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Developing a fuzzy risk assessment model for guaranteed maximum price and target cost contracts in South Australia

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Abstract

Purpose - This paper aims to develop a fuzzy risk assessment model for construction projects procured with target cost contracts and guaranteed maximum price contracts (TCC/GMP) using the fuzzy synthetic evaluation method, based on an empirical questionnaire survey with relevant industrial practitioners in South Australia.

Design/methodology/approach - A total of 34 major risk factors inherent with TCC/GMP contracts were identified through an extensive literature review and a series of structured interviews. A questionnaire survey was then launched to solicit the opinions of industrial practitioners on risk assessment of such risk factors.

Findings - The most important 14 key risk factors (KRFs) after the computation of normalised values were selected for undertaking fuzzy evaluation analysis. Five key risk groups (KRGs) were then generated in descending order of importance as: (1) Physical risks; (2) Lack of experience of contracting parties throughout TCC/GMP procurement process; (3) Design risks; (4) Contractual risks; and (5) Delayed payment on contracts. These survey findings also revealed that physical risks may be the major hurdle to the success of TCC/GMP projects in South Australia.

Practical implications - Although the fuzzy risk assessment model was developed for those new-build construction projects procured by TCC/GMP contracts in this paper, the same research methodology may be applied to other contracts within the wide spectrum of facilities management or building maintenance services under the target cost-based model. Therefore, the contribution from this paper could be extended to the discipline of facilities management as well.

Originality/value - An overall risk index (ORI) associated with TCC/GMP construction projects and the risk indices of individual KRGs can be generated from the model for reference. An objective and a holistic assessment can be achieved. The model has provided a solid platform to measure, evaluate and reduce the risk levels of TCC/GMP projects based on objective evidence instead of subjective judgments. The research methodology could be replicated in other countries or regions to produce similar models for international comparisons, and the assessment of risk levels for different types of TCC/GMP projects (including new-build or maintenance) worldwide.

Keywords Target cost contracts, Guaranteed maximum price contracts, Risk assessment, Fuzzy synthetic evaluation, South Australia.

Paper type Research paper

Introduction

The potential problems with the traditional procurement method are identified as causing confrontational working relationships between contracting parties. Different parties only tend to achieve their own individual objectives in the projects rather than the overall project objectives under such traditional procurement arrangement. Target cost contracts (TCC), which aim to align the commercial interests of both parties (e.g. clients and contractors) together to achieve win-win situation (Yeung *et al.*, 2007), are considered to be one of the possible solutions to improve such adversarial relationships (Construction Industry Review Committee, 2001). However, this kind of contract is claimed to be better used in those projects with high risk (Wong, 2006). Venues for the London 2012 Olympic and Paralympic Games, and the Terminal 5 at the Heathrow Airport in London are famous examples of applying the New Engineering Contract (NEC) with Option C (Target Cost with Activity Schedule). It was manifested that previous research studies on this procurement area mainly focus on their respective benefits and limitations (Davis and Stevenson, 2004; Chan *et al.*, 2007), establishment of the gain-share/pain-share ratio (Broome and Perry, 2002; Badenfelt, 2008), and the like. However, few, if any, research studies have specifically focused on the risk assessment of TCC and GMP (TCC/GMP) contracts.

In fact, both TCC and GMP schemes, as relatively novel forms of procurement in South Australia, have created new challenges for risk management towards both clients and contractors. Therefore, it is essential for both the client organisations and the main contractors to evaluate all of the potential risks throughout the entire project delivery process. However, empirical research studies on this research area are rather limited. In addition, hands-on experience derived from the cases of the United Kingdom and Australia has indicated that the TCC/GMP style of procurement could bring considerable mutual benefits to all of the contracting parties involved, provided that the risk factors are properly identified, analysed, shared and managed (Trench, 1991; Walker *et al*., 2000).

Even though some successful cases of TCC/GMP are reported (Construction Industry Council, 2010), not all construction projects procured with TCC/GMP are equally successful. For example, Rojas and Kell (2008) reported that the final construction cost of 75% of school projects surveyed in the northwest of the United States exceeded the GMP value, while the same phenomenon was found in about 80% of non-school projects. These findings did not support the notion that GMP is really a guarantor of construction cost. There is an urgent need for more systematic and in-depth research to examine the risk aspects and to develop a risk assessment model for delivering TCC/GMP construction projects.

Thus, the aim of this paper is to develop a fuzzy risk assessment model for measuring the risk level of a certain key risk group (KRG) and the overall risk level associated with TCC/GMP construction projects using the fuzzy synthetic evaluation method via an empirical questionnaire survey in South Australia. It is envisaged that this research study can shed light on the risk management of TCC/GMP projects not only locally but also worldwide.

Though the fuzzy risk assessment model was generated for use by those new-build construction projects procured with TCC/GMP contracts in this paper, the same research methodology may be adopted to other contracts in the broad sector of facilities management or building maintenance under the target cost-based model. Hence, the contribution from this paper could cover the discipline of facilities management as well. As economic factors play an increasingly important role in the way we deliver various facilities, it is vital that facilities managers and property managers stay tuned with current ideas or innovative thinking so that they can plan, develop and equip buildings to satisfy the needs of their end-users fully in the most cost-effective way and with the lowest risk exposure.

Review of previous studies

Concepts of TCC and GMP

The concepts of TCC are believed to serve as a means to establish mutual trust between owners and contractors, by putting the common project goals in cost together (Bower *et al.*, 2002). The National Economic Development Office (1982) based in the United Kingdom considered that "…… target cost contracts specify a 'best' estimate of the cost of the works to be carried out. During the course of the works, the initial target cost will be adjusted by agreement between the client or his nominated representative and the contractor to allow for any changes to the original specifications". Wong (2006) shared a similar view that the contractor is paid the actual cost for the work done during the construction stage. When the final construction cost differs from the initial target cost, the variance would be spilt between the employer and the contractor based on a pre-determined gain-share/pain-share ratio as stated in the contract.

GMP is perceived as a type of contractual arrangement that is more suitable when the design is based on conventional means. However, the scope of works is not clear for fixed-price bidding at the time of contract award (Saporita, 2006). Fan and Greenwood (2004) suggested that a GMP contract caps the final contract sum at an agreed fixed maximum price, i.e. the GMP, a cost guarantee that the final cost of the project will not exceed such stipulated GMP. Cantirino and Fodor (1999) supported a similar perception that under the GMP contract, the contractor is entitled to receive a specified guaranteed maximum price only if the actual cost is equal to or higher than the amount of negotiated guaranteed maximum price. The contractor has to bear the excess if the actual cost is higher than the agreed GMP value. On the other hand, the contractor is entitled to receive the actual cost along with a share of any savings to the owner with a pre-agreed share ratio. Kaplanogu and Arditi (2009) considered that this kind of contract offers the owner the best protection relative to the price he will pay for the works; however, it is a risky contract for the contractors.

