2 of this study.

3.2 Phase 2: scale refinement

This phase covers the pilot testing, as shown in Figure 1. For pilot testing, a questionnaire of 30 items was prepared and evaluated on a five-point Likert scale (where 1 = “not agree...
at all," 2 – “mostly disagree,” 3 – “neither agree nor disagree,” 4 – “mostly agree,” and 5 – “completely agree”). The questionnaire was divided into two sections, where the first section consisted of classification questions pertaining to education, age, gender, experience in the construction industry, primary liking of client to work within, net worth of handled projects in the last year, liking of projects (with multiple selection) and specializations of interest (with multiple selection). The second section was formed of 30 items finalized in phase 1. A sample size of 115 respondents from users of architectural services was used for pilot testing of the items following steps suggested by Churchill (1979). The complete refinement of the scale was ensured through EFA followed by item and reliability analysis. The procedure for scale refinement has been described in the following section.

3.2.1 EFA. This study applied principal component analysis using Varimax rotation for conducting EFA on 30 finalized service quality items to extract factors using SPSS 14.0 software. The EFA resulted in a six-factor model with eigen value greater than 1. These six factors were to be dimensions of service quality for architects. They accounted for 61.148 percent variance with Kaiser-Meyer-Olkin (KMO) value as 0.837. For authentic results of factor analysis, the value of KMO must be greater than 0.600 (Tabachnick and Linda, 2012). This suggests appropriateness of data for grouping into a smaller set of underlying factors (Kwofie et al., 2016). Further, Bartlett’s test of sphericity was also significant ($p < 0.01$). Furthermore, a loading of 0.50 or greater on the factor was considered good for sample size up to 120 for EFA (Hair et al., 2010) because of which “be enthusiastic,” “display and communicate ideas clearly,” “adhere the budgets,” “take initiative to offer suggestions,” and “have adequate full time permanent employees” were dropped in the first phase (see, Table III). Finally, a total of 25 items for all the six factors as shown in Table III were retained in this phase.

3.2.2 Item and reliability analysis. Nunnally (1994) reported that the threshold value of Cronbach’s $\alpha$ must be at least 0.60 and is considered highly reliable beyond 0.70. The present study used this technique for internal consistency in determining the reliability separately for each factor pertaining to service quality of architects using the SPSS 14.0. The strong evidence of reliability was ensured in the developed scale after dropping the delivery quality factor as shown in Table III.

3.3 Phase 3: scale validation
After the scale refinement phase, the scale validation process was followed as shown in Figure 1. For scale validation, the replication of the confirmatory factor model was done in an independent sample to check for convergent, discriminant and nomological validity. The steps of the scale validation phase are as follows.

3.3.1 CFA. CFA is the next step after reliable EFA to determine the validated factor structure of the data set with principal axis factoring method using Varimax rotation. Further, a loading of 0.45 or greater on the factor was considered good for sample size up to 160 for CFA (Hair et al., 2010). Accordingly, an item labeled as “develop a well-balanced tender document” was deleted for having factor loading less than 0.45 (Table IV). Then confirmatory factor measurement model for the present study was developed using AMOS 6.0.0 and maximum likelihood method of estimation was performed for the entire set of remaining items. This measurement model was evaluated by examining the goodness-of-fit indices and factor loadings. The goodness-of-fit indices of the measurement model appear as ($\chi^2 = 730.193$, $p = 0.000$, $df = 314$, $\chi^2/df = 2.325$, $CFI = 0.864$, $TLI = 0.848$, $IFI = 0.865$, $RMSEA = 0.091$). Suggested value of $\chi^2/df$ is between 1.0 and 3.0 because small values (<1.000) can indicate an over-fitted model while high values (>3.000) can indicate an under-parameterized model. Incremental fit indices (CFI, IFI, and TLI) range from 0 (no fit at all) to 1.0 (perfect fit), and an acceptable decision
rule is to accept the fit as moderate for values above 0.80 and good for values above 0.90 (Hair et al., 2010). Finally, the RMSEA value of 0.091 represents reasonable model fit (Hair et al., 2010; Prakash et al., 2011).

