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Developing a Fuzzy Risk Assessment Model for Guaranteed Maximum Price and Target Cost Contracts in Construction

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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 factor analysis and fuzzy synthetic evaluation method, based on an empirical questionnaire survey with relevant industrial practitioners in Hong Kong.

Design/methodology/approach - A total of 34 key 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 practitioner on risk assessment of such risk factors.

Findings - The most important 17 Principal Risk Factors (PRFs) after the calculation of normalised values were selected for undertaking factor analysis. Five Principal Risk Groups (PRGs) were then generated in descending order of importance as: (1) Design risks; (2) Pre-contract risks; (3) Economic and financial risks; (4) Lack of experience in TCC/GMP procurement process; and (5) Post-contract risks. These survey findings also reveal that design risks may be the major hurdle to the success of TCC/GMP projects in Hong Kong.

Originality/value - An Overall Risk Index (ORI) associated with TCC/GMP construction projects and the risk indices of individual PRGs can be generated from the model for reference. An objective and reliable assessment can be achieved. The model provides 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 worldwide.

Keywords: Target cost contracts, Guaranteed maximum price contracts, Risk assessment, Fuzzy synthetic evaluation, Hong Kong.

Paper type Research Paper

Introduction

The problems of the traditional procurement method are identified as causing confrontational working relationships between contracting parties (e.g. owners and contractors). Target cost contracts (TCC), which align the interests of both parties together, was considered as 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 are famous examples of applying the New Engineering Contract (NEC) with Option C (Target Cost with Activity Schedule). It has been found that research on this procurement area mainly focused 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 looked at the risk assessment of TCC.

In fact TCC, as a relatively new form of procurement in Hong Kong, has created new challenges for risk management for both clients and contractors in Hong Kong. Therefore, it is essential for both the client organizations and main contractors to evaluate all potential risks throughout the entire project delivery process. However, empirical research studies in this research area are rather limited. The aim of this paper is to develop a fuzzy risk assessment model for measuring the risk level of a certain PRG and the overall risk level associated with TCC/GMP construction projects using factor analysis and fuzzy synthetic evaluation method via an empirical questionnaire survey in Hong Kong. It is believed that this research study can shed light on the risk management of TCC/GMP projects not only locally but also worldwide.

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 mutual 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 contract 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 contract arrangement that is more suitable when the design is based on conventional means. However, the scope of work 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.

Development of a Fuzzy Risk Assessment Model

Hands-on experience derived from the United Kingdom and Australian cases has indicated that the TCC 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). However, not all construction projects procured with TCC/GMP are equally successful. For example, in the United States, 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 was really a guarantor of construction cost. In light of this, there is an urgent need for more systematic and in-depth research to examine the risk aspects and hence to develop a risk assessment model for delivering TCC/GMP construction projects.

Overall Research Framework

Literature Review

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 key 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) and a series of face-to-face interviews with industrial practitioners with extensive experience of TCC/GMP construction projects (Chan *et al.*, 2010). Therefore, the list of 34 key risk factors in relation to TCC/GMP contracts was considered to be sufficient, relevant and representative.

Structured Interviews

A series of seven face-to-face structured interviews on the identification of key risk factors associated with TCC/GMP contracts were launched 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 work, quality and clarity of tender documents, unforeseen ground conditions, fluctuation of materials price, and approval from regulatory bodies for alternative cost saving designs, were the key risk factors inherent with TCC/GMP projects in Hong Kong (Chan *et al.*, 2010). 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.

Questionnaire Survey

The fieldwork was commenced in March of 2009. A total of 300 self-administered blank survey forms were distributed to various target construction professionals associated with the Hong Kong construction industry, including those working for developers, consultant firms, main contractors, trade sub-contractors, quasi-government organizations and relevant government works departments. The completed forms were collected through postal mails, emails, 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 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 141 valid and duly completed forms were returned, yielding a response rate of 47%. Among the 141 respondents, 47 of them declared that they had "No hands-on experience in procuring TCC/GMP construction projects" and they were advised on the questionnaire not to complete the survey and return the forms for record. The remaining 94 respondents either had acquired hands-on experience in procuring TCC/GMP projects or they declared to have a 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 in order to assure the value and creditability of survey results. Therefore, only the data and information obtained from these 94 responses were used for further data analysis. Table 1 depicts a summary of the profiles of the survey respondents.