Hughes *et al.* (2011) advocated that GMP is a TCC with an additional feature that the maximum amount to be paid by the employer is capped. Masterman (2002) shared a similar perception that GMP is a variant of TCC. Boukenbour and Bah (2001) also opined that GMP can be considered as a target cost which provides a better hedge to the owner. The concepts of TCC and GMP are in fact very similar. Given the definitions mentioned above, the main difference between these two contractual arrangements is that there is only gain-share approach in GMP contracts, while the deviation of target cost and final actual cost is shared between the employer and the contractor with a pre-determined share ratio (i.e. gain-share/pain-share approach).

Actually, TCC and GMP are grouped together in previous research studies on construction management for discussions. For example, Chan *et al.* (2007) launched several interviews to investigate the underlying motives, benefits, difficulties, success factors, key risk factors, and optimal project conditions for applying TCC and GMP in Hong Kong. Chan *et al.* (2010b) reported on the major findings of a questionnaire survey on critical success factors in the implementation of TCC/GMP schemes in Hong Kong. Chan *et al.* (2011a) ranked and analysed the key risks inherent with TCC/GMP contracts through an empirical survey in Hong Kong. In view of the viewpoints of the researchers mentioned above, the similar nature of TCC and GMP and the practices of previous research studies, TCC and GMP are put together for subsequent analyses and discussions in this paper.

Application of TCC/GMP contracting in Australia

In South Australia, the application of GMP contracting has recently become popular. In many cases where the scope of works is not able to be as clearly defined as in a lump-sum contract, the client may opt for adopting a Guaranteed Maximum Price (GMP) contract type. However, there is a clear lack of understanding and scarcity of local research undertaken on the performance of this procurement strategy. According to Davis Langdon and Seah (2004), a standard GMP form of contract does not exist. Therefore, in order to produce a GMP, the conditions must be introduced into another standard form of contract, such as a design-and-build contract. Because of this, a GMP contract can be viewed as a pricing method rather than a method of delivering a construction project (Steele and Shannon, 2005). A typical example of this is when a design-and-construct contract (Australian Standard: AS4300) comprises the added conditions of GMP with it, which results in a project where the design costs and additional risks are included into the contractor's scope.

Davis and Stevenson (2004) conducted ten interviews on the benefits and limitations of procuring projects using GMP in Western Australia. Their findings concluded that price certainty, time saving and the encouragement of better team relationships were considered to be the major advantages of GMP by the interviewees. In contrast, a lack of common understanding of the underlying concepts of GMP, a lack of standard form of contract for GMP schemes, a lack of appropriate skills in design management and capital cost being compromised were perceived as the key limitations of GMP. Perkin and Ma (2010) launched an extensive desktop search and found out that the GMP procurement method was introduced in as early as 1997 within the construction industry of South Australia, and there was a strong trend towards the use of GMP. The procurement methods applied to procure the GMP approach include negotiated, design-and-construct and fixed-price lump-sum, with design-and-construct method observed as the most popular of the delivery systems.

On the other hand, based on a case study of a conversion project in Adelaide, Hooi and Ma (2011) indicated that there is an arrangement for a 50/50 gain-share (but not pain-share) agreement incorporated into the contract documents. Unfortunately, the project went into a legal dispute because of the ambiguity of scope of works. In general, the court will not interfere with risk allocation clauses unambiguously written into construction contracts by which the risk of unforeseen events is transferred to one party. However, it is not uncommon for a contract to include in its heading ”Guaranteed Maximum Price”. The fact that this heading exists does not in itself mean that the contractor, except for scope changes, has taken on all the risks. Since there is no standard form of GMP contract, clients on domestic projects that require a GMP are left with either amending an existing standard form or having a bespoke contract specifically drafted. The interviewees involved in the project suggested that a contractor tendering for a GMP contract should be very cautious about the wordings of the contract and to check whether the client has transferred all the risks to the contractor.

Rose and Manley (2007) recommended that the construction risks could be shared equitably between the client and the contractor with flexibility being provided in the contract to handle unforeseen situations and relationship management in order to design a financial incentive mechanism strategy. Therefore, both the client and the contractor must fully understand what risks they are assuming. Open discussions about these points should be held so that the components and price in the contract are clarified and understood before signing on the contract. The GMP contracting is not the solution to all projects; it is only one of many procurement options all of which have a place depending on the circumstances of individual projects and experiences of key project stakeholders. It must be emphasised that a GMP is not really guaranteed or a maximum because scope changes will always arise as part of the nature of construction projects. According to Tay *et al.* (2000) and Lim (2001), the major hindrance encountered in procuring a GMP contract is the definition of a “scope change”. If the definition is not well-defined, it will certainly fall into the loophole for intractable disputes and contractual claims.

Overview of risk management process

There is indeed a vast amount of reported literature which documents the elements in risk management. Risk can be defined as “the chance of something happening that will have an impact upon the objectives” (AS/NZS 4360:2004). Risk is related to the likelihood and consequences of an event, and the resultant influence on project objectives (Environment, Transport and Works Bureau, 2005). Risk can be managed, diminished, transferred or accepted, but it should not be ignored in construction projects (Latham, 1994). The objectives of risk management are to make sure that: (1) risk is allocated to the party who can best handle it; (2)

risks are shared as much as possible; and (3) allowance for every unavoidable cost associated with the risk which is assumed to be made somewhere during project delivery (Ahmed *et al.*, 1998). Risk management comprises risk planning, risk identification, risk analysis, risk evaluation and risk treatment supported by continuous monitoring, review and recording of the identified risks, together with effective communications and consultations with project stakeholders (AS/NZS 4360:2004; Environment, Transport and Works Bureau, 2005) and they are illustrated in Figure 1.