3.3.2 Convergent and discriminant validity. It is absolutely necessary to establish convergent and discriminant validity, as well as reliability, when doing a CFA. All of these can be established using input as standardized residuals and modification indices, which results from the successful execution of the measurement model. For establishing convergent validity, the threshold value of composite reliability, average variance extracted (AVE), and MaxR(H) is 0.700, 0.500, and 0.800, respectively such that CR > AVE

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<th>Factor 1: design quality</th>
<th>Mean</th>
<th>SD</th>
<th>Factor loading (communalities)</th>
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<td>0.8906</td>
<td>0.719 (0.647)</td>
<td>10.248</td>
<td>0.8544</td>
</tr>
<tr>
<td>2. Provide appropriate functionality in building design</td>
<td>4.669</td>
<td>0.6313</td>
<td>0.675 (0.565)</td>
<td>9.603</td>
<td>0.8544</td>
</tr>
<tr>
<td>3. Develop accurate design documents</td>
<td>4.573</td>
<td>0.7499</td>
<td>0.655 (0.691)</td>
<td>8.820</td>
<td>0.8544</td>
</tr>
<tr>
<td>4. Provide space flexibility for accommodating future changes</td>
<td>4.356</td>
<td>0.8500</td>
<td>0.645 (0.588)</td>
<td>8.393</td>
<td>0.8544</td>
</tr>
<tr>
<td>5. Have a solution orientation in design</td>
<td>4.495</td>
<td>0.6802</td>
<td>0.644 (0.682)</td>
<td>8.627</td>
<td>0.8544</td>
</tr>
<tr>
<td>6. Maintain coordination between drawings</td>
<td>4.687</td>
<td>0.5676</td>
<td>0.591 (0.661)</td>
<td>8.627</td>
<td>0.8544</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factor 2: project administration quality</th>
<th>Mean</th>
<th>SD</th>
<th>Factor loading (communalities)</th>
<th>Eigen value</th>
<th>Chronbach’s α</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Administer contracts meticulously</td>
<td>3.834</td>
<td>1.2420</td>
<td>0.749 (0.629)</td>
<td>2.333</td>
<td>0.7615</td>
</tr>
<tr>
<td>2. Obtain fast statutory approvals</td>
<td>4.078</td>
<td>1.0853</td>
<td>0.711 (0.701)</td>
<td>2.175</td>
<td>0.7615</td>
</tr>
<tr>
<td>3. Settle claims</td>
<td>3.052</td>
<td>1.3691</td>
<td>0.660 (0.545)</td>
<td>1.879</td>
<td>0.7615</td>
</tr>
<tr>
<td>4. Develop a well-balanced tender document</td>
<td>3.678</td>
<td>1.2034</td>
<td>0.523 (0.628)</td>
<td>1.582</td>
<td>0.7615</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factor 3: communication quality</th>
<th>Mean</th>
<th>SD</th>
<th>Factor loading (communalities)</th>
<th>Eigen value</th>
<th>Chronbach’s α</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Listen requirements of clients</td>
<td>4.695</td>
<td>0.5646</td>
<td>0.732 (0.660)</td>
<td>1.687</td>
<td>0.7576</td>
</tr>
<tr>
<td>2. Seek and use cutting edge information for quick response</td>
<td>4.347</td>
<td>0.7014</td>
<td>0.716 (0.740)</td>
<td>1.532</td>
<td>0.8024</td>
</tr>
<tr>
<td>3. Document all the changes in the project</td>
<td>4.443</td>
<td>0.7837</td>
<td>0.614 (0.529)</td>
<td>1.399</td>
<td>0.7312</td>
</tr>
<tr>
<td>4. Pay attention to details for client requirements</td>
<td>4.704</td>
<td>0.4951</td>
<td>0.572 (0.592)</td>
<td>1.399</td>
<td>0.7312</td>
</tr>
<tr>
<td>5. Be enthusiastic#</td>