Table 1. Personal Profiles of Survey Respondents

Category	Respondent		Category	Respondent	
	Freq	%		Freq	%
Nature of Organization			*Number of TCC/GMP Construction Projects Experienced*		
Client Organization	33	35.1	1-2 projects	34	36.2
Main Contractor	22	23.4	3-4 projects	12	12.8
Architectural Consultant	2	2.1	More than 4 projects	9	9.6
Engineering Consultant	3	3.2	Have obtained basic understanding of the underlying principles of TCC/GMP schemes	39	41.5
Quantity Surveying Consultant	19	20.2			
Project Management Consultant	2	2.1			
Subcontractor	2	2.1			
Academic	9	9.6			
Others	2	2.1			
Total	**94**	**100%**	**Total**	**94**	**100%**
Grouping by Nature of Organization			*Experience Level in Construction Industry*		
Client	33	35.1	Below 5 years	17	18.1
Contractor	27	28.7	5-10 years	11	11.7
Consultant	34	36.2	11-15 years	11	11.7
			16-20 years	12	12.8
			Over 20 years	43	45.7
Total	**94**	**100%**	**Total**	**94**	**100%**

Factor Analysis

The purpose of Factor Analysis (FA) is to reduce a large number of observed variables to a smaller number of factors with a minimum loss of information and to reveal the interrelationship between variables (Hair *et al*., 1998). The number of individual factors which would be required to represent the set of data is determined by investigating the total percentage of variance explained by each individual factor. Principal components analysis was performed to capture the underlying grouped factors via FA and Equamax rotation method with Kaiser normalisation being conducted through the SPSS FACTOR program. The method of Equamax rotation gives the highest individual factor loadings for the same set of individual factors and more interpretable overall results as applied and recommended by both Abraham *et al*. (1994) and Emsley *et al*. (2003). The aim of principal components analysis is to derive a smaller number of variables in order to convey as much information about the top 17 key risk factors crystallised by normalisation of combined mean scores as possible out of a total of 34.

The suitability of using FA was assessed by the Kaiser-Meyer-Olkin (KMO) test and Barlett's test of sphericity. The KMO test measures the adequacy of sample in terms of the distribution of the values for the execution of FA (Geourge and Mallery, 1999). The value of KMO statistic varies between 0 and 1. A value of 0 indicates that the sum of partial correlations is large relative to the sum of correlations, indicating diffusion in the pattern of correlations and hence, factor analysis would be inappropriate (Norusis, 1993). In contrast, a value close to 1 indicates that patterns of correlations are relatively compact and factor analysis would yield distinct and reliable individual factors. The KMO value should be higher than the acceptable threshold of 0.5 for a satisfactory FA to proceed (Norusis, 1993). On top of the KMO test, the Barlett's test for sphericity was undertaken to highlight the presence of correlations among the variables. This test will be used to determine if the correlation matrix is an identity matrix or not. If there is an identity matrix, factor analysis will become meaningless (Field, 2005).

Fuzzy Synthetic Evaluation

Fuzzy Synthetic Evaluation was applied to this study to derive the Risk Index of each Principal Risk Group (PRG) after factor analysis and also the Overall Risk Index (ORI) of TCC/GMP construction projects in Hong Kong.