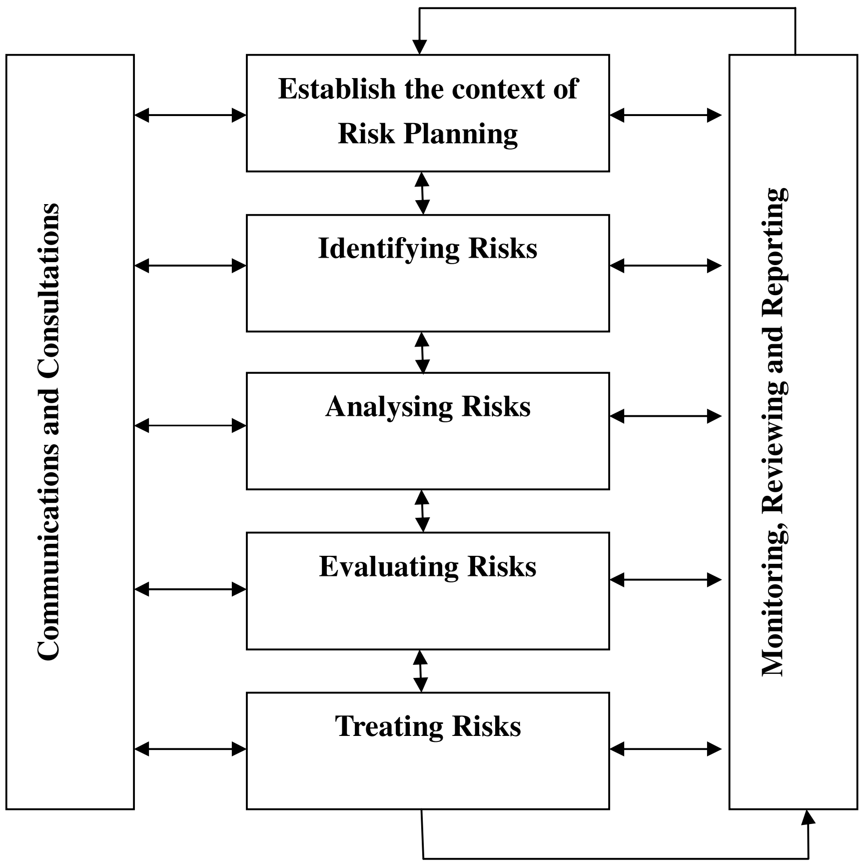

Figure 1. Systematic risk management process
(adapted from AS/NZS 4360:2004; Environment, Transport and Works Bureau, 2005)

Risk assessment in construction projects

There have been a considerable number of previous research studies on risk assessment in construction projects. According to Laryea and Hughes (2008), the findings derived from their interviews with five estimators of construction firms in the United Kingdom manifested that four of them applied a risk register mechanism in practice (i.e. risk impact as a function of the probability of occurrence multiplied by the level of severity). The risk assessment started with a brainstorming review workshop and the participants identified the risks of the project in the workshop. After that, the risks were evaluated with a spreadsheet matrix which helped to work out the contingencies based on the severity values and the probability values according to the hands-on experience and intuitive judgments of the participants. Adams (2008) advocated that risks in construction projects are often analysed in an arbitrary manner. Contractors tend to resort to the addition of a single arbitrary cost contingency to give their overall impression of the total risk instead of assessing the risks they are asked to carry. This view is supported by an earlier study by Akintoye and Macleod (1997). They investigated how contractors performed risk analysis through a questionnaire survey launched in the United Kingdom. They drew a similar conclusion with Adams (2008) that formal risk analysis techniques were rarely used in the industry due to lack of knowledge and doubts of suitability of those techniques in the construction industry.

Risk management is beneficial to a project development if it is implemented in a systematic approach from the planning stage up to project completion, in order to help project participants to make better and more informed decisions (Baloi and Price, 2003). The unsystematic and arbitrary nature of risk management inherent with the construction industry could endanger the success of projects. Indeed, risk management is an art as well as a science (Baloi and Price, 2003). Despite a large amount of available literature and continuous development of risk management in the construction management discipline, it appears that industrial practitioners have not much appreciated their significance (Flanagan and Norman, 1993). Unlike other industries such as the oil industry and petrochemical industry, there seems to be a wide gap between existing theories and current practices in risk management of the construction industry (Thompson and Perry, 1992).

Appropriateness of fuzzy set theory

The primary objective of risk management is to reduce uncertainties and improve the process of decision making. Four main approaches are adopted to handle uncertainties and they include the Probability Theory; Certainty Theory, Dempster-Shafer Theory and Fuzzy Set Theory (Baloi and Price, 2003).

Bayesian theory of probability is a classical approach to addressing uncertainties. Probability Theory is suitable for modelling repetitive experiments with observable but uncertain outcomes. The assumption behind this theory is that all uncertainties are measures of randomness or subjective measures of confidence. Probability Theory is only effective and reliable in dealing with uncertainties having historical records. In other words, Probability Theory considers that all uncertainties are random, however, not all kinds of uncertainties are random. In fact, the issues of project management in the construction industry may not comply with such random properties (Baloi and Price, 2003).

Certainty Theory was first formulated to handle uncertainties in medical expert systems (Shafer, 1976). It was developed to address the limitations of the Probability Theory. According to Baloi and Price (2003), under the Certainty Theory, certainty measures are associated with factual statements. Certainty measures comprise numbers which range from -1 to +1, where -1 means complete certainty that a proposition is false and vice versa for +1. The factual statements are rules which comprise antecedents and consequences (Shafer, 1976).

Dempster-Shafer Theory is based on the Probability Theory, but it allows yet probability judgments to capture the imprecise nature of the evidence. As a result, degrees of likelihood are measured by probability intervals, rather than point probabilities under the Bayesian approach (Yen, 1992). Although the Dempster-Shafer Theory is richer in terms of semantics as it allows an expression of partial knowledge, yet its limitation is the elicitation and interpretation of belief functions,

Fuzzy Set Theory is an extension of classical binary logic. A set is a collection of objectives having a general property in classical set theory (e.g. a set of contractors). An element is either or not a member of a set. The boundaries of concepts are rigid and there is no grey room or in-between state (Chan *et al.*, 2009). This deterministic approach is a widespread practice in system modelling and computing. However, the problem with such approach is that it cannot convey information effectively because the state between full membership and non-membership is ignored. Fuzzy Set Theory is considered as a branch of modern mathematics to model vagueness intrinsic in human cognitive process (Chan *et al.*, 2009). It has been adopted to tackle ill-defined and complex problems due to incomplete and imprecise information which characterise the real world system (Baloi and Price, 2003). Sadiq *et al.* (2004) was of a similar opinion that Fuzzy Set Theory is an important tool for modelling uncertainties or imprecision due to human perceptions and subjectivity should be accounted for in a rational manner to decision making. This theory has been proved to be a powerful technique to model unstructured problems and there has been a remarkable increase in application within the construction industry.