<td>4.513</td>
<td>0.6538</td>
<td>0.458 (0.577)</td>
<td>1.399</td>
<td>0.7312</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factor 4: relationship quality</th>
<th>Mean</th>
<th>SD</th>
<th>Factor loading (communalities)</th>
<th>Eigen value</th>
<th>Chronbach’s α</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Exercise honesty and integrity</td>
<td>4.643</td>
<td>0.5951</td>
<td>0.772 (0.703)</td>
<td>1.399</td>
<td>0.7312</td>
</tr>
<tr>
<td>2. Be trustworthy</td>
<td>4.713</td>
<td>0.5737</td>
<td>0.637 (0.644)</td>
<td>1.399</td>
<td>0.7312</td>
</tr>
<tr>
<td>3. Be polite and friendly</td>
<td>4.217</td>
<td>0.9059</td>
<td>0.598 (0.621)</td>
<td>1.399</td>
<td>0.7312</td>
</tr>
<tr>
<td>4. Have a harmonious relationship with stakeholders</td>
<td>4.382</td>
<td>0.7560</td>
<td>0.581 (0.618)</td>
<td>1.399</td>
<td>0.7312</td>
</tr>
<tr>
<td>5. Demonstrate commitment to a project approach in implementation</td>
<td>4.339</td>
<td>0.8774</td>
<td>0.524 (0.693)</td>
<td>1.399</td>
<td>0.7312</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factor 5: dependability quality</th>
<th>Mean</th>
<th>SD</th>
<th>Factor loading (communalities)</th>
<th>Eigen value</th>
<th>Chronbach’s α</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Make creative use of space and offer esthetics in their designs</td>
<td>4.626</td>
<td>0.6277</td>
<td>0.643 (0.630)</td>
<td>1.147</td>
<td>0.4930</td>
</tr>
<tr>
<td>2. Adhere timelines</td>
<td>4.504</td>
<td>0.7651</td>
<td>0.589 (0.645)</td>
<td>1.147</td>
<td>0.4930</td>
</tr>
<tr>
<td>3. Make quick and responsible decisions.</td>
<td>4.426</td>
<td>0.6360</td>
<td>0.580 (0.529)</td>
<td>1.147</td>
<td>0.4930</td>
</tr>
<tr>
<td>4. Anticipate and resolve problems</td>
<td>4.513</td>
<td>0.7177</td>
<td>0.546 (0.565)</td>
<td>1.147</td>
<td>0.4930</td>
</tr>
<tr>
<td>5. Display and communicate ideas clearly#</td>
<td>4.773</td>
<td>0.4786</td>
<td>0.459 (0.603)</td>
<td>1.147</td>
<td>0.4930</td>
</tr>
<tr>
<td>6. Adhere the budgets#</td>
<td>4.417</td>
<td>0.8289</td>
<td>0.446 (0.498)</td>
<td>1.147</td>
<td>0.4930</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factor 6: delivery quality</th>
<th>Mean</th>
<th>SD</th>
<th>Factor loading (communalities)</th>
<th>Eigen value</th>
<th>Chronbach’s α</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Educate clients</td>
<td>4.017</td>
<td>0.9821</td>
<td>0.695 (0.550)</td>
<td>10.248</td>
<td>0.8544</td>
</tr>
<tr>
<td>2. Ensure appropriate furnishings and finishes of the space</td>
<td>4.434</td>
<td>0.8071</td>
<td>0.665 (0.684)</td>
<td>9.603</td>
<td>0.8544</td>
</tr>
<tr>
<td>3. Take initiative to offer suggestions#</td>
<td>4.313</td>
<td>0.7764</td>
<td>0.427 (0.498)</td>
<td>8.820</td>
<td>0.8544</td>
</tr>
<tr>
<td>4. Have adequate full time permanent employees#</td>
<td>4.139</td>
<td>0.9165</td>
<td>0.381 (0.430)</td>
<td>8.627</td>
<td>0.8544</td>
</tr>
</tbody>
</table>

Note: #Dropped measurement item in Table III
Further, for establishing discriminant validity, both maximum shared variance (MSV) and average shared variance (ASV) should be less than that of AVE (Bagozzi et al., 1991; Hair et al., 2010) (Table V).