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 set of grade alternatives $E = \{e_1, e_2, ...e_n\}$; 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 Principal Risk Factors (PRFs) and Principal Risk Groups (PRGs). All PRFs and PRGs should be taken into consideration to enable an effective 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, which is one of the applications of fuzzy set theory, was applied to develop a fuzzy risk assessment model for TCC/GMP projects in Hong Kong. This method has been introduced to research in many other fields. For example, Lu *et al.* (1999) applied fuzzy synthetic evaluation in analysis of water quality in Taiwan and found that change in water quality was expressed in such evaluation. Singh *et al*. (2008) employed the same method for the assessment of physico-chemical quality of groundwater for drinking purpose in India. Xu *et al.* (2010) adopted a similar fuzzy synthetic evaluation approach to developing a fuzzy risk allocation model for public-private partnership (PPP) projects in Mainland China. 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 develop a risk assessment model for the TCC/GMP projects in this study.

Research Results and Discussions

Selection of 17 Principal Risk Factors (PRFs) by Normalisation of Combined Mean Score

It is generally accepted that the impact of a risk is computed by multiplying its level of severity with its likelihood of occurrence (Cox and Townsend, 1998; Garlick, 2007). The risk impact of the 34 key risks identified on the survey form was computed by this approach. The individual combined scores of the 34 risks are presented in Table 2. Only those risk factors with normalised values equal to or greater than 0.50 were perceived as important and then selected for the subsequent factor analysis. Table 2 reveals that there are 17 risk factors with normalized values equal to or greater than 0.50 and they were selected for carrying out factor analysis. Such selection complies with the pre-requisite of the factor analysis technique, which requires a ratio of 1:5 for variables to sample size (Lingard and Rowlinson, 2006), i.e. 17 risk factors x 5 samples required for each factor = at least 85 samples for assuring sufficient sample size to proceed with factor analysis.

Identification of 5 Principal Risk Groups (PRGs)

The impact of a single risk factor was measured by the product of the level of severity and likelihood of occurrence. Based on the results of the normalisation, a taxonomy was developed with factor analysis which explored the structure of inter-relationship among data by defining a set of common underlying constructs known as factors (Roshe, 1988).

The appropriateness of applying factor analysis was examined by KMO test and Barlett's test of sphericity. The KMO value after factor analysis of the 17 individual risks was found to be 0.810 equivalent to a "good" degree of common variance according to Field (2005), which was higher than the threshold requirement of 0.50 (Norusis, 1993). The value of the test statistic for Barlett's sphericity was large (chi-square value = 681.79) and the associated significance level was small (p-value < 0.001), implying that the population matrix was not an identity matrix. Moreover, the internal consistency (reliability) of factor analysis was checked by examining the value of Cronbach's alpha reliability coefficients for both severity and likelihood. The standard rule is that the alpha value must exceed 0.70 to conclude that the measurement scale is reliable (SPSS, 2003). The overall alpha values for severity and likelihood were calculated to be 0.924 and 0.936 respectively, indicating a high degree of internal consistency (reliability) in terms of the correlations amongst the PRFs and a high level of uniformity on the survey questionnaires (Norusis, 1993). As the requirements of KMO value and Barlett's test of sphericity were both fulfilled, the collected data were appropriate for factor analysis which could be conducted with confidence and reliability in this study.

Principal factor extraction with Equamax rotation was applied to the selected 17 PRFs derived from a sample of 94 responses to obtain factor solutions which were easier to interpret. Factor loadings of each factor are shown in Table 3 to explain the correlations between the PRFs and the PRGs. These loadings give an indication of the extent to which the risks are influential in forming the PRGs. As seen in Table 3, five PRGs were extracted in this case with their eigenvalues larger than 1.0, totally accounting for 69% of the total variance in the responses. A new underlying grouped factor was appropriately labelled in accordance with the set of individual factors it contained. In order to facilitate the explanation of the results of FA, it is necessary to assign an identifiable, collective label to the groups of individual factors of high correlation coefficients, as each of the underlying grouped factors is an aggregation of individual factors (Sato, 2005). It is however stressed that the suggested label is subjective and other researchers may come up with a different label.