In recent years, a plethora of risk assessment models have been developed with applications of Fuzzy Set Theory to enrich the body of knowledge of risk management in the construction management discipline. For example, Baloi and Price (2003) developed a fuzzy decision framework to model the global risk factors affecting construction cost. Zhang and Zou (2007) established a risk assessment model for joint venture projects in Mainland China with the fuzzy analytical hierarchy process. Zeng *et al.* (2007) applied the fuzzy reasoning techniques to generate a tool for handling risks in construction projects. However, no risk assessment model (few if any) has been developed for TCC/GMP schemes in the construction industry. The above findings from the desktop search further reinforce the primary aim of this study (i.e. to develop a risk assessment model for TCC/GMP construction projects).

Research methodology

Desktop search

Risk management is a key element of procuring TCC/GMP projects and risk identification is the first step towards risk management. A total of 34 individual risk factors associated with TCC/GMP contracts were identified through a comprehensive literature review of the refereed journals, conference proceedings, research reports, company newsletters, previous dissertations, online resources, etc. based on the work of Chan *et al*. (2008) which presented an extensive desktop search over the risk factors for TCC/GMP projects and a series of face-to-face interviews with industrial practitioners with extensive experience of TCC/GMP construction projects in Hong Kong (Chan *et al.*, 2010a) and Australia (Perkin, 2008). Both the literature review and research interviews formed a solid foundation of the development of the questionnaire survey launched in this study. Therefore, the list of 34 risk factors in relation to TCC/GMP contracts was considered to be sufficient, relevant and representative.

Structured interviews

Seven face-to-face structured interviews on the identification of key risk factors associated with TCC/GMP contracts were launched by Chan *et al.* (2010a) in Hong Kong between June and July of 2008. As all of the interviewees were senior construction professionals who have obtained abundant direct hands-on experience with TCC/GMP schemes, their opinions and feedback were regarded as representative and valid for general applications. The interviewees suggested that the nature of variations, change in scope of works, quality and clarity of tender documents, unforeseen ground conditions, fluctuation of materials price, and approval from regulatory bodies for alternative cost saving designs, are the key risk factors inherent with TCC/GMP projects in Hong Kong (Chan *et al.*, 2010a). The results of the seven interviews also enabled the fine-tuning and confirmation of the 34 key risk factors sought from the literature review to be included on the empirical research survey questionnaire used in Hong Kong (Chan *et al.*, 2011a). While this research forms part of an international study of risk management of TCC/GMP contracts in Australia, Hong Kong and the United Kingdom, the same survey form was adopted in these three jurisdictions in order to enable international comparisons. Some findings of this research have been already disseminated through various academic publications (e.g. Chan *et al.*, 2011b).

Perkin (2008) launched four case studies of TCC/GMP construction projects in South Australia by interviewing the key actors of these cases. This study found that several key risk factors associated with TCC/GMP schemes in Hong Kong were applicable in South Australia as well (e.g. errors and omissions in tender documents; unforeseen ground conditions; unforeseeable design development risks at tender stage; poor quality of work; and change in scope of works). To ensure the suitability and applicability of the same survey questionnaire from Hong Kong to Australia, a "pilot" study was performed in early 2009 towards a few academics and practitioners based in Australia before launching the industry-wide full-scale questionnaire survey. There were no adverse comments received from the pilot study. In addition, since the contact details of the researchers were provided on the survey form, the respondents could be able to contact the researchers for any clarifications on the contents there. Given that the operational mechanism of TCC/GMP schemes is similar in principle between Hong Kong and Australia, and the positive results of the pilot study, the same survey instrument containing the list of 34 risk factors in relation to TCC/GMP contracts based in the context of Hong Kong is applicable to and replicated for use in South Australia as well.

Questionnaire survey

The questionnaire survey was carried out in April of 2009. A total of 200 self-administered blank survey forms were distributed to various target construction professionals associated with the construction industry in South Australia, including those working for private property developers, consultant firms, main contractors, trade subcontractors, quasi-government organisations and relevant government works departments. The completed survey forms were collected through postal mails, electronic mails, faxes as well as personal networking. The respondents were requested to estimate both the level of severity to the project and the likelihood of occurrence of the 34 potential key risk factors identified on the survey form according to a Likert measurement scale of 1 to 5 for severity (where 1 = very low and 5 = very high) and of 1 to 7 for likelihood (where 1 = very very low and 7 = very very high) respectively. They were welcome to add any new extra risk factors which were not covered on the survey form, but no additional risk was finally suggested by them.

A total of 43 valid completed survey forms were returned in July of 2009, yielding a response rate of 22%. Amongst these 43 returned forms, 36 respondents had acquired direct hands-on experience in procuring TCC/GMP construction projects whereas 7 of them had declared to have basic understanding of the underlying principles of TCC/GMP schemes even though without direct exposure to TCC/GMP contracts before. Such screening enabled the researchers to make sure that the respondents have gained fundamental understanding of TCC/GMP concepts in order to assure the value and credibility of survey results.

An independent two-sample t-test was conducted to test for any statistical differences on the risk assessment of each of the listed risk factors between the experienced group of respondents (i.e. those with direct hands-on TCC/GMP experience) and the non-experienced group of respondents (i.e. those without direct TCC/GMP experience before but with basic understanding of the underlying principles of TCC/GMP schemes), as previously adopted by both Xu *et al.* (2010b) and Chan *et al.* (2011a). The test results reflected that there are no statistically significant differences on the risk assessment of each of the risk factors elicited for TCC/GMP projects between the experienced group and the non-experienced group. Hence, all the responded survey respondents are qualified to answer the questionnaire and would be capable to offer genuine opinions on the research. The two independent sets of opinion data can thus be lumped together for analysis and the survey findings are regarded as consistent, reliable and representative. Therefore, only the data and information obtained from these 43 responses were used for further data analysis. Table I depicts a summary of the personal profiles of survey respondents.

Table I. Personal profiles of survey respondents

Category	Respondent		Category	Respondent	
	Frequency	%		Frequency	%
Nature of organisation			*Number of TCC/GMP construction projects involved*		
Client organisation	7	16.3	1-2 projects	12	27.9
Main contractor	20	46.5	3-4 projects	9	20.9
Architectural consultant	6	14.0	More than 4 projects	15	34.9
Engineering consultant	5	11.6	Have obtained basic understanding of the underlying principles of TCC/GMP schemes	7	16.3
Quantity surveying consultant	3	7.0			
Project management consultant	2	4.7			
Total	**43**	**100%**	**Total**	**43**	**100%**
Grouping by nature of organisation			*Experience level in construction industry*		
Client	7	16.3	Below 5 years	2	4.7
Contractor	20	46.5	5-10 years	2	4.7
Consultant	16	37.2	11-15 years	7	16.3
			16-20 years	12	27.9
			Over 20 years	20	46.5
Total	**43**	**100%**	**Total**	**43**	**100%**

Fuzzy synthetic evaluation method

Fuzzy Synthetic Evaluation, being one of the applications of Fuzzy Set Theory, was applied to this study to derive the risk index of each key risk group (KRG) and also the overall risk index (ORI) of TCC/GMP construction projects in South Australia.