3.3.3 Nomological validity assessment. Nomological validity relates to the principles that resemble laws, especially the laws of nature which are neither logically necessary nor theoretically explicable, but just are so. This validity has been supported by demonstrating

(Hancock and Mueller, 2001; Hair et al., 2010) (Table V). Further, for establishing discriminant validity, both maximum shared variance (MSV) and average shared variance (ASV) should be less than that of AVE (Bagozzi et al., 1991; Hair et al., 2010) (Table V).

### Table IV. Scale Purification

<table>
<thead>
<tr>
<th>Constructs</th>
<th>CR</th>
<th>AVE</th>
<th>MSV</th>
<th>ASV</th>
<th>MaxR(H)</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Relationship quality</td>
<td>0.873</td>
<td>0.545</td>
<td>0.267</td>
<td>0.126</td>
<td>1.064</td>
<td>0.738</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) Design quality</td>
<td>0.950</td>
<td>0.554</td>
<td>0.274</td>
<td>0.450</td>
<td>0.856</td>
<td>0.517</td>
<td>0.745</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) Project administration quality</td>
<td>0.910</td>
<td>0.722</td>
<td>0.095</td>
<td>0.076</td>
<td>0.741</td>
<td>0.262</td>
<td>0.308</td>
<td>0.850</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(4) Communication quality</td>
<td>0.855</td>
<td>0.551</td>
<td>0.178</td>
<td>0.108</td>
<td>1.037</td>
<td>0.256</td>
<td>0.368</td>
<td>0.229</td>
<td>0.743</td>
<td></td>
</tr>
<tr>
<td>(5) Dependability quality</td>
<td>0.862</td>
<td>0.566</td>
<td>0.274</td>
<td>0.116</td>
<td>1.020</td>
<td>0.484</td>
<td>0.523</td>
<td>0.215</td>
<td>0.422</td>
<td>0.752</td>
</tr>
</tbody>
</table>

Table V. Measurement model: CR, AVE, MSV, and ASV
that the constructs are related to other constructs included in the model in a manner that
supports highly significant predictive assessment at the level of significance 0.001 (Hair
et al., 2010) (Table VI).

4. Discussion
This study confirms that the service quality of architects is represented by five factors
labeled as design quality, project administration quality, communication quality,
relationship quality and dependability quality in the context of India. This number
confirms the literature that service quality for architects is multidimensional
(e.g. Parasuraman et al., 1988) and also mirrors the number of factors that have been
identified in other studies in service quality for architects albeit with a different cohort of
respondents (e.g. Baker and Lamb, 1994; Sunindijo et al., 2014). Essentially, this study
identified that design quality has a significant impact on performance of service quality for
architects in India (Table VI). It can also be stated that this study confirms the Nordic
(Grönroos, 1982) and SERVQUAL (Parasuraman et al., 1988) model of service quality with
identified factors. For example, design quality is mostly associated with technical (Grönroos,
1982), and tangible (Parasuraman et al., 1988) aspects of service quality. Dependability
quality is clearly linked to the reliability dimension in the initial SERVQUAL study.
Relationship quality is an amalgamation of aspects like assurance, empathy and
responsiveness. Likewise, communication quality is a blend of aspects like empathy and
responsiveness. Notably, project administration quality did not seem to align clearly with
any of the SERVQUAL or the Nordic model of service quality. Project administration
quality is to be considered as an aspect with a substantial source of performance indicator
for service quality of architects (Shieh and Wu, 2002).