The five PRGs included the underlying risk factor groups with labels of: (1) Pre-contract risks; (2) Post-contract risks; (3) Lack of experience in TCC/GMP procurement process; (4) Design risks; and (5) Economic and financial risks. The first three grouped factors contributed to 40.3%, 8.8% and 7.2% of the total variance. All factor loadings were found to be above or very close to 0.5. The factor loadings and the interpretation of the factors extracted were reasonably consistent in general. So it is perceived that the five risk factor groups generated to be essential to the success of TCC/GMP construction projects in Hong Kong.

Table 2. Overall Ranking of Risk Factors for TCC/GMP Construction Projects in Hong Kong

RF	Risk factor	Impact = Severity x Likelihood				
		Severity	Likelihood	Impact	Rank	Normalised Value
5	Change in scope of work	3.53	4.48	15.84	1	1.00
17	Insufficient design completion during tender invitation	3.47	4.30	14.93	2	0.88
20	Unforeseeable design development risks at tender stage	3.38	4.13	13.98	3	0.74
6	Errors and omissions in tender document	3.44	4.05	13.97	4	0.74
21	Exchange rate variations	3.31	4.19	13.86	5	0.73
29	Unforeseeable ground conditions	3.50	3.93	13.76	6	0.71
3	Unrealistic maximum price or target cost agreed in the contract	3.66	3.64	13.30	7	0.65
1	Actual quantities of work required far exceeding estimate	3.46	3.83	13.27	8	0.65
22	Inflation beyond expectation	3.34	3.91	13.08	9	0.62

32	**Lack of experience of contracting parties throughout GMP/TCC process**	**3.30**	**3.93**	**12.99**	**10**	**0.61**
26	**Global financial crisis**	**3.70**	**3.50**	**12.94**	**11**	**0.60**
4	**Disagreement over evaluating the revised contract price after submitting an alternative design by main contractor**	**3.21**	**4.02**	**12.93**	**12**	**0.60**
18	**Poor buildability / constructability of project design**	**3.40**	**3.77**	**12.82**	**13**	**0.59**
2	**Delay in resolving contractual disputes**	**3.28**	**3.88**	**12.72**	**14**	**0.57**
9	**Loss incurred by main contractor due to unclear scope of work**	**3.46**	**3.62**	**12.54**	**15**	**0.55**
7	**Difficult for main contractor to have back-to-back GMP/TCC contract terms with nominated or domestic subcontractors**	**2.97**	**4.21**	**12.49**	**16**	**0.54**
16	**Delay in work due to third party**	**3.24**	**3.81**	**12.37**	**17**	**0.52**
28	Inclement weather	2.92	4.11	12.01	18	0.47
8	Inaccurate topographical data at tender stage	3.24	3.65	11.84	19	0.45
15	Selection of subcontractors with unsatisfactory performance	3.34	3.52	11.76	20	0.44
19	Little involvement of main contractor in design development process	2.98	3.92	11.68	21	0.43
31	Difficult to obtain statutory approval for alternative cost saving designs	3.16	3.69	11.65	22	0.42
33	Impact of construction project on surrounding environment	3.11	3.69	11.48	23	0.40
11	Technical complexity and design innovations requiring new construction methods and materials from main contractor	3.18	3.57	11.35	24	0.38
12	Poor quality of work	3.19	3.53	11.25	25	0.37
23	Market risk due to the mismatch of prevailing demand of real estate	3.06	3.64	11.14	26	0.35
24	Change in interest rate on main contractor's working capital	2.97	3.54	10.50	27	0.27
13	Delay in availability of labour, materials and equipment	3.10	3.37	10.46	28	0.26
34	Environmental hazards of constructed facilities towards the community	3.04	3.40	10.34	29	0.24
10	Difficult to agree on a sharing fraction of saving / overrun of budget at pre-contract award stage	3.06	3.37	10.29	30	0.24
30	Change in relevant government regulations	3.00	3.42	10.27	31	0.23
25	Delayed payment on contracts	3.07	3.31	10.14	32	0.22
14	Low productivity of labour and equipment	3.02	3.19	9.63	33	0.15
27	Force Majeure (Acts of God)	3.24	2.64	8.56	34	0.00