A fuzzy synthetic evaluation model requires three basic elements:

1. A set of basic criteria / factors $\pi = \{f_1, f_2, ..., f_{17}\}$; e.g. $f_1 =$ delay in work due to third party; $f_2 =$ disagreement over evaluating the revised contract price after submitting an alternative design by main contractor; …… $f_{17} =$ inflation beyond expectation.
2. A linguistic scale $E = \{e_1, e_2, ...e_n\}$; e.g. e_1 = very low; e_2 = low; e_3 = moderate; $e_4 =$ high; and $e_5 =$ very high (for severity); and $e_1 =$ very very low; $e_2 =$ very low; e_3 = low; e_4 = moderate; e_5 = high; e_6 = very high; and e_7 = very very high (for likelihood);
3. For every object $u \notin U$ (which means the fuzzy subset u does not belong to the fuzzy set U), there is an evaluation matrix $R = (r_{ij})_{m \times n}$. Under the fuzzy environment, r_{ij} is the degree to which alternative e_j satisfies the criterion f_j . It is presented by the fuzzy membership function of grade alternative e_j with respect to the criterion f_j . With the preceding three elements, for a given $u \notin U$, its evaluation result can be derived.

The risk assessment of TCC/GMP construction projects involves a considerable number of Key Risk Factors (KRFs) and Key Risk Groups (KRGs). All KRFs and KRGs should be taken into consideration to enable an effective holistic risk assessment. It is therefore desirable if the synthetic evaluation method adopted in this study can tackle problems with both multi-attributes and multi-levels. Fuzzy Synthetic Evaluation was used to develop a fuzzy risk assessment model for TCC/GMP projects. This method has been introduced to research projects in many other fields. For example, Lu *et al.* (1999) adopted fuzzy synthetic evaluation in analysis of water quality in Taiwan and found that change in water quality was expressed in such evaluation. Xu *et al.* (2010a) applied fuzzy synthetic evaluation to develop a fuzzy risk allocation model for public-private partnership (PPP) projects in Mainland China. In addition, a more recent study by Liu *et al.* (2013) proposed a risk assessment method based on fuzzy synthetic evaluation for ultra deep drilling works projects. As subjective judgments of evaluators are always involved in the risk assessment of TCC/GMP projects which are often multi-layered and fuzzy in nature, fuzzy synthetic evaluation is considered to be a suitable tool to generate a risk assessment model for TCC/GMP projects in this study.

Research results and discussions

Selection of Key Risk Factors (KRFs) by normalisation of combined mean score

Risk is usually measured with two essential parameters, i.e. risk likelihood and risk severity as recommended in a multitude of previous research studies on risk management in construction (Bohem and DeMarco, 1997; Chapman and Ward, 1997; Ward, 1999; Patterson and Neailey, 2002; Chan *et al.*, 2011a). Risk likelihood indicates the chance of risk event occurring, while risk severity represents the outcome of the risk event (Ahmed *et al.*, 2007). It is a common practice that the "impact" of a risk is equal to the product of its level of severity and its likelihood of occurrence (Cox and Townsend, 1998; Garlick, 2007; Xu *et al.,* 2010b; Chan *et al.*, 2011a). The risk impact of the 34 key risks identified on the survey form was computed by this method. The individual combined scores of the 34 risk factors are presented in Table II. Only those risk factors with normalised values equal to or greater than 0.537 (i.e. the mean of all normalised values) were perceived as important and then selected for the subsequent data analysis.

Table II. Overall ranking of risk factors for TCC/GMP construction projects in South Australia

RF	Risk factor	Impact = Severity x Likelihood				
		Severity	Likelihood	Impact	Rank	Normalised value
28	Inclement weather	3.49	5.05	17.93	1	1.000
29	Unforeseeable ground conditions	3.95	4.47	17.88	2	0.996
6	Errors and omissions in tender documents	4.12	4.23	17.58	3	0.974
17	Insufficient design completion during tender invitation	3.84	4.26	16.93	4	0.925
32	Lack of experience of contracting parties throughout TCC/GMP procurement process	3.81	4.16	16.84	5	0.918
5	Change in scope of works	3.77	4.49	16.60	6	0.900
9	Loss incurred by main contractor due to unclear scope of works	4.12	3.93	16.37	7	0.883
20	Unforeseeable design development risks at tender stage	3.86	4.14	16.28	8	0.876
25	Delayed payment on contracts	3.70	3.81	14.67	9	0.755
18	Poor buildability / constructability of project design	3.67	3.91	14.58	10	0.748
19	Little involvement of main contractor in design development process	3.56	3.95	14.44	11	0.737
2	Delay in resolving contractual disputes	3.84	3.60	14.02	12	0.706
3	Unrealistic maximum price or target cost agreed in the contract	3.86	3.56	14.02	13	0.706
4	Disagreement over evaluating the revised contract price after submitting an alternative design by main contractor	3.58	3.70	13.44	14	0.662
1	Actual quantities of work required far exceeding estimate	3.44	3.37	11.72	15	0.532
11	Technical complexity and design innovations requiring new construction methods and materials from main contractor	3.21	3.53	11.67	16	0.529
12	Poor quality of work	3.28	3.33	11.49	17	0.515
16	Delay in work due to third party	3.42	3.19	11.47	18	0.513
10	Difficult to agree on a sharing fraction of saving / overrun of budget at pre-contract award stage	3.21	3.47	11.09	19	0.485
26	Global financial crisis	4.26	2.53	10.77	20	0.461
7	Difficult for main contractor to have back-to-back TCC/GMP contract terms with nominated or domestic subcontractors	2.98	3.26	10.42	21	0.434
13	Delay in availability of labour, materials and equipment	3.19	3.16	10.12	22	0.412
15	Selection of subcontractors with unsatisfactory performance	3.09	2.93	9.51	23	0.366
8	Inaccurate topographical data at tender stage	3.16	2.88	9.49	24	0.364
14	Low productivity of labour and equipment	3.00	2.91	8.88	25	0.319
33	Impact of construction project on surrounding environment	2.84	2.81	8.30	26	0.275
31	Difficult to obtain statutory approval for alternative cost saving designs	2.98	2.63	7.81	27	0.238
22	Inflation beyond expectation	2.93	2.40	7.49	28	0.214
21	Exchange rate variations	2.91	2.56	7.37	29	0.205
34	Environmental hazards of constructed facilities towards the community	2.67	2.58	7.35	30	0.203
30	Change in relevant government regulations	2.91	2.37	7.12	31	0.186
24	Change in interest rate on main contractor's working capital	2.58	2.37	6.37	32	0.130
27	Force Majeure (Acts of God)	4.51	1.33	6.14	33	0.112
23	Market risk due to the mismatch of prevailing demand of real estate	2.14	1.86	4.65	34	0.000