The finding that 20 of the 22 items received a mean score over four confirms the
literature that customers of architectural service expect a high level of service quality

<table>
<thead>
<tr>
<th>Regression</th>
<th>Estimate</th>
<th>SE</th>
<th>CR</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>DQ1 ← Design quality</td>
<td>1.001</td>
<td>0.081</td>
<td>12.364</td>
<td>***</td>
</tr>
<tr>
<td>DQ2 ← Design quality</td>
<td>0.720</td>
<td>0.067</td>
<td>10.714</td>
<td>***</td>
</tr>
<tr>
<td>DQ3 ← Design quality</td>
<td>1.051</td>
<td>0.075</td>
<td>13.991</td>
<td>***</td>
</tr>
<tr>
<td>DQ4 ← Design Quality</td>
<td>0.892</td>
<td>0.103</td>
<td>8.672</td>
<td>***</td>
</tr>
<tr>
<td>DQ5 ← Design quality</td>
<td>0.862</td>
<td>0.074</td>
<td>11.672</td>
<td>***</td>
</tr>
<tr>
<td>DQ6 ← Design quality</td>
<td>0.743</td>
<td>0.062</td>
<td>11.962</td>
<td>***</td>
</tr>
<tr>
<td>PAQ1 ← Project administration quality</td>
<td>0.859</td>
<td>0.051</td>
<td>16.815</td>
<td>***</td>
</tr>
<tr>
<td>PAQ2 ← Project administration quality</td>
<td>0.656</td>
<td>0.047</td>
<td>13.848</td>
<td>***</td>
</tr>
<tr>
<td>PAQ3 ← Project administration quality</td>
<td>0.956</td>
<td>0.055</td>
<td>17.292</td>
<td>***</td>
</tr>
<tr>
<td>CQ1 ← Communication quality</td>
<td>0.678</td>
<td>0.070</td>
<td>9.623</td>
<td>***</td>
</tr>
<tr>
<td>CQ2 ← Communication quality</td>
<td>0.814</td>
<td>0.084</td>
<td>9.685</td>
<td>***</td>
</tr>
<tr>
<td>CQ3 ← Communication quality</td>
<td>0.929</td>
<td>0.086</td>
<td>10.753</td>
<td>***</td>
</tr>
<tr>
<td>CQ4 ← Communication quality</td>
<td>0.684</td>
<td>0.059</td>
<td>11.545</td>
<td>***</td>
</tr>
<tr>
<td>RQ1 ← Relationship quality</td>
<td>0.678</td>
<td>0.051</td>
<td>13.269</td>
<td>***</td>
</tr>
<tr>
<td>RQ2 ← Relationship quality</td>
<td>0.480</td>
<td>0.069</td>
<td>7.931</td>
<td>***</td>
</tr>
<tr>
<td>RQ3 ← Relationship quality</td>
<td>0.987</td>
<td>0.077</td>
<td>12.736</td>
<td>***</td>
</tr>
<tr>
<td>RQ4 ← Relationship quality</td>
<td>0.810</td>
<td>0.069</td>
<td>11.778</td>
<td>***</td>
</tr>
<tr>
<td>RQ5 ← Relationship quality</td>
<td>0.865</td>
<td>0.077</td>
<td>11.247</td>
<td>***</td>
</tr>
<tr>
<td>DEQ1 ← Dependability quality</td>
<td>0.721</td>
<td>0.083</td>
<td>8.704</td>
<td>***</td>
</tr>
<tr>
<td>DEQ2 ← Dependability quality</td>
<td>0.891</td>
<td>0.076</td>
<td>11.785</td>
<td>***</td>
</tr>
<tr>
<td>DEQ3 ← Dependability quality</td>
<td>0.890</td>
<td>0.099</td>
<td>12.830</td>
<td>***</td>
</tr>
<tr>
<td>DEQ4 ← Dependability quality</td>
<td>0.832</td>
<td>0.076</td>
<td>11.001</td>
<td>***</td>
</tr>
</tbody>
</table>