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

Table 3. Structure of Principal Factor Extraction and Equamax Rotation on the 17 Principal Risk Factors (PRFs) of TCC/GMP Construction Projects in Hong Kong

RF	Item	Factor loading	Eigenvalue	Percent of variance explained	Cumulative percent of variance explained
	PRG 1 – Pre-contract risks				
16	Delay in work due to third party	0.670	6.857	40.338	40.338
4	Disagreement over evaluating the revised contract price after submitting an alternative design by main contractor	0.645			
3	Unrealistic maximum price or target cost agreed in the contract	0.577			
20	Unforeseeable design development risks at tender stage	0.575			
18	Poor buildability / constructability of project design	0.554			
17	Insufficient design completion during tender invitation	0.498			
	PRG 2 – Post-contract risks				
7	Difficult for main contractor to have back-to-back TCC/GMP contract terms with nominated or domestic subcontractors	0.849	1.500	8.822	49.159
1	Actual quantities of work required far exceeding estimate	0.718			
2	Delay in resolving contractual disputes	0.634			
9	Loss incurred by main contractor due to unclear scope of work	0.501			
	PRG 3 – Lack of experience in TCC/GMP procurement process				
32	Lack of experience of contracting parties throughout TCC/GMP process	0.878	1.217	7.157	56.316
	PRG 4 – Design risks				
5	Change in scope of work	0.821	1.119	6.581	62.897
29	Unforeseeable ground conditions	0.557			
6	Errors and omissions in tender document	0.483			
	PRG 5 – Economic and financial risks				
26	Global financial crisis	0.783	1.046	6.154	69.051
21	Exchange rate variations	0.727			
22	Inflation beyond expectation	0.606			

Development of Appropriate Weightings for the 17 PRFs and 5 PRGs

The next step of developing the fuzzy risk assessment model for TCC/GMP construction projects is to derive the appropriate weightings for each PRF and PRG. The weightings for each of the 17 PRFs and 5 PRGs were obtained by the following formula (Yeung *et al.*, 2007):

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

where: W_i represents the weighting of a particular PRF or PRG;

M_i represents the mean ratings of a particular PRF or PRG;

$\sum M_i$ represents the summation of mean ratings of all the PRFs or PRGs.

Table 4 presents the corresponding weightings for each of the 17 PRFs and 5 PRGs.

Table 4. Weightings for the 17 Principal Risk Factors (PRFs) and 5 Principal Risk Groups (PRGs) for TCC/GMP Construction Projects in Hong Kong

Risk Factor (RF)	Risk Level of Severity				Risk Likelihood of Occurrence			
	Mean for Severity	Weighting for each PRF	Total Mean for each PRG	Weighting of each PRG	Mean for Likelihood	Weighting for each PRF	Total Mean for each PRG	Weighting of each PRG
RF 16	3.24	0.16			3.81	0.16		
RF 4	3.21	0.16			4.02	0.17		
RF3	3.66	0.18			3.64	0.15		
RF20	3.38	0.17			4.13	0.17		
RF18	3.40	0.16			3.77	0.16		
RF17	3.47	0.17			4.30	0.19		
PRG 1 – Pre-contract Risks			**20.36**	**0.35**			**23.67**	**0.35**
RF 7	2.97	0.23			4.21	0.27		
RF 1	3.45	0.26			3.83	0.25		
RF 2	3.28	0.25			3.88	0.25		
RF 9	3.46	0.26			3.62	0.23		
PRG 2 – Post-contract Risks			**13.16**	**0.23**			**15.54**	**0.23**
RF 32	3.30	1.00			3.93	1.00		
PRG 3 – Lack of experience in TCC/GMP procurement process			**3.30**	**0.06**			**3.93**	**0.06**
RF 5	3.53	0.34			4.47	0.36		
RF 29	3.50	0.33			3.93	0.32		
RF 6	3.44	0.33			4.05	0.33		
PRG 4 – Design risks			**10.47**	**0.18**			**12.45**	**0.19**
RF 26	3.70	0.36			3.50	0.30		
RF 21	3.31	0.32			4.19	0.36		
RF 22	3.34	0.32			3.91	0.34		
PRG 5 – Economic and financial risks			**10.35**	**0.18**			**11.60**	**0.17**
Total			57.64	1.00			67.19	1.00