Normalised value of impact = (Average actual value – Average minimum value) / (Average maximum value – Average minimum value)

Identification of Key Risk Groups (KRGs)

The impact of a single risk factor was measured by the product of the level of severity and likelihood of occurrence. A total of 14 individual KRFs with normalised values equal to or greater than 0.537 (i.e. the mean of all normalised values) are categorised into 5 KRGs according to the original classification by the researchers themselves on the survey form (see Table III). However, "Delayed payment on contracts" and "Lack of experience of contracting parties throughout TCC/GMP procurement process" become "stand-alone" items, since they are the sole key risk factors under the categories "Economic and financial risks" and "Others", respectively.

Table III. KRGs for TCC/GMP construction projects in South Australia

RF	Risk factors
2	Delay in resolving contractual disputes
3	Unrealistic maximum price or target cost agreed in the contract
4	Disagreement over evaluating the revised contract price after submitting an alternative design by main contractor
5	Change in scope of works
6	Errors and omissions in tender documents
9	Loss incurred by main contractor due to unclear scope of works
	KRG1 – Contractual risks
17	Insufficient design completion during tender invitation
18	Poor buildability / constructability of project design
19	Little involvement of main contractor in design development process
20	Unforeseeable design development risks at tender stage
	KRG2 – Design risks
25	Delayed payment on contracts
	KRG3 – Delayed payment on contracts
28	Inclement weather
29	Unforeseeable ground conditions
	KRG4 – Physical risks
32	Lack of experience of contracting parties throughout TCC/GMP procurement process
	KRG5 - Lack of experience of contracting parties throughout TCC/GMP procurement process

The next step of developing the fuzzy risk assessment model for TCC/GMP construction projects is to derive the appropriate weightings for each KRF and KRG. The weightings for each of the 14 KRFs and 5 KRGs were obtained by the following equation (Chow, 2005; Yeung *et al.*, 2007; Eom and Paek, 2009; Chan and Chan 2012):

$$W_i = \frac{M_i}{\sum_{i=1}^{5} M_i}$$

where: W_i represents the weighting of a particular KRF or KRG;
M_i represents the mean rating of a particular KRF or KRG;

$\sum M_i$ represents the summation of mean ratings of all the KRFs or KRGs.

Development of appropriate weightings for the KRFs and KRGs

Table IV presents the corresponding weightings for each of the 14 KRFs and 5 KRGs.

Table IV. Weightings for the 14 Key Risk Factors (KRFs) and 5 Key Risk Groups (KRGs) for TCC/GMP construction projects in South Australia

Risk factor (RF)	**Risk level of severity**				**Risk likelihood of occurrence**			
	Mean for severity	Weighting for each KRF	Total mean for each KRG	Weighting of each KRG	Mean for likelihood	Weighting for each KRF	Total mean for each KRG	Weighting of each KRG
RF 2	3.84	0.16			3.60	0.15		
RF 3	3.86	0.17			3.56	0.15		
RF 4	3.58	0.15			3.70	0.16		
RF 5	3.77	0.16			4.49	0.19		
RF 6	4.12	0.18			4.23	0.18		
RF 9	4.12	0.18			3.93	0.17		
KRG 1 – Contractual risks			**23.29**	**0.44**			**23.51**	**0.41**
RF 17	3.84	0.26			4.26	0.26		
RF 18	3.67	0.24			3.91	0.24		
RF 19	3.56	0.24			3.95	0.24		
RF 20	3.86	0.26			4.14	0.25		
KRG2 – Design risks			**14.93**	**0.28**			**16.26**	**0.28**
RF 25	3.70	1.00			3.81	1.00		
KRG 3 – Delayed payments on contracts			**3.70**	**0.07**			**3.81**	**0.07**
RF 28	3.49	0.47			5.05	0.53		
RF 29	3.95	0.53			4.47	0.47		
KRG 4 – Physical risks			**7.44**	**0.14**			**9.52**	**0.17**
RF 32	3.81	1.00			4.16	1.00		
KRG 5 – Lack of experience of contracting parties throughout TCC/GMP procurement process			**3.81**	**0.07**			**4.16**	**0.07**
Total			53.17	1.00			57.26	1.00

Note: Please refer to the abbreviations in Table III

Computation of Membership Function (MF) of each KRF and KRG

A total of 14 KRFs were identified from normalisation of combined mean scores for measuring the overall risk level of TCC/GMP construction projects in South Australia. Suppose that the set of basic criteria used in the fuzzy risk assessment model to be $\pi = \{f_1, f_2, ..., f_{14}\}$; and the grades for selection are defined as $E = \{1,2,3,4,5\}$ where 1 = very low; 2 = low; 3 = moderate; 4 = high; and 5 = very high (for severity); and $E = \{1,2,3,4,5,6,7\}$ where 1 = very very low; 2 = very low; 3 = low; 4 = moderate; 5 = high; 6 = very high; and 7 = very very high (for likelihood). For each particular KRF, the membership function can be formed by the evaluation of survey respondents. For example, the survey results on the “Actual quantities of work required far exceeding estimate” indicated that 5% of the respondents opined the level of severity of this risk to the project as very low, 15% as low; 30% as moderate; 32% as high and 18% as very high, therefore the membership function of this risk is set as:

$$C1 = \frac{0.05}{\text{very low}} + \frac{0.15}{\text{low}} + \frac{0.30}{\text{moderate}} + \frac{0.32}{\text{high}} + \frac{0.18}{\text{very high}}$$

$$C1 = \frac{0.05}{1} + \frac{0.15}{2} + \frac{0.30}{3} + \frac{0.32}{4} + \frac{0.18}{5}$$

The membership function can also be expressed as (0.05, 0.15, 0.30, 0.32, 0.18). Similarly, the membership functions of other 14 KRFs and the 5 KRGs for both severity and likelihood are computed in Table V and Table VI, respectively.