Table VI.
Regression weights for Predictive assessment

Note: ***Stands for level of significance 0.001
when choosing an architect (Table IV). Similarly to the literature (e.g. Douglas, 1994),
being trustworthy and providing appropriate functionality in building design were
ranked extremely high. Interestingly, the items that were rated the lowest were related to
administering contracts meticulously and settling claims. As India is a developing
country with relatively less stringent procedures, it is highly likely that respondents considered
these aspects of service quality less important than actual design development. With the
legislation of the Real Estate Regulation Act getting into force to protect home buyers and
courage genuine private players in India, these project administration services offered
by the architects would be more attractive for business that wants meticulous facilitation
of contracts, fast reporting of statutory approvals and comfortable settlement of claims
(Prakash et al., 2017). Claim settlement had the highest variance amongst the items as
related manifestations are likely to be short lived in the minds of the clients, which
corresponds with the literature on service quality (Kumaraswamy, 1997). Additionally,
the results validate Parasuraman et al.’s (1988) original claim that reliability is one
of the most critical elements of service quality regardless of the services being studied.
Thus, our findings are in line with the intuitive thinking about the validated factors of
service quality for architects (see e.g., Lim and Tkaczynski, 2017).

This study also supports the argument that service quality of architects varies based
on personal characteristics like level of education, age, gender, experience in the
construction industry, primary liking of clients, net worth of handled projects in last year,
liking of projects and specializations of interest (see e.g. Johnston, 1995). This research has
also provided considerable insights into the service quality of international architects as
they place a higher value on expertise by specialization than on needs of customers
(Gleason et al., 2006). Ideally, such generalization of a social or psychological phenomenon
requires situations to exactly match with those of the original study (Strauss and
Corbin, 1990). Further, Forsythe (2015) asserts that proposing one version to be generic
would be inappropriate. Nevertheless, the generalization of this study can be attempted
with countries in intergovernmental organizations with similarity in culture like South
Asian Association for Regional Cooperation (Hofstede, 1984) and/or economics
(Jaeger and Adair, 2013).

5. Conclusion

5.1 Contribution
The idea to fulfill the gap between perception and expectation from an architect in India is a
unique theoretical contribution of this study. Since researchers contend that performance
dimensions of service quality for architects require augmentation to increase their relevance
in their contexts (Carman, 1990), the project administration quality factor produced in this
study is a key theoretical contribution. As design quality includes items like functionality of
the building design, flexibility for future changes and solution orientation to design, their
manifestation in the validated scale is also a key contribution. These items of design quality
are beneficial to the clients for ensuring the long life of their built structure.

5.2 Practical implications
The scenario of architectural design pertaining to service quality in construction, real estate,
and infrastructure projects is unique in India. The determinants of service quality
established in this study for architects would be useful for international firms interested in
opportunities relating to contracting, consulting and engineering in India due to the further
exponential increase in investments in construction projects.

This is the first empirically validated instrument for measuring the service quality of
architects or the architectural firms. This scale of service quality can allow measurement
periodically for comparison over time. Depending upon criticality of items, priorities can be
decided to address the weaker areas and leverage the stronger areas. This study can also facilitate an architect to explore possibilities of higher fees in case of referral business. Additionally, this study extends the scant extant literature on service quality of architects.

5.3 Limitations and directions for further research
This research is not without its limitations. First, as conducted in the Indian context, the generalizability of this study to other countries is limited. There is an opportunity for this research to be replicated in other international contexts to verify the findings. Second, whilst this study identified five valid service quality factors, the classified information relating to the formation of expectations was not collected. Therefore, the future research can focus on identifying how expectations of architects are formed. This can be identified with service attitude, customer satisfaction and patronage intension to predict potential behavior linkages. The third limitation of this research is that it has not tested hypotheses for no difference based on available demographic information. An opportunity for future research is to classify sampled data into different socio-demographic groups to exercise control on their service quality gaps. Fourth, this study has used snowball sampling which is a non-probability sampling technique. Future research may apply a more accurate and realistic probability sampling technique.

References


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