(please refer to the abbreviations in Table 3)

Computation of Membership Function of Each PRF and PRG

A total of 17 PRFs were identified from normalisation of combined mean scores for measuring the overall risk level of TCC/GMP construction projects in Hong Kong. Suppose that the set of basic criteria used in the fuzzy risk assessment model to be $\pi = \{f_1, f_2, ..., f_{17}\}$; 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 PRF, 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 2% of the respondents opined the level of severity of this risk to the project as very low, 17% as low; 33% as moderate; 30% as high and 18% as very high, therefore the membership function of this risk is set as:

$$C1 = \frac{0.02}{\text{very low}} + \frac{0.17}{\text{low}} + \frac{0.33}{\text{moderate}} + \frac{0.30}{\text{high}} + \frac{0.18}{\text{very high}}$$

$$C1 = \frac{0.02}{1} + \frac{0.17}{2} + \frac{0.33}{3} + \frac{0.30}{4} + \frac{0.18}{5}$$

The membership function can also be expressed as (0.02, 0.17, 0.33, 0.30, 0.18). Similarly, the membership functions of other 16 PRFs and the 5 PRGs for both severity and likelihood are computed in Table 5 and Table 6, respectively.

Table 5. Membership Functions of all PRFs in Relation to Risk Severity

PRF	W	MF of Level 3	MF of Level 2
RF 16	0.16	(0.01,0.21,0.38,0.32,0.08)	**(0.03,0.16,0.34,0.35,0.12)**
RF 4	0.16	(0.05,0.17,0.40,0.29,0.09)	
RF3	0.18	(0.01,0.12,0.28,0.38,0.21)	
RF20	0.17	(0.03,0.15,0.33,0.39,0.10)	
RF18	0.16	(0.03,0.16,0.35,0.29,0.17)	
RF17	0.17	(0.04,0.13,0.30,0.40,0.13)	
RF 7	0.23	(0.10,0.19,0.43,0.20,0.08)	**(0.04,0.17,0.36,0.30,0.13)**
RF 1	0.26	(0.02,0.17,0.33,0.30,0.18)	
RF 2	0.25	(0.02,0.18,0.38,0.33,0.09)	
RF 9	0.26	(0.04,0.13,0.30,0.37,0.16)	
RF 32	1.00	(0.08,0.16,0.27,0.37,0.12)	**(0.08,0.16,0.27,0.37,0.12)**
RF 5	0.34	(0.03,0.10,0.37,0.30,0.20)	**(0.02,0.12,0.35,0.35,0.16)**
RF 29	0.33	(0.02,0.14,0.30,0.39,0.15)	
RF 6	0.33	(0.02,0.12,0.37,0.37,0.12)	
RF 26	0.36	(0.07,0.09,0.26,0.25,0.33)	**(0.06,0.13,0.32,0.31,0.18)**
RF 21	0.32	(0.03,0.18,0.33,0.36,0.10)	
RF 22	0.32	(0.07,0.11,0.37,0.32,0.13)	