Table V. Membership functions of all KRFs in relation to risk severity

KRF	Weighting	MF of Level 3	MF of Level 2
RF 2	0.16	(0.00,0.02,0.35,0.40,0.23)	**(0.00,0.06,0.26,0.41,0.27)**
RF 3	0.17	(0.00,0.09,0.19,0.49,0.23)	
RF 4	0.15	(0.00,0.07,0.47,0.28,0.18)	
RF 5	0.16	(0.00,0.12,0.23,0.42,0.23)	
RF 6	0.18	(0.00,0.02,0.19,0.44,0.35)	
RF 9	0.18	(0.00,0.02,0.19,0.44,0.35)	
RF 17	0.26	(0.00,0.07,0.26,0.44,0.23)	**(0.01,0.05,0.32,0.42,0.20)**
RF 18	0.24	(0.02,0.07,0.28,0.47,0.16)	
RF 19	0.24	(0.02,0.05,0.44,0.33,0.16)	
RF 20	0.26	(0.00,0.02,0.33,0.42,0.23)	
RF 25	1.00	(0.00,0.14,0.23,0.42,0.21)	**(0.00,0.14,0.23,0.42,0.21)**
RF 28	0.47	(0.02,0.19,0.28,0.30,0.21)	**(0.01,0.16,0.24,0.30,0.29)**
RF 29	0.53	(0.00,0.12,0.21,0.30,0.37)	
RF 32	1.00	(0.02,0.05,0.35,0.30,0.28)	**(0.02,0.05,0.35,0.30,0.28)**

Notes: KRF = Key risk factor; MF = Membership function

Table VI. Membership functions of all KRFs in relation to risk likelihood

KRF	Weighting	MF of Level 3	MF of Level 2
RF 2	0.16	(0.00,0.09,0.37,0.40,0.12,0.02,0.00)	**(0.00,0.05,0.37,0.35, 0.13,0.07,0.03)**
RF 3	0.17	(0.00,0.07,0.51,0.30,0.07,0.00,0.05)	
RF 4	0.15	(0.00,0.02,0.42,0.42,0.12,0.02,0.00)	
RF 5	0.16	(0.00,0.00,0.19,0.37,0.23,0.19,0.02)	
RF 6	0.18	(0.00,0.00,0.19,0.37,0.23,0.19,0.02)	
RF 9	0.18	(0.00,0.07,0.33,0.37,0.09,0.12,0.02)	
RF 17	0.26	(0.00,0.05,0.26,0.35,0.12,0.20,0.02)	**(0.00,0.07,0.25,0.36, 0.18,0.11,0.03)**
RF 18	0.24	(0.00,0.09,0.28,0.35,0.19,0.09,0.00)	
RF 19	0.24	(0.02,0.12,0.23,0.28,0.23,0.10,0.02)	
RF 20	0.26	(0.00,0.02,0.22,0.47,0.19,0.05,0.05)	
RF 25	1.00	(0.00,0.14,0.34,0.19,0.19,0.14,0.00)	**(0.00,0.14,0.34,0.19, 0.19,0.14,0.00)**
RF 28	0.47	(0.00,0.02,0.12,0.19,0.27,0.26,0.14)	**(0.01,0.06,0.10,0.25, 0.23,0.27,0.08)**
RF 29	0.53	(0.02,0.09,0.09,0.30,0.20,0.28,0.02)	
RF 32	1.00	(0.02,0.12,0.36,0.07,0.12,0.19,0.12)	**(0.02,0.12,0.36,0.07, 0.12,0.19,0.12)**

Notes: KRF = Key risk factor; MF = Membership function

Development of a fuzzy risk assessment model

After establishing appropriate weightings for the 14 KRFs and 5 KRGs for TCC/GMP construction projects in South Australia, together with the fuzzy membership functions for each KRF, a total of 4 models were taken into consideration to determine the results of the evaluation (Lo, 1999).

Model 1: M (∧, ∨), $$bj = \bigvee_{i=1}^{m} (wi \wedge rij) \qquad \forall bj \in B$$

Model 2: M (•,∨), $$bj = \bigvee_{i=1}^{m} (wi \times rij) \qquad \forall bj \in B$$

Both Models 1 and 2 are suitable for single-item problems because only the major criteria are considered; and other minor criteria are ignored (Lo, 1999). Since the calculation of the Overall Risk Index (ORI) involves multi-criteria, each KRF should have its own influence on the overall risk level. Therefore, both Models 1 and 2 are regarded as not suitable for this study.

Model 3: M (•, ⊕), $$bj = \min(1, \sum_{i=1}^{m} wi \times rij) \qquad \forall bj \in B$$

Model 4: M (∧, +), $$bj = \sum_{i=1}^{m} (wi \wedge rij) \qquad \forall bj \in B$$

The symbol ⊕ in Model 3 represents the summation of products of weighting and membership function. Model 3 is suitable when many criteria are considered and the difference in the weighting of each criterion is not great. Model 4 will miss some information with smaller weightings. Therefore, it yields similar results to those derived from Models 1 and 2. To conclude, Model 3 is most suitable for calculating the ORI and the respective risk indices of various KRGs for TCC/GMP construction projects among the four models, since the differences in weightings for KRFs are not great and the calculation of ORI involves many criteria (a total of 14 KRFs).

There are three levels of membership functions. Level 3 refers to each of the 14 KRFs. Level 2 refers to each of the 5 KRGs, and Level 1 refers to the ORI. Let ORI_A denote the ORI of TCC/GMP construction projects in South Australia. W and R denote the weighting and membership function of each KRF (Level 2), respectively. Table VII summarises the overall results of fuzzy synthetic evaluation.

Table VII. Results of fuzzy synthetic evaluation for all KRGs

	Key risk group (KRG)	**Weighting in Table IV**	**MF for Level 2**	**MF for Level 1**
Risk Severity (from Level 2 to Level 1)	Contractual risks	0.44	(0.01,0.07,0.28,0.39,0.25)	**(0.01,0.07,0.28,0.39,0.25)**
	Design risks	0.28	(0.01,0.05,0.32,0.42,0.20)	
	Delayed payment on contracts	0.07	(0.00,0.14,0.23,0.42,0.21)	
	Physical risks	0.14	(0.01,0.16,0.24,0.30,0.29)	
	Lack of experience of contracting parties throughout TCC/GMP procurement process	0.07	(0.02,0.05,0.35,0.30,0.28)	
Risk Likelihood (from Level 2 to Level 1)	Contractual risks	0.44	(0.00,0.05,0.37,0.35,0.13,0.07,0.03)	**(0.00,0.08,0.30,0.31, 0.16,0.11,0.04)**
	Design risks	0.28	(0.00,0.07,0.25,0.36,0.18,0.11,0.03)	
	Delayed payment on contracts	0.07	(0.00,0.14,0.34,0.19,0.19,0.14,0.00)	
	Physical risks	0.14	(0.01,0.06,0.10,0.25,0.23,0.27,0.08)	
	Lack of experience of contracting parties throughout TCC/GMP procurement process	0.07	(0.02,0.12,0.36,0.07,0.12,0.19,0.12)	

Notes: Membership Function (MF) of Level 1 = Sum-product of weighting and MF of Level 2

After deriving the membership function of Level 1, the ORI can be calculated using the following equation:

$$ORI_A = \sum_{k=1}^{5} \left(W \times R_k \right) \times L$$

where ORI_A is the Overall Risk Index;
W is the weighting of each KRF;
R is the degree of membership function of each KRF; and
L is the linguistic variable where 1 = very low; 2 = low; 3 = moderate, 4 = high; and 5 = very high (for severity); and 1 = very very low; 2 = low; 3 = low; 4 = moderate; 5 = high; 6 = very high and 7 = very very high (for likelihood)

Overall Risk Index (ORI) of TCC/GMP construction projects in South Australia
= (0.01 x 1 + 0.07 x 2 + 0.28 x 3 + 0.39 x 4 + 0.25 x 5) x
(0.00 x 1 + 0.08 x 2 + 0.30 x 3 + 0.31 x 4 + 0.16 x 5 + 0.11 x 6 + 0.04 x 7)
= 3.80 x 4.04
= **15.35**

The results generated by the fuzzy synthetic evaluation method indicated that the ORI of TCC/GMP projects is 15.35 which is considered as higher than "moderate" since it is higher than the median value of 12 (severity of 3 multiplied by likelihood of 4). Furthermore, to conduct an in-depth analysis, the risk index of a particular KRG can also be calculated in the same way. The aggregate results are indicated in Table VIII.

Table VIII. Risk indices of Key Risk Groups (KRGs)

Key risk group (KRG)	Severity	Likelihood	Risk index
1. Contractual risks	3.89	3.89	15.13
2. Design risks	3.75	4.10	15.38
3. Delayed payment on contracts	3.70	3.85	14.25
4. Physical risks	3.70	4.76	17.61
5. Lack of experience of contracting parties throughout TCC/GMP procurement process	3.77	4.20	15.83
Overall risk level	**3.80**	**4.04**	**15.35**

As observed from Table VIII, "Physical risks" were perceived as the most critical risk group, with a risk index of 17.61, followed by "Lack of experience of contracting parties throughout TCC/GMP procurement process", with a risk index of 15.83. "Design risks" was ranked as the third, with risk index of 15.38, "Contractual risks" being the fourth, and "Delayed payment on contracts" being the least. The above findings indicated that physical risks, including inclement weather and unforeseeable ground conditions, may be a major obstacle to the success of TCC/GMP contracts in South Australia. Indeed, unforeseeable ground conditions was discerned as one of the most critical risks in TCC/GMP projects both in the United Kingdom and Hong Kong (Chan *et al.*, 2011b). The finding may also be explained by, as Davis and Stevenson (2004) suggested, latent ground conditions can be one of the major grounds of increasing the contract sum in GMP contracts, implying that ground conditions can be a significant risk to be considered in this kind of contract.

Disputes may also arise due to some unexpected weather changes (e.g. inclement weather or heavy rainfall) or physical changes (e.g. unforeseen ground conditions or incorrect utility locations) in these kinds of procurement approach. Since any unexpected changes may generate a considerable number of TCC/GMP variations (Fan and Greenwood, 2004), it would prolong the overall development programme as well as incur significant cost implications to the projects concerned. Improper handling on these issues may provoke intractable disputes and thus diminishing the mutual trust and partnering relationship developed within the project team (Sadler, 2004). While "Delayed payment on contracts" was identified as the least significant risk group among the five KRGs, the problems associated with delayed payments have attracted worldwide attention of the construction industry in recent years and a plethora of effective regulatory measures have been put forward to mitigate this risk in Australia in particular (e.g. Coggins *et al.*, 2010), so the respondents did not regard it as a very significant risk group in this study.

Conclusions

This research study has established an objective, reliable, and comprehensive risk assessment model for TCC/GMP construction projects in Australia by adopting a fuzzy synthetic evaluation approach. The development of this model has enhanced the understanding of project team members on implementing a successful TCC/GMP construction project. The model may help the industrial practitioners to measure, evaluate and mitigate the risk level of the projects based on objective evidence instead of subjective judgments. The research findings demonstrated that "Physical risks" is the most critical risk group associated with TCC/GMP schemes that places significant barriers for TCC/GMP projects to succeed in real practice. This may be attributed to the fact that common physical risk factors like inclement weather and unforeseeable ground conditions are severe risks within the construction industry worldwide, while under TCC/GMP schemes, the contractors are liable to any cost overruns, and the respondents would consider such risk to be a significant one.

The main contribution of this study is that it has generated a solid framework for assessing the key risks associated with TCC/GMP contracts. The fuzzy risk assessment model derived may serve as an effective tool for risk assessment during the peer-review process for the same type of projects on the contractor's side (i.e. to help the contractors to assess the relative overall risk levels among their several current TCC/GMP projects in hand or to decide whether to bid for a new project if procured with TCC/GMP form of contract during tender stage). On the other hand, the clients or consultants can apply the same model to evaluate the overall risk levels of various TCC/GMP projects and decide whether to adopt TCC/GMP contractual arrangement in their construction projects under planning. The established model would also be useful for project managers, facilities managers and property management personnel in administering TCC/GMP contracts especially when estimating the overall risk levels of their future projects (including new-build or maintenance) well in advance during the planning stage.

Further research can be launched to replicate the same research methodology to assess the risk levels of TCC/GMP construction projects in the United Kingdom and Sweden where the development of TCC/GMP schemes is more mature so as to draw international comparisons and for benchmarking purposes, by comparing the risk levels of the projects with their counterparts across different countries and across different types of TCC/GMP projects, provided that there is ample amount of completed project data available for analysis. Likewise, the same research methodology may be applicable to other procurement methods (e.g. design-and-build) for generating the corresponding risk assessment models for use in future.

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