Notes: PRF = Principal Risk Factor, W = Weighting, MF = Membership Function

Table 6. Membership Functions of all PRFs in Relation to Risk Likelihood

PRF	W	MF of Level 3	MF of Level 2
RF 16	0.16	(0.01,0.13,0.27,0.34,0.14,0.09,0.02)	**(0.04,0.11,0.22,0.32, 0.16,0.11,0.04)**
RF 4	0.16	(0.03,0.11,0.21,0.33,0.14,0.12,0.06)	
RF3	0.18	(0.09,0.16,0.19,0.30,0.15,0.07,0.04)	
RF20	0.17	(0.04,0.08,0.19,0.33,0.17,0.12,0.07)	
RF18	0.16	(0.04,0.12,0.24,0.33,0.17,0.12,0.07)	
RF17	0.17	(0.02,0.07,0.20,0.29,0.19,0.19,0.04)	
RF 7	0.23	(0.07,0.14,0.12,0.20,0.22,0.17,0.08)	**(0.07,0.14,0.19,0.26, 0.20,0.10,0.04)**
RF 1	0.26	(0.07,0.14,0.12,0.20,0.22,0.17,0.08)	
RF 2	0.25	(0.03,0.14,0.16,0.36,0.23,0.04,0.04)	
RF 9	0.26	(0.09,0.10,0.29,0.28,0.13,0.09,0.02)	
RF 32	1.00	(0.03,0.11,0.26,0.24,0.24,0.10,0.02)	**(0.03,0.11,0.26,0.24, 0.24,0.10,0.02)**

RF 5	0.34	(0.03,0.11,0.26,0.24,0.24,0.10,0.02)	**(0.03,0.14,0.14,0.28, 0.22,0.13,0.06)**
RF 29	0.33	(0.03,0.17,0.12,0.34,0.23,0.07,0.04)	
RF 6	0.33	(0.02,0.16,0.18,0.25,0.21,0.11,0.07)	
RF 26	0.36	(0.09,0.20,0.22,0.28,0.10,0.04,0.07)	**(0.05,0.13,0.21,0.33, 0.15,0.07,0.06)**
RF 21	0.32	(0.02,0.11,0.18,0.20,0.19,0.13,0.07)	
RF 22	0.32	(0.03,0.07,0.23,0.41,0.19,0.04,0.03)	

Notes: PRF = Principal Risk Factor, W = Weighting, MF = Membership Function

Development of a Fuzzy Synthetic Risk Assessment Model

After establishing appropriate weightings for the 17 PRFs and 5 PRGs for TCC/GMP construction projects in Hong Kong, together with the fuzzy membership functions for each PRF, a total of 4 models were considered 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 Model 1 and Model 2 are suitable for single-item problems because only the major criteria are considered; other minor criteria are ignored (Lo, 1999). Since the calculation of the Overall Risk Index (ORI) involves multi-criteria, each PRF should have its influence on the overall risk level. Therefore, both Models 1 and 2 are regarded as being 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 product 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 PRGs for TCC/GMP construction projects among the four models, since the differences in weightings for PRFs are not great and the calculation of ORI involves many criteria (a total of 17 PRFs).

It should be noted that there are three levels of membership functions. Level 3 refers to each of the 17 PRFs. Level 2 refers to each of the 5 PRGs, and Level 1 refers to the ORI. Let ORI_A denote the ORI of TCC/GMP construction projects in Hong Kong. W and R denote the weighting and membership function of each PRF (Level 2) respectively. Table 7 summarizes the overall results of fuzzy synthetic evaluation.
After deriving the membership function of Level 1, the ORI can be calculated using the following equation:

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

where ORI_A is the Overall Risk Index;
W is the weighting of each PRF;
R is the degree of membership function of each PRF;
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)

Table 7. Results of Fuzzy Synthetic Evaluation for all PRGs

	Principal Risk Group	W	MF for Level 2	MF for Level 1
Risk Severity (from Level 2 to Level 1)	Pre-contract Risks	0.35	(0.03,0.16,0.34,0.35,0.12)	**(0.04,0.15,0.34,0.33,0.14)**
	Post-contract Risks	0.23	(0.04,0.17,0.36,0.30,0.13)	
	Lack of Experience in TCC/GMP Procurement Process	0.06	(0.08,0.16,0.27,0.37,0.12)	
	Design Risks	0.18	(0.02,0.12,0.35,0.35,0.16)	
	Economic and Financial Risks	0.18	(0.06,0.13,0.32,0.31,0.18)	
Risk Likelihood (from Level 2 to Level 1)	Pre-contract Risks	0.35	(0.04,0.11,0.22,0.31,0.16,0.11,0.04)	**(0.05,0.13,0.20,0.30,0.18, 0.11,0.05)**
	Post-contract Risks	0.23	(0.07,0.14,0.19,0.26,0.20,0.10,0.04)	
	Lack of Experience in TCC/GMP Procurement Process	0.06	(0.03,0.11,0.26,0.24,0.24,0.10,0.02)	
	Design Risks	0.18	(0.03,0.14,0.14,0.28,0.22,0.13,0.06)	
	Economic and Financial Risks	0.18	(0.05,0.13,0.21,0.33,0.15,0.07,0.06)	

Notes: W = Weighting in Table 4, Membership Function (MF) of Level 1 = Sum-product of weighting and MF of Level 2

Overall Risk Index (ORI) of TCC/GMP construction projects in Hong Kong

$$= (0.04 \times 1 + 0.15 \times 2 + 0.34 \times 3 + 0.33 \times 4 + 0.14 \times 5) \times (0.05 \times 1 + 0.13 \times 2 + 0.20 \times 3 + 0.30 \times 4 + 0.18 \times 5 + 0.11 \times 6 + 0.05 \times 7)$$

$$= 3.38 \times 4.02$$

$$= 13.59$$

The results generated by the Fuzzy Synthetic Evaluation indicated that the ORI of TCC/GMP projects is 13.59 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 have an in-depth analysis, the Risk Index of a particular PRG can also be calculated in the same way. The aggregate results are indicated in Table 8.

Table 8. Risk Indices of Principal Risk Groups (PRGs)

Principal Risk Group	Severity	Likelihood	Risk Index
1. Pre-contract risks	3.37	3.94	13.28
2. Post-contract risks	3.31	3.84	12.71
3. Lack of experience in TCC/GMP procurement process	3.29	3.93	12.93
4. Design risks	**3.51**	**4.15**	**14.57**
5. Economic and financial risks	3.42	3.85	13.17
Overall risk level	**3.38**	**4.02**	**13.59**

According to Table 8, "Design risks" were perceived as the most critical risk group, with a risk index of 14.57, followed by "Pre-contract risks", with a risk index of 13.28. "Economic and financial risks" was ranked as the third, with risk index of 13.17, "Lack of experience in TCC/GMP procurement process" being the fourth, and Post-contract risks being the least. The above findings indicated that design risks may be a major obstacle to the success of TCC/GMP contracts in Hong Kong. For example, the nature of variations can be a significant risk in projects procured with the TCC/GMP methodology. Disputes may arise due to the changes in scope of work in these kinds of procurement approach

(Tang and Lam, 2003). The construction projects are dynamic with the external environments, such as change in market demand and economic climate which may cause changes in the scope of work and design. Since any unexpected changes in scope of work 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.

Moreover, the extent of design development changes would also be difficult to define. 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). These research outcomes have enabled both client organizations and main contractors to better understand how various key risk factors are identified, analyzed, measured, assessed and reduced for future TCC/GMP construction projects, taking Hong Kong as an example, which bear similar characteristics (such as predominantly high rise complex construction) as other metropolitan cities in the world.

Conclusions

This research study has applied an innovative approach to establishing an objective, reliable, and comprehensive risk assessment model for TCC/GMP construction projects by using factor analysis and 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. It has also provided a strong platform for industrial practitioners to measure, evaluate and mitigate the risk level of the projects based on objective evidence instead of subjective judgments. The research findings reflected that "Design risks" are 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 grey areas in determining whether a post contract change is classified as a design development item or a contract variation which has cost implications to the projects concerned.

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 TCC/GMP projects in hand or to decide whether to bid for a project if procured with TCC/GMP form of contract during tender stage). On the other hand, the clients 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.

Further research can be launched to apply the same research methodology to assess the risk levels of TCC/GMP construction projects in the United Kingdom and Australia where the development of TCC/GMP is more mature so as to draw an international comparison 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.

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